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Original paper

Open Science in Seismology: The Role of Citizen Science in the Transition from Seismic Observatory to Science Museum

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Abstract Catastrophic events, including worldwide pandemics and natural disasters, may lead to ambivalent attitudes toward science among the public. On the one hand, there may be pessimistic feelings toward the limitations of scientific knowledge and technology. On the other hand, there may be optimistic prospects for science-based solutions to the problems caused by these catastrophes. Science communication plays an integral part in shaping societal attitudes toward science. The aim of this research was to build more fruitful relationships between science and society by improving science communication in the field of seismology. Based on the concept of open science, we conducted action research at a seismic observatory as it transitioned from a science facility to a science museum. The museum adopted a citizen-science approach to communicating the science of seismology. In this approach, citizens not only learned about seismology from scientists, but they worked collaboratively with scientists to do science. The results of our research showed that citizen science can play a critical role in making science more accessible and communicating the science of seismology to society.

Keywords: open science, citizen science, science communication, science museum, seismology

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1. BACKGROUND

1.1 Science communication

In recent years, the occurrence of major earthquakes and tsunamis, a nuclear disaster, disasters caused by typhoons linked to global climate change, and the worldwide spread of the COVID-19 pandemic have underscored the limitations of the knowledge that science brings to society while simultaneously reminding us that science is the only thing that we can rely on to resolve and eliminate such problems. This is the case in Japan, particularly in a deep friction between seismology and society after experiencing the devastating "should-have-been-escaped" catastrophe at nuclear power stations, caused by the "unexpectedly" huge tsunami in the year of 2011 (see also Section 1.3). Having this ambivalent relationship between science and society in mind, this paper takes up the example of seismology – specifically, science communication around seismology – to discuss the relationship between science and society, with "open science" (Nielsen 2011) as a key concept. Open science represents a new approach to the scientific process based on cooperative work and new ways of diffusing knowledge by using digital technologies and new collaborative tools (European Commission (2016, p.33). By using open science in this way, a perspective differing from conventional research and practice will be introduced in connection with the relationship between experts (*i.e.*, seismologists) and the general public in terms of the risk of earthquake disasters, thereby producing results that have not previously been seen.

Chiefly, this paper discusses seismology as an "open science" from the aspect of "citizen science" (*i.e.*, participation by the general public in scientific research or scientific research carried out by members of the public) (National Institute of Informatics Research Center for Open Science and Data Platform 2017). Citizen science is regarded as "bearing a close connection with open science" (Furuya, Sumimoto, and Hayashi 2018, p.37) and it has been pointed out that "a citizen-science perspective is also important and needs to be recognized as a potential outcome for open science" (Study Group on International Trends in Open Science 2015, p. 5). In sum, as seen in Figure 6 below in Section 3, we use open science in this paper as an umbrella concept, encompassing citizen science and open data by using ICT (Information and Communication Technology).

Specifically, we report on action research that we have conducted over the past decade with the objective of developing a seismic observatory which is both a research facility affiliated with a university and an earthquake science museum. In the course of this research, we point out the necessity of realizing science communication not merely as scientific "outreach," which focuses on learning and understanding information about seismology, but rather as something that involves the collaborative planning and execution of seismological observations, experiments, and so forth by scientists and the general public – something that is carried out as "citizen science" – in order to establish seismology in society as an open science.

1.2 Open Science and Citizen Science

Open science is a movement that seeks to transform scientific research into an activity that is open to the public (*i.e.*, to non-experts). In a narrow sense, open science is often used to refer to "open data," which means that more people can gain access to the data and results that form the basis for scientific research. In a broader sense, open science refers to extending conventional science communication in order to build scientific and educational theories for realizing scientific research that more people, including the general public, will be involved with and trust (see also Section 3). In other words, open science is called a social movement that seeks to realize a participatory form of science.

A distinction proposed by Yamori and Iwahori (2016) is useful for understanding the idea of open science while differentiating it, particularly from science communication and outreach, the importance of which has been emphasized previously. This distinction, as noted above, is between the structure of outreach, in which the general public (non-experts) learn/know science from scientists (experts), and the composition of citizen science, in which the general public (non-experts) do/perform science with scientists (experts). In other words, in the outreach model, even when experts come down from the mountaintop to participate in events like science cafes and science labs and the participatory, interactive, and bi-directional involvement of citizens is promoted, there remains a great division between scientists who promote the scientific activity itself and the citizens who learn from and enjoy the fruits of research activities. Therefore, the dichotomy between those who create scientific knowledge and those who learn it remains (see also Figure 6 below in Section 3).

In contrast, citizen science refers to participation, however limited, by the general public in scientific activities (*i.e.*, research activities conducted to produce scientific knowledge). An important characteristic of citizen science is that the general public takes part and plays a role in the research, even if such participation represents only rudimentary work or incidental activities from the perspective of the research as a whole. From a different perspective, the dichotomous structure noted above can be overcome to some extent, if not completely, so that we can position citizen science toward the reorganization of a new "community of practice" (Lave and Wenger 1991; Iwahori, Yamori, Miyamoto, Shiroshita, and Iio 2017) in which scientists and the general public do/perform joint research activities in the name of science as open science.

The collaborative practice of science as "citizen science" or "open science" is far from a pipe dream and is already on its way to becoming a reality. Indeed, open science is not only indirectly helping to transform the relationship between science and society in the medium-to-long term, but is already producing immediate and direct results at the cutting edges of some areas of scientific research. The most typical examples are ecology, which uses data obtained from citizen-reported observations of the ecology of migratory birds and insects (butterfly counting being a notable example); maritime (environmental) studies, which have incorporated citizens' observations of ocean garbage and coral reefs; and astronomy, where the observation of celestial objects by amateur astronomers has long held an important position in academia. Similar moves are also apparent in the social sciences and humanities as well, including the Japanese Psychological Association's "Citizen Science Project" in the field of psychology (Japanese Psychological Association 2019).

1.3 Open Science in the Field of Disaster Prevention

In fields related to disaster prevention and mitigation, including seismology, which is the focus of the present study, the idea of open science is not only reorganizing the relationship between science and society in the medium-to-long term, but is beginning to produce effects in the short term, as well. For example, the idea of open science has begun to be applied in connection with observation activities in the context of extremely localized and short-term meteorological and flood events, including heavy rainstorms and inland floods, which have become more frequent due to the effects of climate change.

Specifically, the general public observes immediate and short-term meteorological phenomena through their own instruments and sightings, separately from the instruments that experts (at meteorological stations, for example) have already deployed. The results of these observations are used by researchers as predictive data and by local residents for initiatives such as "Local Weather Information" and "Evacuation Switch," which might be useful for their own early evacuation (Takenouchi, Kawata, Nakanishi, and Yamori 2014). In addition, some private-sector weather companies have begun offering services that use local meteorological information provided by users through smartphones and similar devices that are used for more accurate weather prediction, the results of which are then shared with their userbase (WeatherNews 2010). This, too, could be described as an initiative based on open science.

However, as we can easily see, this type of activity is open to a choice of themes and areas. The involvement of the general public in scientific activities – mainly observation – depends not only on the feasibility of observation, but also requires that the results be widely disseminated as systems, activities, and products in the real world; that the general public has direct access to these activities; and that there should be no rejection of the scientific field by society. In other words, there should be no serious conflicts between citizens and scientists, although such conflicts could be used productively in a further stage for deeper understandings between scientists and citizens.

In this sense, seismology would seem to be difficult to reorganize as an open science, like the fields of advanced medicine and nuclear technology but unlike disciplines such as astronomy and ecology, except the case of earthquake prediction in the boundary between legitimate seismological research and folk or pseudo seismology (*e.g.*, Hough, 2009). This is because, first of all, seismology – which generally lacks perceptible phenomena or readily available indicators in daily life – could be considered relatively "inaccessible" to citizens, as compared with meteorology, for example, where, given the strong winds and heavy rains that can be felt on a daily basis, tools like wind speed and rainfall indicators enjoy a high level of social recognition. Secondly, in Japanese society, especially in the wake of the Great Hanshin Earthquake in 1995, killing over 6.4 thousand people, and the Great East Japan Earthquake in 2011, killing over 20 thousand, there has been a strong backlash against seismology and adjacent fields, as evidenced by questions such as "Was the 'myth of safety' a lie?" and "After spending such a large amount of tax revenue on research, is 'unexpected' good enough?" such that the relationship between seismology and the general public is by no means smooth (SSJ 2012). It was in consideration of these adverse conditions that this research deliberately took up the challenge of creating an "open science of seismology."

2. ACTION RESEARCH AT AN EARTHQUAKE SCIENCE MUSEUM

2.1 The Abuyama Observatory Science Museum Project

In this section, we offer a detailed report of the action research that we have conducted over the past ten years, mainly at the Abuyama Observatory, which is part of the Kyoto University Disaster Prevention Research Institute. Specifically, we focused on the reorganization of the observatory, which had previously been a pure research facility, into an earthquake science museum, as well as carrying out related research activities with the aim of establishing seismology as an open science. In addition to ourselves, as constant participant observers, this action research also involved seismological researchers, seismic observation technical staff, museum management and curatorial experts, local government officials, and most importantly, the citizen volunteers who later came to be known as the Abuyama Supporters.

The entire process was observed and documented by the authors who engaged in this project as participant observers. Main information sources for this action research are minutes of monthly meeting of Abuyama Supporters, narrative data obtained from a series of semi-structured interview of the supporters made by the authors, and responses to questionnaire surveys answered by visitors of the science museum. A total of over 100 minutes of Abuyama Supporters' monthly meeting provide very useful information on how science museum has been organized and managed for over 10 years by Abuyama Supports as well as observatory staff. Data from a series of interview we conducted once a year, provides good resources to assess how Abuyama Supporter got involved in this project first, and how they have changed their attitudes. Questionnaire surveys conducted every time after guided tours, mentioned below, with the responses of over 3000 visitors now, are helpful to assess how science museum visitors feel about museum activities and Abuyama Supporter's contribution to the museum.

When the Science Museum Project was first conceived in 2010, the very survival of the Abuyama Observatory was in doubt. Observation systems in which a small number of seismic stations are operated by literal legwork had become a thing of the past, and observation networks that could be operated remotely had spread throughout the country. As a result, the observatory, which played a central role in the older observation network and whose maintenance incurred considerable costs, faced questions about whether its time was at an end.

In response to this situation, we asked ourselves whether we might be able to reorganize the observatory as not merely a research facility, but as a base for carrying out seismology as an open science – in other words as a kind of science museum. As stated in the planning document from that time, "rather than simply being for academic research, perhaps [the observatory] could be reborn as a science museum that interprets the history of seismology, open to the general public as a facility that provides learning to as many people as possible, while being firmly rooted in the local community" (Abuyama Science Museum Concept Project 2011).

Located on the outskirts of Takatsuki in Osaka Prefecture, the Abuyama Observatory (Figure 1) is situated on a small mountain overlooking the Osaka Plain, almost directly above the Arima-Takatsuki Fault Zone, which is on a line extending from the Rokko-Awaji Fault Zone, which is considered to have produced the Great Hanshin Earthquake. The observatory was constructed in 1930. With a modern atmosphere evocative of the early Showa era in which it was constructed, the building was listed in a 2007 report by the Osaka Prefectural government as "notable modern heritage."

Figure 1. Abuyama Seismological Observatory, Kyoto University

Given its venerable history, the Abuyama Observatory is home to many seismographs of historical value that were introduced in the early days of seismology in Japan, and which supported the subsequent development of the field. Examples include the Wiechert seismograph, a massive early unit weighing approximately a metric ton that took measurements in both horizontal and vertical directions (for reference, the state-of-the-art Manten seismograph described below weighs about one kilogram); and the US-made Press-Ewing seismograph, which was also used to detect nuclear tests during the US-Soviet Cold War. For a more detailed description of the equipment mentioned here, see Abuyama Observatory (2018) and Yamori and Iwahori (2016).

In planning the Science Museum Project, we decided to make effective use of the valuable historical instruments housed at the observatory, and as our first initiative, we arranged for the general public to view these historic seismographs as an exhibition called the "Abuyama Open Lab." However, just as preparations had gotten underway for the exhibit, which was scheduled to start in April 2011, the Great East Japan Earthquake struck, raising concerns about whether or not the event could be held. We observed friction and conflict between science and society represented by voices dominant in society at the time (and which remain persistent even now)

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that questioned whether disaster prevention science was of any use to society and whether seismology was properly communicating risks. In light of the friction and conflict, it was felt that the time was right to begin the attempt, by introducing the perspectives of open science and citizen science, with the aim of rebuilding the relationship between science and society and between scientists and the general public at a fundamental level. With such considerations in mind, the first Abuyama Open Lab was held as scheduled, approximately one month after the Great East Japan Earthquake struck.

Table 1. Basic statistics on the Science Museum Project

YEAR	EVENTS HELD	MINI SEISMOGRAPHY WORKSHOPS	VISITORS TO THE OBSERVATORY	CUMULATIVE TOTAL NUMBER OF "SUPPORTERS"
2011	20	0	799	70
2012	29	0	762	350
2013	51	3	1699	630
2014	20	9	1095	130
2015	53	8	1329	126
2016	73	5	1960	1117
2017	81	5	2332	1005
2018	71	7	2117	1121
2019	67	9	2465	1206
TOTAL	465	46	14558	5755

(Note) Due to seismic retrofitting work, activities were held for only three months in 2014 and four months in 2015.

Since then, events involving public participation related to the Open Lab and science museum (*e.g.*, public lectures) have been held a total of 465 times over the nine years from 2011 to 2019, although their format and names have changed. In recent years, there have been about 70 events a year – or about one event per week. The total number of visitors who have come to the observatory to participate in events has risen to 14,558 (Table 1). This is a remarkable number considering that before this project began in FY 2010, the facility had attracted almost no visitors from the general public.

2.2 Abuyama Supporters: The Existence of Citizen Volunteers

It is important to note that the responsibility of engaging with these visitors – specifically, the role of presenting basic lectures on seismology and serving as guides for tours of the observatory – has mostly (in 90% of cases since 2012) been assumed by the citizen volunteers

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known as the Abuyama Supporters. As shown in Table 1, the number of active Supporters in recent years has surpassed 1,000 people each year. Specifically, due to the fact that approximately 25 core members take part in activities on a repeated basis anywhere from a few up to 40 times a year, the total number people who participate in activities in a given year is upwards of 1,000 people. Accordingly, if we frame the involvement of general visitors as a "shallow engagement by many people," the involvement of Supporters can be expressed as a "deep engagement by a few."

Abuyama Supporters are citizen volunteers who responded to public recruitment campaigns and attended training courses organized by the observatory, thereby acquiring qualifications that allowed them to assume responsibility for giving lectures and serving as guides on tours of the observatory. Many of these volunteers are ordinary citizens (non-experts) who initially visited the observatory to attend the Abuyama Open Lab. Given that a detailed account of these events is presented in Yamori and Iwahori (2016), here we limit ourselves to presenting the basic background.

As of the end of FY 2019, there were 23 active Abuyama Supporters (of the approximately 80 total registered over the nine years of the project so far). Of these, 20 were men and most were retirees. Although the average age was over 70 years, the members are quite active and have even formed their own organization, called the Golitsyn Association, in honor of Boris Borisovich Golitsyn, the inventor of the seismograph. While promoting mutual exchange and the sharing of information, the association also works to the disseminate information to the greater public, for example, by publishing articles on its own blog (Golitsyn Association 2018). As shown in Table 1, as a result of repeated involvement in activities by about 25 core members, there have been a cumulative total of 5,755 engagements by Supporters in events over the past nine years. During this period, the number of activities grew with each passing year, and since 2016, in particular, the number of engagements grew substantially, with the addition of activities related to analysis, as described below in subsection 2.5. Supporters' motivations for applying to be volunteers are diverse, including participating in seismic observation and research, gaining practical knowledge about earthquake disaster prevention, wanting to learn about the observatory building and its surrounding environment, as well as interacting with peers and contributing to society.

Having presented an overview of the Abuyama Seismological Observatory as a science museum, we next consider three challenges to using observatory-based activities to realize open science in the field of seismology. The first of these is the aspect of guidance already mentioned. As it relates to seismology and observation instruments, guidance is an activity that falls into the category of 'outreach' (see subsection 1.2). However, if we consider the fact that ordinary citizens (Abuyama Supporters) are assuming the role previously held by scientists (*i.e.*, experts) in terms of outreach, we can say that this is an approach to open science that is rooted in citizen science.

The second aspect relates to activities for realizing citizen participation in observation, which has traditionally been at the center of open science, as evidenced by the examples of astronomy and ecology mentioned in subsection 1.2. In other words, although the Abuyama Observatory has begun to function as a science museum, it has not lost all of its original observation and research functions and remains an active seismic observatory. The main activity of the observatory in which the general public participates is observation. Specifically, Abuyama Supporters and others take part in advanced observation activities pertaining to inland earthquakes that are led by the Abuyama Observatory – the next-generation dense seismic observation system, nicknamed the “Manten Project” (Iio 2011, 2012).

The third aspect is analysis. A step beyond observation, this is an activity in which Abuyama Supporters take part in the interpretation of seismic waveform data obtained by the aforementioned Manten Project. In addition, there is also a related project known as Minna De Honkoku (Kanō 2017), in which members of the general public work to decipher records of seismic activity contained in historical documents. Public participation in this kind of analysis can also be said to deepen an open science centered not on learning science, but on doing/performing science collaboratively.

2.3 Guidance

In this subsection, we summarize citizen participation in seismology as an open science by focusing on the guidance roles that Abuyama Supporters have played at the Abuyama Observatory. Here, guidance refers to activities such as the basic lectures on seismology and seismic observation (which usually last about one hour) as well as the guided tours (also generally about one hour in length) of the observatory and the many historical seismograph installations. Several Supporters are in charge of this two-part tour (see Figure 2). The guidance carried out by citizens (*i.e.*, Supporters) has been very well received. A report by Yamori and Iwahori (2016), based on the results of a questionnaire survey conducted at the end of these tours, found that tours led by Supporters were rated more highly (sometimes much more so) than those led by observatory staff (scientists).

Figure 2. Guided explanation of the observatory by an Abuyama Supporter

Next, we would like to point out that the activities of the Supporters, which initially began with guidance at events such as Open Lab, have entered a new stage in the last few years. One such example is the PET Bottle (Simple) Seismograph Workshop, which began in 2013 (Figure 3). Supporters are in charge of all aspects of the planning and execution of this program, which is targeted primarily at children. Table 1 shows the number of times these workshops have been held each year. Although the workshops have also been held at the observatory, most have taken place outside the facility.

Figure 3. A workshop on making PET bottle seismographs

These facts show that the guidance activities carried out by Supporters, which were started as a substitute for the outreach activities that had previously been carried out by scientists (*i.e.*, seismology experts), had even received the high praise of experts. The scientists have recognized the real possibility of doing/performing the activities of outreach and education in relation to seismology, which they had previously been in charge of, together with ordinary citizens. Certainly, unlike activities such as analysis, which are discussed below, guidance might be considered to have only a slight degree of involvement in the main work of seismology. However, in light of the fact that the general public has taken on the role of scientists in terms of outreach, this too could be described as an attempt to further an attitude on the part of scientists and citizens to do/perform science together – in other words, to bring them ever closer to open science by producing personally meaningful products together.

2.4 Observation

The activities of the Abuyama Supporters are not limited to guidance. It is important that Supporters also participate in observation undertaken as part of an ongoing study at the Abuyama Observatory, namely, the Manten Project mentioned above. The Manten Project (officially "Next-Generation Dense Seismic Observation Research") differs from conventional observation networks in that it requires seismographs to be installed at an extremely high density in seismically active areas. This study aims to investigate the mechanisms of inland seismic activity with unprecedented accuracy (see Iio 2011, 2012). For this research plan, a new type of seismograph – the Manten seismograph – has been developed, which is far less expensive than conventional seismographs and much easier to install and maintain. The Abuyama Observatory serves as the base for the implementation of the Manten Project.

However, the Manten Project had significant challenges to overcome. As noted in Yamori and Iwahori (2016), these challenges consisted of securing land for the installation of a vast number of seismographs and the task of maintaining the seismographs themselves. The researchers lacked the time and resources to find a suitable location for the installation of such a large number of seismographs (orders of magnitude greater than before), to secure the rights to use the land, or to perform regular inspections of the equipment once installed. Therefore, we decided to promote the establishment of a system to jointly implement these activities with ordinary citizens (including children) who were interested in seismology, as well as local residents in the communities where the seismographs would be installed. We felt this would be effective in promoting understanding of seismology and raising interest in earthquake disaster prevention, as well as helping to alleviate the friction and conflict between society and the field of seismology mentioned earlier.

Here, we briefly present the achievements of this project. There are two main areas in which the general public have been deeply involved in observation. One of these is in western Tottori Prefecture, a seismically active area that includes the site of the epicenter of the Western Tottori Earthquake in 2000. In 2014, it was here that, as part of the Manten Project, we began the One-Tenth Manten Project, with the aim of installing 1,000 seismographs (*i.e.*, one-tenth of the full 10,000; for details, see Matsumoto, Iio, Saki, and Katō 2018). Around 1,000 seismographs were installed within a circular diameter of approximately 35 kilometers. Ordinary citizens participated in the installation of 375 of the 1,000 seismographs, and continue to play an important part in terms of maintenance as well as the observation activities themselves. Most of those involved are residents of the local community (including some local elementary school students). However, Abuyama Supporters have also taken part in activities in the field on seven occasions for a total of 19 days, serving as leaders of citizens who volunteered after being recruited and trained in Tottori. Seismological results from this observational study have already been published as Hayashida, Matsumoto, Iio, Sakai, and Kato (2020).

The other achievement is public participation in a rapidly organized aftershock monitoring program that was conducted in northern Osaka Prefecture in the immediate aftermath of the Northern Osaka Earthquake, which occurred in 2018, more or less right under the Abuyama Observatory. As reported in Iio (2020), in just the four days after the earthquake, an emergency aftershock grid consisting of 100 stations had been laid out by several university research institutes, including the Abuyama Observatory. Of these, Abuyama Supporters were in charge of the installation work at 12 locations (Figure 4). Monitoring of aftershocks in the immediate aftermath of an earthquake is extremely important in seismology and requires the rapid

Figure 4. Installation of a seismograph by Abuyama Supporters
(part of the aftershock observation activities in the wake of the Northern Osaka Earthquake)

installation of seismographs. This was another scenario in which citizens provided support for research activities. Notably, the implementation of a second phase of aftershock monitoring activities in this area was scheduled to begin in 2020–2021, and an open call has gone out for volunteers. Here, too, there is the expectation of participation by Abuyama Supporters and other citizen volunteers. The project also contributes to local people's higher attention to, and better understanding of scientist's continuing effort of observing and predicting possible aftershocks in the locality.

2.5 Analysis

The reading of seismic waveform data by Abuyama Supporters is an important step forward for open science, particularly for citizen science, in which ordinary citizens, rather than simply learning scientific knowledge, take part in the production of that knowledge. The first step in the analysis of earthquake data is to determine the epicenter of the earthquake. To that end, it is necessary to accurately 'decipher' the point at which the seismic waves reached each observation point. This is a task that has been performed for more than 100 years, and that is essentially still done manually.

The basic concept of the Manten Project being carried out by the Abuyama Observatory is to acquire a large volume of seismic data, and the amount of work required to 'decipher' that data is enormous. Accordingly, the conventional system, in which only researchers are involved, is no longer tenable. And although the accuracy of automatic processing by computers is improving, the results cannot be used for detailed analysis at present.

Figure 5. Abuyama Supporters reading seismic waveforms

Therefore, as mentioned in subsection 2.4, Abuyama Supporters who had taken part in the installation of Manten Project observation points and were well-versed in the details of the plan itself were called upon to participate in the task of reading the data (*i.e.*, the arrival time of seismic waves). After receiving the support of many Abuyama Supporters, expert-led training seminars were held, and these Supporters began reading data in 2016 (Figure 5). The analysis that began at the Abuyama Observatory in this way has continued over the past five years, reaching a total of 787 work sessions (with several Supporters conducting as many as 100 sessions each) with a total working time that has already exceeded 5,000 person-hours. Moreover, the data obtained through this project are being made available for academic analysis to elucidate the eruption mechanisms of inland earthquakes such as the Western Tottori earthquake in 2000. These results have already been published as a research article in one of the top international journals in the field of seismology (*e.g.*, Iio *et al*. 2020).

With regard to analysis, although not an activity carried out directly by the Abuyama Observatory, we should mention Minna de Honkoku, which is a closely related activity carried out by Kanō *et al*. (2017). Minna De Honkoku is a project involving public participation that aims to decipher historical records of earthquakes. By deciphering historical records of natural disasters such as earthquakes, volcanic eruptions, and storms and floods and producing full-text reprints (in which cursive Japanese script [kuzushiji] has been deciphered and converted into electronic type), this project is playing a role in expanding the perspective of disaster science – which has more or less been limited to records no older than the modern period – into the premodern past. It has also contributed to the promotion of interdisciplinary joint research with fields such as history, geography, informatics, and Japanese literature.

Even so, the biggest feature of Minna de Honkoku is its mechanism for public participation, which can appropriately be called open science. The deciphering and transcribing (honkoku) of historical documents requires an enormous investment of time and effort, for which public participation is indispensable. Thus, Minna de Honkoku has devised several strategies to make the work of transcription easier and more appealing to the general public. Examples include the introduction of an "automatic cursive script recognition apparatus" that provides support for the task, as well as a system that encourages communication and collaboration with fellow transcribers engaged in the same task (*e.g*., when someone suggests a particular way of reading some text, their work might be checked and revised by other participants, or they might be given hints for deciphering the text). The latter is particularly important, as evidenced by comments from participants that "the experts will fix it for us later, so this is an opportunity to study" because it functions as an effective mechanism for maximizing the benefits of open science by generating a so-called "collective knowledge" (see subsection 3.2 below).

3. DISCUSSION: THREE TYPES OF SCIENTIFIC LITERACY AND THE CONCEPTUAL LADDER OF CITIZEN SCIENCE

In this section, we discuss a program of action research focusing on the activities of citizen volunteers (the Abuyama Supporters) at the earthquake science museum introduced in the previous section. Together with a supplementary discussion of related research and practical examples, we consider this program from three main perspectives before summing up the research as a whole. The first perspective comprises the three aspects introduced as the typological axis of activities conducted by the Abuyama Supporters, namely guidance, observation, and analysis. The second perspective adopts Shen's (1975) elementary arrangement of scientific literacy into its practical, civic, and cultural aspects. The third perspective is the conceptual ladder of citizen science presented by Furuya, Sumimoto and Hayashi (2018) and Hayashi (2018), which is a typology that classifies citizen science based on the degree of public participation in science.

3.1 The three aspects of observation, analysis, and guidance

First, we will describe observation. As mentioned in Section 1, observation is a style of participation that has become a core part of fields such as astronomy and ecology, which could be called the pioneering fields in open science. Compared with these areas, it is more difficult to introduce public participation in observation activities for seismology. However, in this action research, we have been able to bring public participation to observation activities in the field of seismology through a system in which Abuyama Supporters and local residents were involved in the installation, maintenance and inspection of a large number of seismographs used for the observation of inland earthquakes.

In fact, in recent years, another activity contributing to the realization of observation in the field of seismology has been attracting increased attention, namely, the "Did You Feel It?" project, commonly referred to as DYFI. Launched in 2004 by the United States Geological Survey (USGS, 2004), DYFI is a system through which members of the general public, upon feeling an earthquake, can use the Internet to report the intensity of the quake motion they felt at the time of the earthquake and describe their own reactions or behavior as a result of the quake, as well as any damage to the surrounding area. Although DYFI takes citizen scientific approach in the area of observation (Goltz, Nakano, Park, and Yamori, 2020), DYFI represents a system through which a very large number of citizens can have a "broad, shallow involvement" in scientific activities via the Internet. It is quite different from the present study, in which a few Supporters have a "long-term, deep involvement" in seismology, while also collaborating with the aspects of analysis and guidance. Nevertheless, there is little doubt that observation will continue to play an important role in making seismology an open science.

Second, we will discuss analysis. Generally speaking, analysis is more closely associated with the core of scientific activities compared with observation and requires more deeply specialized knowledge and skills. For this reason, the realization of public participation in this aspect is considered to be less feasible, and seismology is no exception. In fact, it could be said that there is little room for discretion on the part of citizens in the reading of waveform data from seismic motions that has been carried out as part of this action research because the direction is fixed by the researchers. However, as pointed out by existing theories of education and learning such as the concept of legitimate peripheral participation (Lave and Wenger 1991), the very distinction between experts and non-experts should not be considered in terms of binary opposition. Rather, the work involved in analysis has room for incremental progression from basic to more specialized stages.

For example, with regard to the waveform reading activity at the Abuyama Observatory, scientists (experts) and ordinary citizens (non-experts) cannot (and should not) be regarded as professionally equivalent simply by virtue of performing this task. However, as suggested by the theory of legitimate peripheral participation, securing a conduit between the two groups that allows for various degrees of involvement in the scientific activity in question and devising a way for more people to come and go through that conduit might help to reduce friction between society and science and link the two in a more productive manner. In that sense, analysis at the Abuyama Observatory can also be promoted as a first step toward involvement in the work of seismology itself – in other words, a first step toward scientists and citizens doing/performing science together.

With regard to the Minna De Honkoku project introduced earlier as another example of analysis, the relationship with "collective knowledge" (*e.g.*, Nishigaki 2013), which can also be seen in such examples as Wikipedia and open-source software, is important. This kind of attempt to collectively refine knowledge – including the fact that knowledge and information can be "overwritten" by a large number of people, which can sometimes lead them in the wrong direction, as well as the existence of open databases needed for such attempts – is one that can appropriately be called open science.

Also, the mentality expressed in the words of the participants mentioned in subsection 2.5, that "the experts will fix it for us later, so this is an opportunity to study," indicates that the analysis aspect of open science not only contributes to the scientific activities themselves (*i.e.*, the refinement and accumulation of knowledge), but also exerts a positive effect on each participant's attitude toward science (see the cultural element featured in the next subsection).

Third, let us briefly mention guidance. As we have repeatedly noted, guidance is, in itself, a normal dissemination and enlightenment activity – that is, the transfer of scientific knowledge from "someone who (already) has it" to "someone who does not (yet) have it" – and thus should be classified as a kind of outreach. In this sense, it may not be a part of open science. However, through this action research, we managed to run an earthquake science museum in a way that led ordinary citizens (Abuyama Supporters) to take on the role of instructors in the context of outreach. If we focus on this structure – that is, a structure in which ordinary citizens take over educational and outreach activities related to seismology conventionally performed by scientists – this could then be called an approach to an open science that includes elements of citizen science.

If we were to generalize the significance of this system, we could say that it is important to avoiding the fixation and rigidity of a structure that differentiates between "one who teaches" and "one who is taught." This binary structure may very well be essential for education and learning in the short term. However, there is no need for the terms to be fixed or rigidly defined as "scientist" and "citizen," respectively. Rather, actively and intentionally working to make this structure more fluid is essential for educational and learning activities at a deeper level, such as transdisciplinary academic movements. In fact, the theory of legitimate peripheral participation described above emphasizes that the degree of participation in a community of practice established by a given social practice (of which science is one) is always diverse (there will be novices, veterans, and everyone in between) and always changing (novices soon gain experience, and the middle rank eventually become veterans).

The same can be said of the Abuyama Supporters. Even though citizens have taken over the role of "instructors" in science communication from scientists, what is important is that further change is still possible. In other words, if this position were to become fixed, things would simply revert to the same binary structure as before, albeit with a slight shuffling of roles. Some Supporters who had originally been only chance visitors have become involved in observation and analysis. From the perspective of new recruits, these men and women are now quasi-experts. In that sense, preserving the fluidity seen in the relationship between veteran and novice Supporters, and thus in the broader community of practice, will also lead to preservation of the fluidity between ordinary citizens (potential Supporters) and current Supporters, as well as between veteran Supporters, who have reached the level of quasi-experts, and the experts themselves (for example, technical staff recently assigned to the observatory). Accordingly, we have realized that in the future, it will be necessary to hold training seminars for Supporters (which have thus far been held up until the third term) more frequently, as well as promote turnover at the science museum as a community of practice made up of observatory staff, Abuyama Supporters, and potential Supporters (*i.e.*, ordinary citizens who may become Supporters in future).

3.2 Three types of scientific literacy: *practical, civic,* and *cultural*

A second perspective from which to summarize the results of this study is the categorization of scientific literacy by Shen (1975) into practical, civic, and cultural forms of scientific literacy.

First, practical scientific literacy in the field of seismology corresponds to the acquisition of practical knowledge and skills – like methods of seismic retrofitting and reinforcement and the use of earthquake early warning systems – as well as the scientific knowledge behind them. Next, civic scientific literacy is expected of citizens as upholders of democracy. This refers to the ability to recognize whether activities related to a given scientific area (and the results generated therein) are being incorporated into society in a form that is compatible with the common-sense values of most citizens and that is consistent with the workings of a democratic society, so that problems can be acknowledged and resolved. In the context of seismology, this is the scientific literacy required to ask questions such as those posed in the wake of the Great East Japan Earthquake, such as “Could the huge tsunami that caused the nuclear disaster actually have been predicted?” and “Has science (as well as scientists) played an appropriate role in the process of determining advance tsunami countermeasures?” Finally, cultural scientific literacy refers to the consumption of scientific information as a form of intellectual entertainment or amusement, and the discovery of joy in learning about science itself.

Now, the problem here is that although it may be easy to recall and illustrate specific examples of the practical and civic aspects of seismology, it is more difficult to do so for the cultural aspects. In other words, at least in contemporary Japanese society, seismology is generally accepted as a science that provides society with practical knowledge. For this reason, seismology is arguably positioned as something that citizens are obliged to pay attention to in terms of whether or not that knowledge is being used in a manner that benefits only certain organizations or interest groups. However, compared with fields such as astronomy or ecology, seismology has not yet been established as a science in which citizens find intellectual enjoyment, something that would seem to be an obstacle to seismology becoming an open science.

On the flip side, therefore, we can think that the promotion of seismology as an open science might be realized by placing greater emphasis on the cultural aspect of scientific literacy as it relates to seismology. In that sense, it is noteworthy that the activities of the Abuyama Supporters have properties that are more strongly associated with this cultural aspect than with the practical or civic aspects. We can see this by looking at the motivations given by respondents for applying to become Abuyama Supporters (subsection 2.2). First, we do not find any motivations that could be classified as civic. Although many of these motivations mention an interest in seismology, references to things like practical earthquake prevention measures – in other words, practical aspects (utility to disaster prevention) – seem more or less limited to "contributing to disaster prevention" and "leading to opportunities to participate in disaster prevention and mitigation activities." Rather, as a whole, there is a strong inclination toward cultural aspects, as in "learning more about specific ideas, like the correct knowledge and science-based prediction technologies," "[having] taught earth science and biology at a high school," "I've been interested in earthquakes and other global phenomena for a long time," and "an interest in seismology (especially active faults and archaeo-seismology), which I am now studying."

Moreover, it is important to note that this orientation toward cultural aspects on the part of the Abuyama Supporters seems to be supported not only by seismology and seismic observation research, but also by the general scientific and intellectual aspects of the environment surrounding the observatory. This is precisely the attitude of someone who is poised to absorb and enjoy scientific information as a form of intellectual entertainment and amusement. For example, in statements such as "global environmental problems," "the building and its atmosphere," "forest volunteer," "volunteer guide at ancient ruins," and "a qualification as an environmental counselor, and I'm interested in the natural environment," we can see that people's motivations for applying to be a Supporter relates not only to an interest in seismology in a narrow sense, but also the support of scientific and cultural activities in general.

As described above, when science is done/performed not by scientists alone but in collaboration with ordinary citizens – in other words, when it involves citizen participation and contribution to a cross-section of scientific activities, whether in terms of guidance, observation, or analysis – it leads to the acquisition of pragmatically useful scientific knowledge and skills (the practical element) and ensures that the need to put the brakes on "runaway" science (or scientists) is monitored from the citizens' perspective (the civic element). Citizens watch and monitor scientific activities, and, if needed, can stop scientists not to move forward without social approval, when they try to develop and implement morally or ethically problematic technologies, for example. Also, as a cultural activity in and of itself, it brings intellectual satisfaction and collective enjoyment to the citizens who participate in these activities. The fact that the Science Museum Project at the Abuyama Observatory was able to promote this cultural aspect could be the key unlocking the door for open science in seismology.

The discussion above shows that open science activity at the Abuyama Observatory, with the improvement in all of three types of scientific literacy, does not simply promote learning and understanding of seismic science. But it brings deeper ownership and commitment to the citizens and fosters mutual trust between scientists and citizens by jointly observing and analyzing the aftershocks of the 2018 local earthquake mentioned in section 2.4. Discovering one's own capacity and feeling joy in the participation in scientific activities is important, particularly now, when we face societal-ecological crises like climate change and pandemics. It is true that what has been achieved at the Abuyama Observatory is small yet, but it is a solid step towards resolving societal distrust of science following the 2011 catastrophic event.

3.3 The 'conceptual ladder' of citizen science

A standard 'conceptual ladder' exists for citizen science, or rather for scientific activities in which ordinary citizens take part (Furuya, Sumimoto, and Hayashi 2018). Figure 6 presents our own framework of this conceptual ladder. Based on an awareness of the widening gap between researchers and citizens in the context of traditional science – which in the case of seismology is attested to by comments such as those concerning the "collapse of the myth of safety" and "unexpectedness" described in subsection 1.3 – outreach from scientists to citizens in the form of activities that seek to convey research outcomes in a manner that is easily understood has taken on increased emphasis. Premised therein, however, remains the belief that those who conduct research and those who enjoy the outcomes of that research are in diametric opposition, and that knowledge and skills flow unidirectionally from the former to the latter. In contrast, citizen science is conceived of as a new form of science predicated on a cooperative relationship between scientists and citizens. And, as described in subsection 1.2, open science, while using citizen science and open data as two wheels on the same axle, is positioned as a movement aimed at realizing a public participatory model of science.

Incidentally, Furuya, Sumimoto, and Hayashi (2018) distinguish four different levels (like steps on a ladder) of citizen science, with a focus on the degree of collaboration involved (Figure 6). It is important to note that, as suggested by the word "level," these four types carry the implication that higher levels are more advanced and therefore more desirable. For example, in this study, the observation realized by Abuyama Supporters would correspond to Level 1 (assisting with data collection), whereas analysis would correspond to Level 2 (data classification). Thus, the activities of the Abuyama Supporters have yet to reach Levels 3 and 4, and in that sense could be evaluated as being only midway along the path to citizen science. Prospectively, we would also like to aim to introduce activities that would correspond to what are described here as Levels 3 and 4.

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<table>
<tr><th colspan="6">OPEN SCIENCE</th></tr>
<tr><td rowspan="4">CITIZEN SCIENCE (DO / PERFORM SCIENCE)</td><td>Level 4</td><td>Joint research</td><td rowspan="4">Collaborative relationships between researchers and citizens</td><td rowspan="4">+</td><td rowspan="4">Open data (utilization of ICT)</td></tr>
<tr><td>Level 3</td><td>Participation in scientific discussions</td></tr>
<tr><td>Level 2</td><td>Data classification</td></tr>
<tr><td>Level 1</td><td>Assisting with data collection</td></tr>
<tr><td colspan="3">OUTREACH (LEARN / KNOW SCIENCE)</td><td>One-way relationship from researchers to citizens</td><td colspan="2" rowspan="2"></td></tr>
<tr><td colspan="3">TRADITIONAL SCIENCE</td><td>Separation of researchers and citizens</td></tr>
</table>

Figure 6. Conceptual ladder of open science and 'citizen science'

However, we would also like to call attention to the fact that there are some aspects in which this is not the case. In the context of citizen science, where the aim is for scientists and ordinary citizens to do/perform science together, what is here imagined as Level 4 – that is, for citizens to engage alongside scientists in professional discussions and carry out joint research as equal partners –is itself seen as the (ideal) goal of citizen science. But this is not necessarily always the case. The impression of an Abuyama Supporter that although "this was my first experience, […] I felt a sense of purpose knowing that I was only just beginning to get involved," would also seem to suggest that public participation in observation (*i.e.*, what is considered to be Level 1), has just as must potential as Levels 3 and 4 to act as a bridge connecting science with society, and scientists with citizens.

Finally, in closing this paper, we wish to touch on some of the negative aspects of open science. In this paper, we have described the open science movement as though it were something that should be promoted without precondition. And in fact we, in principle, evaluate open science positively as an important direction for building (or rebuilding) the relationship between science and society in the future. However, we are also aware of the negative aspects that this might entail, as well as the pitfalls of this movement.

Specifically, first, and as mentioned in Section 3.2, is the potential for the binary structure of "one who teaches" and "one who is taught" to be reproduced by the shuffling of roles; this should be kept in mind as something to be wary of. It is also worth noting that this point has been discussed elsewhere as a theory of risk communication based on the idea of the "double bind," and that concrete countermeasures have been proposed (see *e.g.*, Yamori 2020).

Second, in connection with the civic aspect of scientific literacy described above, public participation in scientific activities in the context of open science, especially when attempted merely as a formality, can be intended solely to give the science (or scientist) the excuse (or license) to say that the research is "democratically run" or "open to the public." This is also something that has long been discussed by people such as Yagi (2009), who has been assiduously studying the dialogue between scientists and citizens while reviewing a variety of participatory methods and dialogue techniques.

Furthermore, unlike fields such as ecology and astronomy, which have already gained a social presence as open science, it must be pointed out that the foundations of open science are still vulnerable in the context of relative latecomers such as seismology. As with the initiatives undertaken at the Abuyama Observatory, such attempts rely on the creativity and enthusiasm of a limited number of researchers, as well as the cooperation and support of a small number of like-minded citizens. As such, it cannot be said that there is yet sufficient momentum for research organizations (*e.g.*, universities) and their related academic societies to come together to promote open science. To overcome this situation, it will be necessary to open up future prospects in two ways. One is to systematically collaborate with activities related to outreach, which has taken on increased relevance in recent years among (seismological) academic societies. The other is to establish an organization, for example, through the incorporation as a non-profit organization and educational organization like schools and science centers, so that it does not depend entirely on the personal efforts of particular researchers and the transient cooperation and support of citizen volunteers.

As mentioned above, simply saying that something is "open science" is no guarantee that the traditional challenges associated with the relationship between science and society will be overcome or that everything will proceed smoothly. What is required of open science is careful planning and prudent management that is simultaneously focused on both the positive and negative aspects presented herein.

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Original paper

Analysis of Regional Response and Development of Disaster Prevention Teaching Materials for "Nankai Trough Earthquake Extra Information"

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Abstract Nankai Trough Earthquake Extra Information is a bulletin issued when the likelihood of a Nankai Trough earthquake is assessed to be relatively higher than normal, and it is expected to contribute to the mitigation of tsunami and earthquake damage. However, there has not been sufficient discussion on the social response to Nankai Trough Earthquake Extra Information. Therefore, this study examined the social response to Nankai Trough Earthquake Extra Information in Hamamachi Ward of Kuroshio, Kochi Prefecture, where response to Nankai Trough Earthquake Extra Information is discussed in the local disaster prevention plan using action research methodology. In addition, issues that were discussed in a workshop for local residents were compiled to create disaster prevention teaching materials. The materials were then used in disaster prevention education at a local junior high school. Through these activities, it became clear that it is important to consider evacuation measures for people who require assistance during disasters when Nankai Trough Earthquake Extra Information is issued, and that it is necessary to consider the continuity of daily life and disaster response in parallel.

Keywords: Nankai Trough Earthquake Extra Information, action research, disaster prevention plan, Crossroad, two-pronged approach

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1. INTRODUCTION

1.1 Nankai Trough Earthquake Extra Information

This study investigated issues related to regional response to Nankai Trough Earthquake Extra Information (hereinafter referred to as NTEEI)[2]. This NTEEI (rinji joho in Japanese) is issued in the following three cases. The first case is when an "unusual phenomenon" is observed along the Nankai Trough and an investigation has been launched to determine whether the phenomenon is related to an impending Nankai Trough earthquake. The second case is when the investigation started in the first case has determined that the likelihood of a Nankai Trough earthquake is relatively higher than normal[3]. The third case is when the investigation started in the first case has determined that the likelihood of a Nankai Trough earthquake is not relatively higher than normal. In the first case, preliminary information is issued before any conclusions have been made, whereas in the third case, the warning status is rescinded. Therefore, this study examined mainly the second case because it is the most important when considering the social response to NTEEI.

The abovementioned unusual phenomena are classified into three cases, each of which hold different implications for social response (Working Group on Disaster Management Response to Unusual Phenomena along the Nankai Trough, Central Disaster Management Council 2018; Aoki 2018; Cabinet Office 2019a). The first is a "half-crack case," in which there is a major earthquake of M8.0 or greater with severe damage. The Nankai Trough is a roughly 4,000-meter-deep trench that runs about 700 km along the ocean floor 100–150 km south of the Japanese archipelago from the Tokai region to the Kii Peninsula, Shikoku, and Kyushu. In a half-crack case, for example, a large-scale earthquake might occur off the Tokai coast but is assumed to remain cracked off the coast of Shikoku and other areas. This case corresponds to the Ansei Nankai Trough Earthquake of 1854, in which huge earthquakes occurred in succession on the eastern and western sides of the Nankai Trough with a time difference of about 32 h after the first earthquake. The second case is the "partially broken case" in which there is an earthquake of M7.0–8.0. For example, this case would correspond to the status right after the M7.3 earthquake that occurred off the Sanriku coast on March 9, 2011, two days before the M9.0 Great East Japan Earthquake on March 11, 2011. The third case is the "slow-

[2] Nankai Trough Earthquake Extra Information (NTEEI) is translated by Cabinet Office (2019a) from the Japanese word "*rinji-joho*," but the word "extra" is a literal translation that may make it difficult to understand the characteristics of this disaster information. Given the role of "*rinji-joho*" as a warning that the likelihood of a Nankai Trough earthquake is higher than usual, "*rinji-joho*" might be better translated into English as "Special Early Warning Information," for instance. It is important to further discuss the appropriate English translation of "*rinji-joho*" so that it can be used by people who do not understand Japanese language.

[3] Since the Mw 6.3 earthquake in L'Aquila, Italy, on April 6, 2009, much attention has been paid to the scientific prediction of earthquakes in advance. A report entitled "Operational Earthquake Forecasting - State of Knowledge and Guidelines for Utilization" was subsequently compiled by 10 seismology experts from 9 countries (International Commission on Earthquake Forecasting for Civil Protection, 2011). The report clearly distinguishes between prediction and forecasting, defining prediction as a deterministic assignment of 0 or 1, and forecasting as a probabilistic reference, not necessarily divided only between 0 and 1. Based on this definition, NTEEI is disaster information based on the concept of forecasting, not prediction.

slip case," in which significant changes are detected by strain gauges; however, this differs greatly from the above two cases in that there is no damage to society at that time.

The Cabinet Office (Cabinet Office 2019b) published guidelines in March 2019, outlining its policy on how to respond to each of the three unusual phenomenon cases. The guidelines cover a wide range of topics, but one of the most significant topics is related to the half-break case described above. The guidelines call for early evacuation in areas that are expected to be inundated by tsunami, as part of a "massive earthquake alert response" for about a week, when the likelihood of another large-scale earthquake is considered particularly high. Specifically, the guidelines target those who would need assistance to evacuate after the earthquake as well as residents of areas where evacuation is difficult. There are also guidelines for various organizations such as educational institutions and hospitals.

Because the NTEEI is released before the occurrence of a Nankai Trough earthquake, it should be extremely effective at reducing the number of victims, which is estimated to exceed 320,000 in the worst-case scenario (Tanaka 2018). In particular, if the recommended pre-evacuation is properly implemented in areas expected to be inundated by tsunami, the number of tsunami victims, who are estimated to account for about 70% of all victims, can be expected to be substantially reduced.

There are some points that should be noted about NTEEI. First of all, the hit rate is unfortunately not very high. Even in the case of a half-cracked earthquake, the probability of a subsequent earthquake occurring within a week or so, which is the criterion for pre-evacuation, is about 1 in 10. The hit rate is even lower in the case of a partially cracked or slow-slip earthquake.

In addition, because pre-evacuation requires residents to take extraordinary actions to evacuate their homes before major damage occurs, following the guidelines may conflict with the continuity of daily life and bring about social disruption. Specifically, there are concerns about the stagnation of social and economic activities, especially in the areas where the information is issued, as well as speculation about the impact of the disaster on the tourism industry. In addition, there is concern that the effectiveness of issuing such information may be adversely affected if the earthquake in question does not occur within a period of about one week after the NTEEI is released, especially if it is regarded as a "swing and miss" *(i.e.*, a pointless evacuation).

Therefore, despite the great potential for NTEEI to mitigate loss of life in a disaster, unless methods and mechanisms for its effective use are carefully considered and implemented by society, it may end up causing unnecessary confusion. The issues that need to be considered regarding NTEEI are enormous and cover a very wide range of areas. Moreover, it has only been about four years since the NTEEI system became operational (November 2017), so it is difficult to fully examine the social response to date. Therefore, in this study, we attempted a basic analysis focusing on the above-mentioned pre-evacuation scenarios.

1.2 Awareness rate of NTEEI

Focusing on the aspect of pre-evacuation, the simplest and biggest problem with the NTEEI is that, at least as of this writing (November 2021), the information is not being sufficiently disseminated to the residents of areas that would need to be evacuated in advance. In many cases, they are not even aware that they are subject to pre-evacuation. The following are survey results that illustrate this point.

First, we introduce data from Hamamachi Ward, Kuroshio, Kochi Prefecture. Hamamachi is one of the areas that the Cabinet Office has used as a model for developing the aforementioned guidelines. However, in April 2018, when a questionnaire survey was conducted of 54 of Hamamachi's nearly 350 residents, 46.2% of the respondents answered that they had "no idea" about the NTEEI. Even the name of the information system was not known by many people, and fewer people still understood the distinction between the three cases.

Next, a survey conducted in May and June 2018 by a planning committee established by Tokushima Prefecture to deal with NTEEI found that of 1,141 residents of the town of Kaiyo (Department of Emergency Management, Tokushima Prefecture 2018) 30.8% knew what NTEEI was, 40.0% had heard about it, and 29.2% had not heard about it. If we consider the fact that there is a certain bias related to social desirability (in this case, we can assume that respondents would consider it more desirable to answer "I know"), the figures should be understood as indicating that about 70% of the residents have at most heard about the situation.

In addition, in a survey conducted by NHK in collaboration with the University of Tokushima during fiscal year 2018 (NHK and Tokushima University 2018) of 293 elder-care facilities located in tsunami inundation areas in the four prefectures of Shikoku, only 5% of respondents were "well aware," whereas 51% were "somewhat aware," 37% were "not well aware," and 6% were "not at all aware." It can thus be concluded that awareness of the NTEEI system is still low and that an insufficient number of people understand it.

1.3 Problems in planning for NTEEI

In addition to the low awareness of the information, there is another important point to consider when thinking about pre-evacuation based on NTEEI, that is, the need for individualized and specific planning. The guidelines discuss pre-evacuation at a general level but do not clearly consider how individual municipalities, which have different susceptibilities to earthquakes and tsunami as well as a wide variety of geographical and social conditions, will make use of NTEEI. There is also no clear consideration of how individual groups and organizations such as schools, commercial facilities, welfare facilities, and voluntary disaster prevention organizations should respond.

However, this does not mean that the government has abandoned its responsibility. The problem lies in the nature of the information itself. As mentioned in the previous section, although NTEEI is expected to have a tremendous disaster mitigation effect, it also comes with a very high degree of uncertainty. For this reason, the government has no choice but to issue a policy stressing the importance of each individual taking safe disaster prevention actions in response to disaster risks while weighing the likelihood of an earthquake against the impact of disaster preparedness on daily life and business activities. Although some municipalities have already formulated disaster reduction plans for NTEEI (Kochi Prefecture 2021; Kagawa Prefecture 2021; Shimanto Town 2021; Tokai City 2021; Hamamatsu City 2021; Sakai City 2020), these plans are prepared by the government and described in a top-down manner, and do not consider the detailed social response according to the characteristics of each community.

We consider that there are three key points to the policy presented here. The first is “bottom-up,” the second is “individuality and diversity,” and the third is a “two-pronged approach.” The published guidelines admit that “the occurrence of an earthquake cannot be clearly predicted” and suggest that there will be no strong top-down regulation of social activities, as in the case of the Tokai earthquake. Indeed, it uses the term “self-help” and calls for the parties concerned to “choose” their own disaster prevention actions. In this sense, it is actually a bottom-up approach. Next, the guidelines state that “risks in the event of an earthquake vary depending on the situation,” and call for responses that are tailored to individual and regional circumstances, rather than a uniform nationwide response. Accordingly, individuality and diversity are emphasized. Finally, the guidelines recommend that “while conducting daily life, take action with caution in the event of an earthquake,” and call for a balance between the daily life and disaster modes. In this sense, a two-pronged approach to both daily life and disasters is emphasized.

In short, in responding to NTEEI, including guidance for pre-evacuation, each organization, group, community, and household is required to think and act independently in a bottom-up manner rather than being regulated or instructed by the government. This is also what is required by the District Disaster Prevention Plan System that was launched in April 2014 after the Basic Act on Disaster Control Measures was revised (Cabinet Office 2014). Of course, it is not so easy to promote such bottom-up efforts. In the future, it will be necessary for residents, disaster prevention organizations, and the government to work together in various parts of the country, especially in areas subject to pre-evacuation.

As a first step toward this goal, this study reports on the efforts implemented in Hamamachi Ward. With a focus on the abovementioned three key points, this case study examines the nation-leading effort to create a specific plan for pre-evacuation based on NTEEI.

2. RESEARCH OBJECTIVES AND CASE REPORTS

2.1 Research Object and Research Method

Hamamachi Ward has a population of around 350 people and an aging rate of 52% (as of April 2019). Because most of the residents are engaged in fishing and operate bonito fishing vessels in the distant seas, there are relatively fewer male residents between February and November each year, so the female residents are primarily responsible for the management of the ward. As a result, fire prevention and disaster prevention activities by women are thriving in Hamamachi. With the slogan “Kakarigamashii” (meaning “caring” or “meddling” in the local dialect), they are diligently considering evacuation measures for the elderly, disabled, and other people who need assistance during disasters.

According to the Nankai Trough earthquake and tsunami forecast issued by the Cabinet Office in 2012, the first wave of tsunami is expected to reach the area about 15 min after the earthquake, with a maximum inundation depth of about 20 m. Moreover, because there is no high ground in the area, it had been designated a “difficult tsunami evacuation zone” for many years. However, in April 2017, one of the tallest tsunami evacuation towers in Japan was built in the Hamamachi, improving the environment for evacuation has improved to a certain extent (Kuroshio Town 2017).

Furthermore, Hamamachi was selected as a model ward in March 2018 by the Cabinet Office’s study group examining NTEEI measures. Study sessions for residents on NTEEI were held four times during FY2018. In parallel with the study group organized by the Cabinet Office, discussions on NTEEI were also held independently at the board of directors meeting of a voluntary disaster prevention organization as part of the activities of the local disaster prevention plan in the Hamamachi ward.

The authors have been involved in the Hamamachi ward since 2015 as advisors for the district disaster management plan, and have also played an advisory role in NTEEI workshops and study groups held in the Hamamachi ward to organize residents' discussions. The authors collected and recorded data through questionnaires and participant observation, and analyzed the debate on NTEEI in Hamamachi ward using the research method of action research (Lewin 1946; Rossman and Rallis 2003; Herr and Anderson 2005; Yamori 2006)[4]. In addition, the authors explained orally to the subjects of the records how the survey results would be used and that privacy protection would be taken into consideration, and obtained their consent.

2.2 Awareness rate of NTEEI in study area

The authors administered a questionnaire on NTEEI to 54 residents (average age 65 years; 52 valid responses for analysis) living in the Hamamachi ward in April 2018. A total of 24

[4] Action research is a concept proposed by K. Lewin, the founder of group dynamics. Levin defined action research as a research activity that leads to the next social activity by conducting an analysis of the situation and impact of social practice activities (Lewin, 1946). Since then, action research has been dealt with in areas related to various social issues, such as medical practice, education, and corporate activities, and action research methods have been refined in academic fields such as psychology, social work, and education (Herr *et al.*, 2005). The advantages of action research include the fact that the research methodology itself has a broad social impact, is expected to empower both researchers and practitioners involved in action research activities (Rossman *et al*., 2003).

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(46.2%) respondents answered that they had "no idea" about the NTEEI. However, when asked about the effectiveness of the information, 43 respondents (82.7%) answered that the information was "very useful" (34 respondents) or "somewhat useful" (9 respondents). When asked about specific actions to be taken after the issuance of NTEEI in an open-ended question, 33 respondents (63.5%) did not provide specific answers. These results suggest that local residents accepted the NTEEI system in a vague way as "something that might be useful," but did not have a full understanding of its contents.

2.3 Planning for NTEEI in the study area

As revealed by our survey, the NTEEI was not well understood by the residents of Hamamachi, but through study sessions and discussions at the board of directors meeting of the voluntary disaster prevention organization, their understanding gradually increased and a countermeasure plan to act on NTEEI was gradually formulated (Fig. 1). Various aspects were discussed, but in the end, the focus of the discussions converged on the method of pre-evacuation for those who require assistance when evacuating. This direction is in line with the focus of the guidelines compiled by the Cabinet Office (Cabinet Office 2019c).

Figure 1. The board of directors meeting of the voluntary disaster prevention organization in Hamamachi ward

We summarized many of the opinions expressed by residents regarding the pre-evacuation of people in need of care into four main measures. Then, in a study session on NTEEI, residents discussed the pros and cons of these four measures.

The first measure is pre-evacuation in groups to a distant location on higher ground (non-inundated area). The advantage of this method is that there is no risk of tsunami at the evacuation site, and because the evacuation is carried out at the ward level, the daily relationships with one's neighbors can be maintained at the evacuation site. For example, one man in his 70s said, "If we run to the elementary school in Iyoki (a non-inundated area located about 4.5 km from Hamamachi), we will be safe, but the elderly cannot live in a shelter for a long time" (March 17, 2018). However, it was pointed out that one of the disadvantages of this method is that the evacuation site is outside the usual living area, making it difficult for many caregivers of people with special needs to take care of them while they are at the evacuation site. In addition, Hamamachi is located in a coastal area, whereas Iyoki is in a mountainous area, and so they differ in terms of lifestyle and culture, making it difficult for residents of Hamamachi to ask the residents of Iyoki to support them when they evacuate. A woman in her

60s said, “We don't have any friends or acquaintances in the Iyoki area, and even if we were to live in an evacuation shelter there, we don’t know who would take care of the elderly evacuees” (February 15, 2019).

The second measure is pre-evacuation in groups to a public facility close to the primary evacuation site in the ward. It is important to note that the facilities to be evacuated are in the tsunami inundation zone, so they will need to be evacuated in the event of an earthquake. Even though the tsunami risk is not completely eliminated, the advantage of this strategy is that the facilities to be evacuated are within the residential part of the Hamamachi, so it is easy to secure caretakers for the people who need them from within the ward. This point was emphasized by a woman in her 60s who said, “We have no choice but to evacuate to a junior high school because we know it well and can take care of my mother there” (February 15, 2019). It was also pointed out that although further evacuation may be necessary, the public facilities to be evacuated in advance are closer to the primary evacuation site than to their homes, and thus have the advantage of enabling quicker tsunami evacuation than fleeing from home. However, there is an emergency evacuation site near the junior high school, but there are not enough facilities to shelter everyone from the rain and wind. For example, a man in his 60s said, “I cannot live in a shelter without worrying because the tsunami is expected to hit the junior high school in Saga. Even if I go up to higher ground, there is no place to shelter from the rain and wind, so old people may die in the rain” (December 16, 2018).

The third measure is to evacuate individually to a distant place in advance. In this method, each household evacuates in advance to a relative’s home in a distant elevated area (non-inundated area), rather than to a shelter. The advantage of this method is that it is easy to secure caretakers for those who need them because they can rely on their relatives and there is no risk of tsunami at the evacuation site. A woman in her 60s said, “My niece lives on high ground in Kochi City, so if I leave my mother there for a while, my niece can take care of her for a few days, but not for months" (July 24, 2018). However, the problem with this method is that because the evacuation is not carried out at the ward level, daily neighborhood relationships will be disrupted, and not all residents have relatives living in non-inundated areas nearby, which limits the number of people who can adopt this method. As one man in his 60s put it, “What about those who have no relatives outside of Kuroshio? There is nothing we can do” (December 16, 2018). In addition, it has been pointed out that if voluntary disaster prevention organizations are unable to determine the evacuation status of individual residents, they may waste valuable time attempting to rescue people who evacuated in advance. For example, one man in his 60s said, “If you evacuate to a relative’s home in advance without notifying the voluntary disaster prevention organization, they will not know who is at home when an earthquake occurs, and you might inadvertently put their lives in danger” (December 16, 2018).

The fourth measure is to continue life as usual at home without pre-evacuating. The advantages of this method are that there is no need to secure a caretaker for the pre-evacuation, the daily relationships with one’s neighbors can be maintained, and there will be no added burden on human relationships during the evacuation. As one woman in her 50s noted, “Even

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the elderly have problems with human relationships. It is difficult to live together in an evacuation shelter, no matter how close you are" (July 24, 2018). However, the need for tsunami evacuation immediately after an earthquake, the distance from one's home to the primary evacuation site, and the risk of being trapped in an indoor space and not being able to evacuate quickly, were pointed out as disadvantages. One man in his 60s said, "We don't know what will happen in an emergency. We have no choice but to prepare and spend our time as usual" (February 15, 2019).

Of the four measures summarized above, the board of directors of the voluntary disaster prevention organization in Hamamachi finally decided to recommend pre-evacuation in groups to nearby areas (the second measure) and pre-evacuation individually to distant areas (the third measure). During this period, the government did not provide any guidance to the residents of the Hamamachi. Rather it was the residents themselves who chose these measures for pre-evacuation. In this respect, the measures were decided in a bottom-up way and were based on the individuality and diversity of the Hamamachi ward (*e.g.*, the high aging rate, rich neighborhood relations, and the fact that the physical distance to the nearest non-inundated area is far and there are few deep ties). In addition, the two measures adopted in the Hamamachi ward are based on a two-pronged approach that balances the two modes of daily life and disaster. Although fully aware of the risk of tsunami, the Hamamachi district has also placed importance on the continuity of daily life, especially in terms of securing caretakers for those who need care.

2.4 Development of disaster prevention teaching materials based on the results of the workshop on NTEEI

In the workshop held in the Hamamachi ward, there were several issues that divided the discussion. Although the participants reached a certain consensus after discussing controversial issues, they decided to continue the discussion. These issues were compiled to create disaster prevention materials, which we called "Crossroad" so that others could easily discuss them too.

Crossroad examines the dilemmas experienced in various phases of a disaster (Yamori 2008; Aziro *et al*. 2011). Crossroad has been studied as a teaching material for various areas such as earthquake disaster prevention, tsunami disaster prevention (Lee *et al*. 2019; Sogawa 2020), evacuation shelter management, and disaster reporting, but there have been no examples of Crossroad teaching materials on the theme of NTEEI. Therefore, developing a crossroad on the theme of NTEEI was highly novel from both academic and practical perspectives.

Using these materials, workshop participants consider the issues as they relate to their own circumstances, answer "yes" or "no" to the questions, and then share the reasons for their answers with the members of their group. Thanks to its simple format, Crossroad can be used to create a variety of questions.

Figure 2. A class on disaster prevention education at Saga Junior High School

In cooperation with residents of the Hamamachi ward, we developed the following two discussion questions and used them to provide disaster prevention education to junior high school students and their parents at Saga Junior High School in Kuroshio on February 7, 2020 (Fig. 2) [5]. Saga Junior High School is also part of the Hamamachi ward, and in order to consider countermeasures against NTEEI in the Hamamachi ward, the junior high school also jointly participated in the Hamamachi ward study group and held a study group on NTEEI using "Crossroad" at Saga Junior High School. The questions are as follows: “Question 1: You are a resident. The Japan Meteorological Agency has issued NTEEI (Major Earthquake Warning). However, the primary tsunami evacuation sites near the coastal areas do not have buildings to shelter you from the rain and wind, and you will have to move to the distant mountainous areas to get to shelters where you can live. Would you evacuate in advance to a residential facility in a coastal area where it would be easier to evacuate to the primary tsunami evacuation site, even though the facility is in the tsunami inundation zone?” and “Question 2: You are a resident. The Japan Meteorological Agency has issued NTEEI (Major Earthquake Advisory). Would you like the elementary and junior high schools in your area to be closed for the next week?”

In the disaster prevention class, a variety of affirmative and negative opinions were expressed by the students and parents. For Question 1, 78% of the students and 75% of the parents responded that they would not evacuate. Reasons for this response included “The elderly who have been living in coastal areas for a long time are not accustomed to living in distant evacuation centers in mountainous areas, and it would be difficult for them to get around. Therefore, I think it is more practical to evacuate in advance to a residential facility in the coastal area where it would be easier to evacuate to the primary tsunami evacuation site, even though it is in the tsunami inundation zone” and “I prefer to evacuate in advance at night since it is hard to see the earthquake damage and evacuate at night. However, it is difficult to move every night from the coastal area where I live to the mountainous area, so I would like to pre-evacuate to a building in the coastal area near the primary tsunami evacuation site, even though it is in the tsunami inundation zone.” Reasons given for not evacuating included “I'm young, so I don't need to evacuate in advance, but I can evacuate from my home in the coastal area to the primary evacuation site when the earthquake happens” and “If I know in advance that an earthquake is going to happen, I would like to evacuate to a shelter in a mountainous area where

[5] Saga Junior High School, established in 1947, is one of two junior high schools in Kuroshio. Since the junior high school is located in the tsunami inundation zone, the school focuses on disaster prevention education. One of the tallest tsunami evacuation towers in Japan was built near the junior high school, and the school has long been involved in disaster prevention activities in collaboration with local residents and school staff and students.

tsunami evacuation is not necessary, even if it is a little inconvenient to leave my home in the coastal area." This issue is related to the second pre-evacuation measure (group evacuation to a shelter close to the evacuation site) in the Hamamachi ward workshop discussed in the previous section. After the participants finished discussing this question, we introduced the pros and cons by the participants at the Hamamachi ward workshop.

There was also a lively discussion about Question 2. Specifically, 46% of the 49 students responded that they would like the school to be closed, while 54% responded that they would not. In contrast, 83% of the 12 parents answered that they would like the school to be closed, whereas only 17% answered that they would not. The reason that parents gave for wanting schools to be closed was the desire for their children to be as far away as possible from places that are at risk of tsunami inundation. However, some of students said, "We have had tsunami drills at school, so we can evacuate safely in the event of a tsunami, so it is not a problem, but we are worried that if the school is closed, we will not be able to evacuate together." In addition, some parents said, "If the school is closed, the children will have to evacuate from their own homes, and if an earthquake hits when the children are at home alone, we are worried that they will not be able to evacuate." This issue was also raised at the Hamamachi workshop. After the participants finished discussing this question, we introduced the opinions shared by the workshop participants.

As of February 7, 2020, Kochi City and Nankoku in Kochi Prefecture were considering a plan to uniformly close schools when NTEEI on a Nankai Trough earthquake was announced. However, based on the results of the Crossroad activities, it became clear that response plans should consider the pros and cons of school closure. We shared our results with the staff of the Kuroshio Board of Education, who considered the points raised by the students and parents in response to Question 2, and they ultimately decided not to uniformly close schools in Kuroshio even when NTEEI is issued. Therefore, we consider that Crossroad was effective at influencing the disaster prevention policies of Kuroshio.

As described above, using Crossroad to provide disaster prevention education was effective at eliciting a wide range of opinions. Further discussions are needed to promote consensus-building among students, parents, local residents, and the government on how best to respond to NTEEI.

3. CONCLUSIONS

3.1 Bottom-up, individuality, diversity, and a two-pronged approach

The disaster prevention and mitigation system in Japan is based on the premise of separating the "routine" from the "unexpected." Expressions such as "switching to disaster mode" and "establishing and dissolving a disaster task force" symbolize this separation. However, there is a lack of experience and know-how necessary for managing and responding to a situation that is a mixture of both routine and unexpected.

As we have discussed so far, to respond to NTEEI, we need to take a two-pronged approach. Although NTEEI is extremely uncertain, it indicates that the probability of a disaster occurring is several hundred to several thousand times higher than usual, and if it is used to decide appropriate responses, it can have a substantial effect on disaster mitigation. Therefore, to make the most of this information, it is important to not fall into the trap of arguing for certainty without being prepared. It is necessary for each entity to consider and prepare for a two-pronged response (a "gray solution" that is neither pure white nor pure black) that is flexible enough to accommodate uncertain information while reducing various trade-offs. It is also important to build new disaster prevention systems and frameworks that will support this over time.

Specifically, it is necessary to make a list of the advantages and disadvantages of both the continuity and convenience of daily life compared with the effectiveness of responses in the event of an earthquake, and to take measures to maximize the advantages and minimize the disadvantages. To prepare for these measures, there is no choice but to formulate bottom-up plans that are individualized and diverse, based on the characteristics of the local community. In this sense, as mentioned earlier, responding to NTEEI has a high affinity with the concept of district disaster prevention plans.

However, there are some points to consider. In the case of Hamamachi, the concrete development of the discussion on NTEEI was made possible by actions that Kuroshio has taken to create a district disaster prevention plan since FY2015. Not only are all the town office staff involved in this initiative under the Kuroshio's unique Regional Staff System, but through this initiative, unique disaster prevention measures such as indoor evacuation drills (evacuation drills to the entrance and to the second floor) and the installation of individual storage boxes at evacuation sites have already been created in a bottom-up manner. The bottom-up approach has already produced some very unique disaster prevention measures (Sugiyama and Yamori 2020; Yamori and Sugiyama 2020). It would likely have been difficult to start a constructive discussion on what measures to take in response to NTEEI from the bottom up, without such preparation.

3.2 Connection between pre-evacuation activities and emergency disaster response

There is always the possibility that a Nankai Trough earthquake and tsunami will occur suddenly before any NTEEI can be issued. For this reason, it is necessary to not only pay transitory attention to NTEEI, but also to integrate it with conventional preparations for sudden disaster scenarios. In fact, countermeasures and preparedness for such scenarios will also enhance countermeasures and preparedness for NTEEI. For example, earthquake-proofing and improving the environment of schools that will serve as evacuation centers will increase the number of options available for temporary evacuation in response to NTEEI. However, promoting measures for NTEEI might also promote preparedness for unexpected scenarios. For example, even if nothing happens during an evacuation in response NTEEI, if we view it as an opportunity for hyper-realistic disaster drills (*i.e.*, “practice swing” (Yamori 2019) rather than considering it a “swing and a miss, we can prepare for sudden-onset scenarios.

Therefore, it is essential to use NTEEI as a reminder to prepare for a Nankai Trough Earthquake and to use it as an opportunity to refine local disaster prevention plans. In fact, since the Cabinet Office announced a heightened alert for a Nankai Trough earthquake and tsunami in 2012, the Hamamachi ward has been conducting disaster prevention activities with the mindset that a disaster could occur at any time, and it could be said that NTEEI has already been issued, at least in the minds of local residents. For this reason, the designation of the area as a model for responding to NTEEI and the recent regional discussion did not result in any qualitative changes in earthquake/tsunami countermeasures or disaster prevention activities. This fact is reflected, for example, in the words of man in his 70s who said, “Even if NTEEI is rescinded after a week, we’ll still act as if it were still in effect” (December 16, 2018). Although it is extremely important to incorporate responses to NTEEI as part of the district disaster prevention plans, it is also important not to overestimate or rely on NTEEI, but rather promote responses in conjunction with those to sudden-onset scenarios.

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Original paper

Natural Factors of Accidents at Power Transmission Lines

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Abstract Power lines are energy infrastructure facilities that are most severely affected by the impacts of various natural hazards, especially those of hydrometeorological genesis. Accidents and emergency situations with power outages triggered by natural hazards and adverse phenomena account for more than a half in the total number of natural-technological accidents registered in Russia. The exposure and vulnerability of overhead power transmission networks to natural impacts is caused by their large length and the harsh environment. The paper considers regional differences in the occurrences of accidents triggered by hazardous natural impacts on power transmission lines, identifies natural factors of these accidents, and reveals regions most at risk. The methods used are the geographic and statistical analysis of the information collected by the author in an electronic database of technological and natural-technological accidents and emergency situations. The majority of natural-technological accidents with power disruptions are caused by wind loads, which are especially dangerous in combination with other hydrometeorological factors such as rain, snow, ice and rime deposit, thunderstorm, and hail.

Keywords: Electric power industry, power transmission line, natural hazard, natural-technological accident, emergency situation, database, hydrometeorological hazard and phenomenon

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1. INTRODUCTION

The electric power industry is one of the sectors of the economy most affected by natural factors of various origins (Chang *et al*. 2007; Petrova 2011; Lu *et al*. 2017; Bian *et al*. 2021; Tervo *et al*. 2021; Dobson 2021). This is due to a large number of power infrastructure facilities including the long-distance overhead power transmission lines, transformer substations, and other elements of the energy systems that often fall into the zone of natural risk.

In its turn, the disruption of power supply due to hazardous natural impacts entails a number of negative synergistic consequences. Particularly dangerous are long-term power outages that disrupt the normal living conditions of the population and the normal operation of various economic objects, thereby creating numerous emergency situations (Eidsvig *et al*. 2017; Huitu *et al*. 2020; Mitsova *et al*. 2018; Ulak *et al*. 2018). The greatest damage as a result of interruptions in power supply is reported in industrial, construction and transport types of economic activity (Kattsov 2017). Long-term interruptions in the operation of industrial and transport facilities not only cause economic losses and social problems, but can lead to a chain of further cascading accidents.

The most disastrous consequences had the severe energy crisis that occurred in February 2021 in the state of Texas (USA) as a result of three severe winter storms that swept the United States and led to a significant drop in temperature. It was accompanied by massive failures in power generation and, as a result, a shortage of water, food and heat supply. More than 4.5 million customers, both homes and businesses were left without power, some of them for days. The death of at least 151 people was directly or indirectly related to this disaster (Weber and Stengle 2021). Significant emissions of pollutants have been reported due to disruption of the infrastructure of chemical plants and fuel processing plants.

Due to the large spatial extent and severe environmental conditions of the power transmission lines, they are the equipment of the power system most affected by natural impacts (Bian *et al*. 2021). Among natural factors, the following are reported by the researchers to cause significant damage to power lines: strong wind and ice storm (Hosek *et al*. 2011; Kunz *et al*. 2013; Nateghi *et al*. 2014; Quiring *et al*. 2011), lightning, wildfire (Bian *et al*. 2021; Liu *et al*. 2021; Shield 2018), falling trees (Tervo *et al*. 2021), heavy snowfall, heavy rain, wet snow, and icing (Bonelli *et al*. 2011; Cigrè 2009; Farzaneh 2008; Llasat *et al*. 2014).

Strong winds are among the most significant natural hazards for overhead power lines (Gardiner *et al*. 2010; Kufeoglu and Lehtonen 2015). They can lead to the collapse of power transmission towers and breakage of wires, both directly and due to falling trees on power transmission lines. Windstorms pose a huge challenge for power distribution companies, especially in highly forested countries such as Finland, where falling trees cause power outages for hundreds of thousands of customers every year. Between the years 2010 and 2018, on average 46 % of all transmission faults in Finland were caused by extra tropical storms (Tervo *et al*. 2021). In the United States, tropical cyclones cause massive damage to electricity supplies. Due to Hurricane Sandy in October 2012, more than 20 million people on the East Coast were affected by power outages that lasted several days to weeks in some regions (Kunz *et al*. 2013).

Icing formation on structures and power lines is another hazardous natural phenomenon that causes damage to electric power industry in many countries and regions with cold and temperate climate such as USA, Canada, Northern Europe, Mediterranean region, Kazakhstan, China, and Japan (Bonelli *et al*. 2011; Chang *et al*. 2007; Cigrè 2009; Dyusebayev *et al*. 2017; Fikke 2005; Fikke *et al*. 2007; Gutman *et al*. 2019; Hosek *et al*. 2011; Llasat *et al*. 2014). High humidity, sudden changes in air temperature from positive to negative contribute to the formation of ice on the wires of overhead lines. For example, wet snow icing accretion on power lines is a real problem in Italy, as well as in other Mediterranean countries, causing failures on high and medium voltage power supplies during the cold season (Bonelli *et al*. 2011). In Norway, ice events can lead to interruptions in the operation of overhead power lines for several days (Gutman *et al*. 2019). The northeast coast of North America is frequently hit by severe ice storms that can produce large ice accretions damaging power transmission and distribution infrastructure (Hosek *et al*. 2011).

In Russia, the energy system covers almost the entire economically developed territory of the country with a variety of weather and climatic conditions, exposing power transmission lines and other power facilities to a large number of different adverse and hazardous natural processes and phenomena. In order to prevent the negative consequences of accidents on power lines caused by natural factors, it is necessary to monitor such events, analyze their causes and identify the places of the greatest risk that need to be dealt with. These issues are especially relevant in the context of ongoing and future climate change. In recent decades, climate warming in Russia was happening faster and about 2.5 times more intense than the average globe. According to climatologists, these trends are expected to continue in the near future (Kattsov 2017).

The purposes of this study are to propose the possibilities of the database in monitoring and analyzing natural-technological accidents and emergency situations (ES) in power facilities; highlight regional features and differences in the manifestation of hazardous natural impacts on power transmission lines in Russia; reveal the main types of adverse and hazardous natural processes and phenomena that have the strongest impact on electrical networks; and identify areas most at risk for such accident occurrences. The lessons from the case study could be learned for regions with similar climatic conditions, since a wide variety of natural hazards and phenomena on the territory of the Russian Federation can be a kind of "testing ground" for studying their consequences for electrical networks.

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2. STUDY REGION

The study region is the Russian Federation. The electric power industry is a key branch of the Russian economy, which provides production, transmission, distribution, and consumption of electrical energy, thereby creating the basic conditions for the functioning of the whole economy of the country and the life support of its population.

The energy system of the Russian Federation includes six interconnected energy systems (IES) that are part of the Unified energy system (UES) of Russia of the first synchronous zone: IES of Center, Middle Volga, Urals, North-West, South, and Siberia, as well as seven territorially isolated energy systems in the Far East of the country (Chukotka Autonomous Okrug, Kamchatka Territory, Sakhalin and Magadan Regions, and Nikolayevsk power district in Khabarovsk Territory) and in the Eastern Siberia (Republic of Sakha (Yakutia) and Norilsk-Taimyr power system in Krasnoyarsk Territory) (Ministry of Energy 2021). The IES of the East of Russia including Amur Region, Primorsky and Khabarovsk Territories, Jewish Autonomous Region, as well as the Republic of Sakha (Yakutia) operates separately from the rest of the energy systems. The functioning of isolated power systems in remote and economically isolated areas is much more vulnerable to the impacts of hazardous natural phenomena.

All power systems are connected by intersystem high-voltage power lines with a voltage of 220-500 kV and above and operate in a synchronous mode (in parallel). The power grid of the UES of Russia has more than 13,000 power transmission lines of 110–1150 kV voltage class with a total length of more than 490 thousand km and more than 10,000 electrical substations of 110–750 kV (Unified Energy System of Russia 2021).

Such a large scale of the Russian energy system and the harsh environment determine its strong exposure to a variety of natural factors.

Meteorological and hydrological hazardous processes and phenomena such as strong winds, heavy rains and snowstorms, wet snow and icing, floods, thunderstorms, hailstorms, especially dangerous for overhead power transmission lines, are widespread in the country. The highest frequency of strong winds is observed in the Far East of Russia, as well as in the south and middle parts of the European Russia. The combination of heavy precipitation in liquid and solid form and strong wind is one of the most dangerous climate situations in the coastal regions of the Far East (Sakhalin Region; Kamchatka, Khabarovsk, and Primorsky Territories). The most intense rains are typical for Kamchatka, Krasnodar, and Primorsky Territories; the heaviest snowfalls happen in the North Caucasus, north and south-west of Siberia, as well as Far East (Sakhalin and Magadan Regions; Chukotka; Kamchatka, Khabarovsk, and Primorsky Territories). Regions of the Far East, such as Republic of Sakha (Yakutia), Khabarovsk and Primorsky Territories, Amur Region, as well as the south part of the European Russia (Republics of the North Caucasus; Krasnodar and Stavropol Territories) are mostly exposed to catastrophic floods (EMERCOM 2010).

The cumulative degree of natural hazard is increasing in Russia from the west to the east and south, with progress to the mountainous regions. The most affected by natural hazards are the North Caucasus, Ural and Altai Mountains, Irkutsk Region and Trans-Baikal Territory, the Pacific coast of the Khabarovsk Territory and Magadan Region, and especially Sakhalin, the Kuril Islands, and Kamchatka (Malkhazova and Chalov 2004).

3. MATERIALS AND METHODS

The study is based on the results of the geographic and statistical analysis of the information collected by the author in an electronic database of technological and natural-technological accidents and emergency situations occurring in the Russian Federation. An emergency situation is considered as a situation that has developed in a certain area as a result of an accident, a dangerous natural phenomenon, a catastrophe, the spread of a disease, a natural or other disaster that may or did entail human casualties, damage to human health or the environment, significant material loss and disruption of the living conditions of people (Federal Law 1994). Natural-technological events include accidents and emergencies in technological systems and infrastructure triggered by the impact of any natural hazard.

The database analyzed in this study was created by the author using Microsoft Access. The relational structure of the database and the procedure of its development and operation were described in Petrova (2009) and Petrova (2020). When creating the database, the following research task was set: to collect data about accidents and emergency situations in a structured form with the possibility of their future processing and analysis. All the pieces of information are accumulated in the main database table that has the following columns / database fields: sequence number (assigned automatically); the date of accident; country; region; location; type of accident; its short description including time of occurrence, main characteristics of the event, its probable causes and triggers, consequences and taken measures; the extent of the emergency situation (from local and regional to national and cross-border); the number of fatalities and injuries, if any; material damage; source of information. Each accident / ES is recorded in a separate line of the table. The types of natural-technological accidents are distinguished by the author according to the types of affected infrastructure and the influencing natural factor.

Currently, the database contains more than 25 thousand pieces of information about accidents and emergencies at various technological systems and infrastructure facilities, including those of power grid, which have occurred in Russia since 1991. The database is constantly updated with new relevant information. It should be emphasized that only open data sources are used to fill the database. The main data are obtained from daily operational reports by the Ministry for Civil Defense, Emergencies, and Elimination of Consequences of Natural Disasters of the Russian Federation (EMERCOM 2022) and media news reports. Daily reports by the Ministry for Emergencies are publicly available on the Ministry website:

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https://en.mchs.gov.ru/for-mass-media/operativnaya-informaciya. The information on the website is a brief list of incidents of natural or technological character and situations under EMERCOM control for the corresponding day. When they are selected for inclusion in the author's database, they are systematized and classified. Of course, not all accidents occurring in Russia fall into the operational reports of the Ministry of Emergency Situations. Each type of accident has specific criteria to be included. The criterion for information by EMERCOM about emergency situations at electric power facilities is a disruption of the living conditions of 50 people or more for one day or more (EMERCOM 2021). Only those accidents that meet these criteria are reported. Since the early 1990s, EMERCOM changed criteria, so the input data is not uniform.

The database format allows an automated search for the information among the accumulated data array, depending on the goals and objectives of the study. For this, such general database tools are used as search queries by keywords and selected parameters and sorting of data. Search results are displayed in tabular form as query tables. These search results may be subjected to further computer processing.

For the purposes of this study, a search of information about accidents and ESs on power transmission lines caused by the impact of adverse and hazardous natural processes and phenomena of various origins was carried out in the author's database. The found information was then sorted by the type of natural hazard and region of their occurrence (constituent entity of the Russian Federation).

The geographic and statistical analysis of the results obtained from the search queries made it possible to trace the spatial and temporal distribution of natural-technological ESs on power lines at the regional level. The proportion of natural-technological events in the total number of accidents and ESs in power grids, as well as their share among all natural-technological events in Russia was evaluated; the main types of natural factors affecting power lines were identified, regions most at risk were revealed.

4. RESULTS AND DISCUSSION

As the statistical analysis of the database has shown, power supply disruptions due to various adverse and hazardous natural influences on electrical networks account for the largest share (more than a half) in the total number of natural-technological accidents and ESs in Russia. Overhead power transmission lines are especially vulnerable to dangerous natural impacts, since they stretch over large distances and inevitably find themselves in the area of activation of natural hazards of various nature and genesis. The greatest damage is caused by hydrometeorological phenomena.

Through search queries in the database, 1470 natural-technological ESs with power outages due to accidents on power lines triggered by natural hazards and phenomena in the period 1991-2020 have been identified. They account for about 30% of the total number of accidents on power lines. Other accident factors include: deterioration of aged infrastructure, shortcomings in operation and repair, mechanical damages, errors and defects in design and installation, *etc*. All the 1470 ESs were examined. Their triggers and consequences, geospatial distribution, long-term and seasonal variations were considered.

Table 1. Hazardous natural processes and phenomena causing accidents at power lines

Type of hazardous natural process and phenomenon	**Intensity of the process leading to losses**	**Season of the greatest danger**
Strong wind	wind speed over 15 m / s	May – August
Ice-rime deposit	more than 10 mm	October – November, February – March
Thunderstorm / lightning	direct lightning strike	June – August
Hail	more than 1 mm	June – August
Precipitation	heavy rain, heavy snowfall, mixed precipitation – of 10 mm or more over an interval of 12 hours or less	May – November; December – February; September – April
Temperature effect	heat, frost – depending on the region	June-August, November – March
Hydrological phenomena	ice jam, rain flood, flood, *etc*.	April-October
Exogenous slope process	debris flow, snow avalanche	depending on the region
Compound events:	• strong wind and ice-rime deposits; • strong wind, hail, and rainfall; • hail and rainfall; • strong wind and rainfall; • strong wind and snowfall (blizzard) – duration of 12 hours or more at a wind speed of 15 m/s or more	October – November, February – March; June -August; June -August; May – November; December – February

The following natural processes and adverse phenomena were found as triggers of ESs at power lines (Table 1). The intensity of each natural event leading to damages in power networks and losses in energy sector was evaluated using information from the author’s database analysis and results by previous investigations (Analytical report 2010; Vlasova and Rakitina 2009). The second column of the table shows the actually registered minimum intensity of the processes during which breakouts in electrical networks were observed in 1991-2020. The seasons of the greatest danger of manifestation of each natural factor (the third column of the table) were found out using the dates of the events recorded in the database. The previous analytical studies cited above came up with similar results. In case of discrepancies, the minimum value was used.

Wind loads prevail among the main factors of accidents at power lines. They account for more than 80% of all the events recorded in the database. In 63% of these events, the impact of strong wind is accompanied by manifestations of other adverse and hazardous meteorological processes and phenomena. The following compound events triggering ESs with power failures and outages combine wind loads with other weather and climatic factors: joint impact of strong wind with rainfall - in 350 ESs (24%), with snowfall (blizzard) -266 ES (18%), with hail and rainfall -135 ES (10%), with ice-rime deposits -76 ES (5% of events) (Figure 1).

Additionally, accidents at power lines were caused by heavy rains - 94 ES, thunderstorm / lightning strikes - 66 ES, snow loads - 65 ES, debris flows - 21 ES, landslides - 17 ES, floods - 11 ES, earthquakes - 7 ES, snow avalanches - 5 ES, and wildfires - 4 ES.

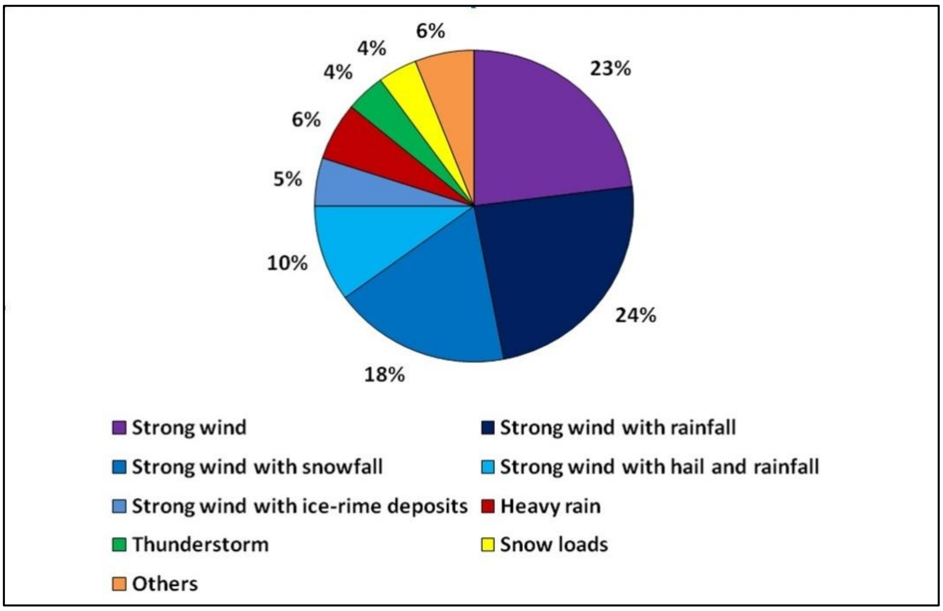

Figure 1. Natural factors of emergencies at power lines registered in Russia in 1991-2020

These results on the identification of the main natural factors of accidents in electrical networks are generally consistent with the findings of other researchers obtained for other countries and regions (see Section 1), although the proportions of the identified factors may have regional differences. Regional features for Russia are discussed below.

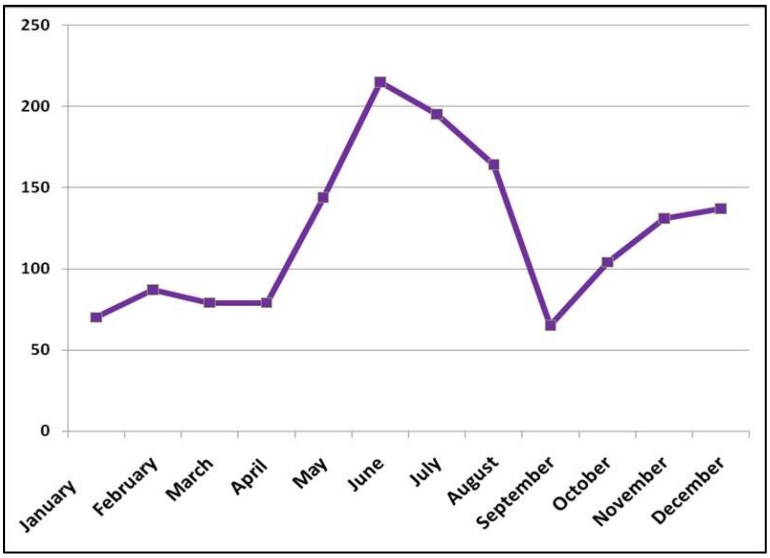

Figure 2. Seasonal cumulative variability in the number of emergencies on power lines caused by natural factors in 1991-2020

The greatest numbers of ESs happen in Russia during the warm months, from May to August, with the maximum in June, as well as during the cold season with the maximum in November and December (Figure 2). Such a seasonal distribution is quite expected, based on the found main accident factors: the summer maximum of emergencies is caused by strong winds, heavy rains and thunderstorms; the winter maximum is mainly due to heavy snowfalls, blizzards and ice-rime deposits.

Geographic distribution of ESs with power outages triggered by compound hydrometeorological events since the early 1990s was examined at the regional level. The results of this analysis are shown in Figure 3. Circles of different colors mark the type of natural hazard combination. The combination of strong winds with rain and snow is widespread throughout the country, while compound events with ice-rime deposits are more characteristic for the middle and south parts of the European Russia and the North Caucasus, as well as the Far East (Sakhalin Region, Primorsky Territory, *etc*.). The distribution of large areas with rather high thicknesses of ice-rime deposits and the most frequent occurrence of their formation on electrical wires in the southern part of Russia including the North Caucasus is mainly due to the unstable weather regime in winter, which is characterized by a frequent change of warm and humid air masses to cold intrusions from the north. In the Far East region, the conditions for the frequent formation of thick ice-rime deposits are favorable due to the intrusion of warm and humid air masses from the Sea of Japan into this area in winter. The largest number of accidents due to rainfall with hail was registered in the south of

Russia and the North Caucasus, which is determined by the geographical location of these regions and their orographic features. Complicated terrain conditions, the close proximity of the Black Sea basin determine the heightened temperature and moisture regimes, which contribute to the activation of atmospheric processes during the warm season in this area (EMERCOM 2010).

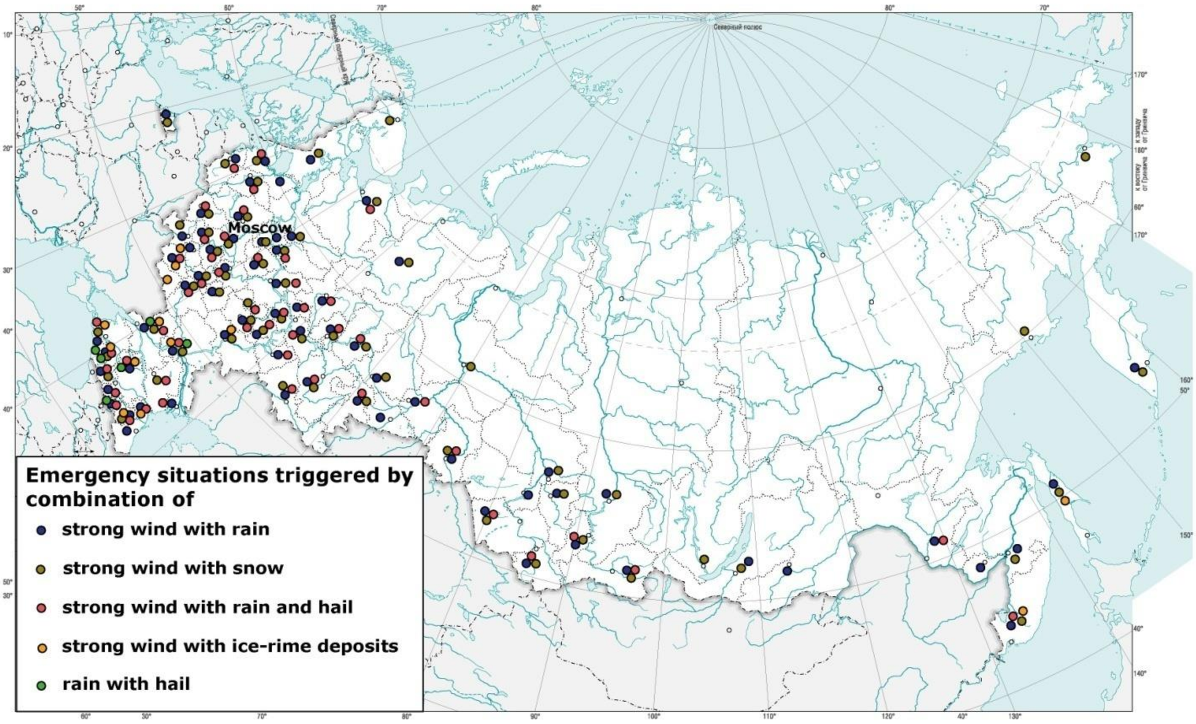

Figure 3. Emergencies at power lines triggered by compound hydrometeorological events in 1991-2020

An average annual frequency of occurrences of ESs at power lines due to all natural factors was calculated at the level of the constituent entities of the Russian Federation. All the 1470 events registered in the database were taken into account in these calculations. At first, a long-term average number of ESs was calculated for each constituent entity, and then the results obtained were compared with the average number for Russia. Based on the comparison, five groups were found according to the frequency (recurrence rate) of such events: 1) very high - more than 2 ESs on average per year; 2) high - 1.5-2 ESs; 3) average – 1-1.5 ESs; 4) low - 0.5-1 ESs and 5) very low - less than 0.5 ESs per year. All constituent entities of the Russian Federation were grouped according to the value of this indicator. The analysis results are shown in the cartogram (Figure 4).

The Sakhalin Region and Krasnodar Territory (with more than 4 ESs on average per year), as well as the Leningrad Region, Primorsky and Stavropol Territories (with more than 2 ESs on average per year) had the highest frequency of occurrences of ESs at power lines due to natural factors in 1991 - 2020. Quite often, these events were also recorded in the Republic of Tatarstan, Khabarovsk Territory, Nizhny Novgorod, Novgorod, Pskov, Rostov, Tver, and Chelyabinsk Regions (1.5-1.8 ESs on average per year). These results reflect not only the manifestation of natural factors of accidents described in Section 2, but also the greatest exposure of power grids to their impacts in the most economically developed regions of the European part of Russia, where the length and density of power lines is much higher. In the north of the European Russia and in remote areas of Siberia, a smaller number of accidents may be explained by a significantly lower density of power lines, despite harsher environmental conditions.

The main triggers of these accidents were meteorological hazards and phenomena such as strong winds in combination with different kinds of liquid and solid precipitations including snowfall, rain and hail, as well as ice-rime deposits and thunderstorms. The ESs due to compound events of hydrometeorological nature listed above occurred most often and caused the greatest damage to power transmission lines and troubles to the economy and population.

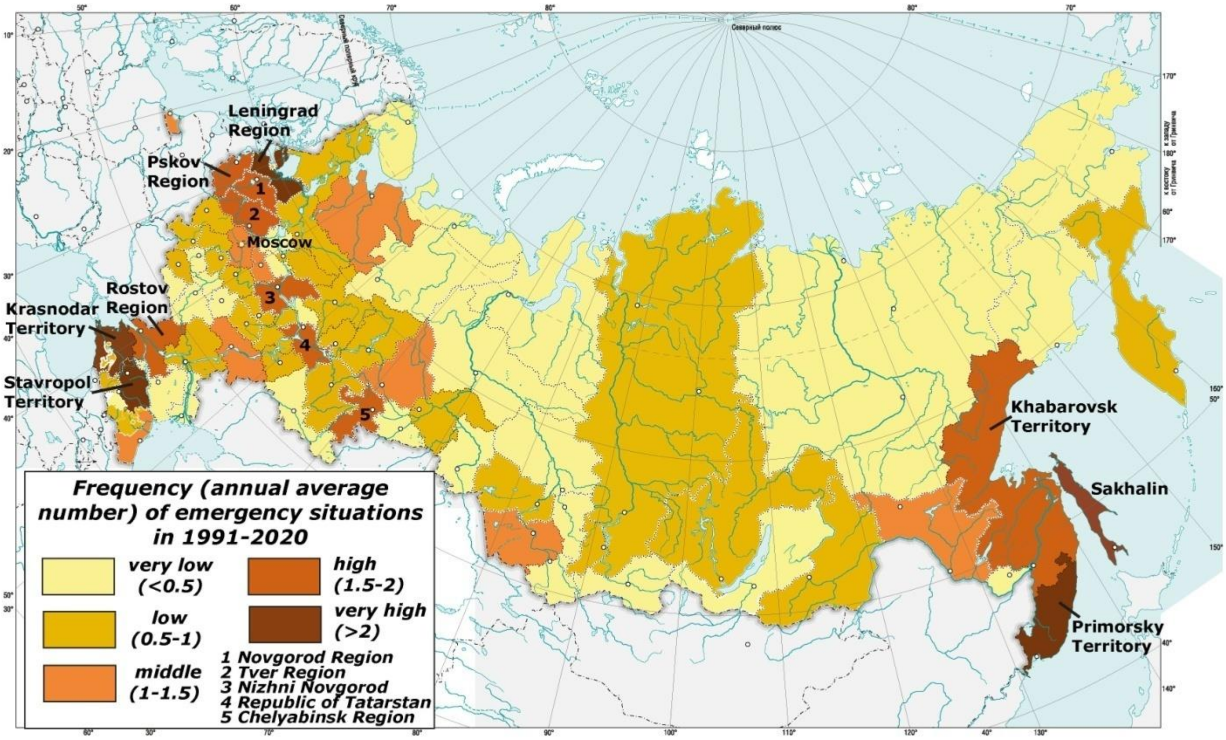

Figure 4. Frequency of occurrences of ESs with power failures caused by natural factors

The climate changes observed in recent decades on the territory of Russia may have significant consequences for the power industry. These climate changes are characterized by increasing in the air temperature during the cold season, increasing in evaporation against the background of a decreasing in precipitation during the warm season, and a more frequent recurrence of hazardous hydrometeorological phenomena in the whole (Kislov et al. 2008; IPCC 2014). Geographic analysis shows the highest growth rate of the average annual temperature on the coast of the Arctic Ocean, especially in the Asian part of Russia (+0.9 ºC/10 years) (Roshydromet 2017). Melting of permafrost is observed in the Arctic zone. In winter, the maximum warming occurs in the northwest, and in summer - in the south of the European part of Russia. On average per year, the least warming is registered in the south of Western Siberia. An increase in precipitation is expected throughout Russia in winter. The increasing in the amount of summer precipitation is observed mainly in the north and east of Russia. In the south of the European part, the number of droughts is increasing and drought conditions are expected to worsen (Kattsov 2017). In general, with warming, the proportion of liquid precipitation increases, which can lead to a change in the hydrological regime of rivers: to decreasing in flood volume and increasing in winter runoff. A further increasing in the intensity of precipitation is expected, which more often will have a stormy character (Kislov *et al*. 2008).

The listed climate changes can lead to increasing in the frequency of occurrences of various natural hazards of meteorological and hydrological origin and other related hazards such as landslides, debris flows, and snow avalanches, as well as to increasing in their intensity and destructive power (Malkhazova and Chalov 2004; Petrova 2019). Over the 21st century, an increase in the number of severe rain floods and high water, storm winds, and weather fluctuations in the form of a series of cold and warm periods are likely to increase within the territory of Russia. In most of the European Russia, an increase in the number of days with an anomalously high amount of precipitation is expected in winter, while in summer, on the contrary, their decrease (Kattsov 2017).

As result, this will entail an increase in the frequency and severity of the consequences of ESs created by them in the technological systems and infrastructure facilities, primarily on overhead power transmission lines, which are especially vulnerable to these natural impacts. In particular, the positive dynamics of precipitation during the cold season, the alternation of thaws and cold snaps, will increase in the risk of wire breakage and destruction of bearing towers of power lines due to snow loads and icing. The melting of permafrost strata creates danger of destruction of various objects of the power grid infrastructure, built on the basis of permanently frozen ground.

In addition, extremely high values of air temperature, leading to a decrease in the original transmitted power, also negatively affect the process of electricity transmission (Bobylev and Dygan 2020). High air temperatures lead to stretching of power lines. In this case, they may sag and contact with adjacent wires, causing a short circuit (Nefedova 2020).

The database does not track statistically significant trends related to climate change due to record inconsistencies and insufficient data collection time. However, we can state an increase in the number and severity of accidents caused by strong winds, heavy snowfalls, rains, ice-rime deposits, and thunderstorms, especially in recent years, which may be due to climate change. Our findings are consistent with the results of studies in other countries. Thus, atmospheric icing has been analyzed from a climate point of view in Czech Republic, measuring ice-load deposition for a long time in the station of Studnice (Cigrè 2005). The analysis shows a positive trend that is explained as a probable effect of Global Warming. In Italy as well, the frequency of “warm and wet” snowfall events, observed by means of SYNOP data since 1951, shows a positive trend (Bonelli and Lacavalla 2010).

Significant climate change is taking place around the world. According to some data, 90% of the damage from natural disasters in the world is due to dangerous weather and climate events (AGCS 2013). Monitoring and investigation of such phenomena and their consequences is an extremely important and urgent task.

5. CONCLUSIONS

The paper reveals the main triggers of accidents and emergency situations on power transmission lines in the Russian Federation using the information of the author’s database. The majority of natural-technological accidents are caused by various hydrometeorological hazards and phenomena. Most of the events (more than 80%) are due to strong winds; in 63% of cases wind loads are accompanied by other adverse and dangerous meteorological processes and phenomena including precipitation in liquid and solid form such as rain, snow, hail, and ice-rime deposits. The proportion of these natural factors of accidents is assessed; their parameters leading to damages in power networks and losses in energy sector are evaluated. Seasonal variations in the ESs occurrences are examined and months of the greatest danger of manifestation of each natural factor are identified. The greatest number of ESs is observed from May to August, with maximum in June, as well as in November and December.

Regional differences in the accident occurrences on power transmission lines due to hazardous natural impacts are also considered. The highest frequency of ESs over 1991 to 2020 is recorded in Sakhalin Region and Krasnodar Territory, as well as in Leningrad Region, Primorsky and Stavropol Territories where hazardous hydrometeorological events most often occur.

The climate changes observed and expected in the near future can lead to increasing in the frequency and intensity of hazardous hydrometeorological phenomena, which, in turn, will increase in the number of accidents and emergencies on power lines.

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CONFLICT OF INTEREST

The author declares no conflicts of interest in this paper.

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Original paper

Factors Affecting the Cyclone Preparedness Programme Volunteers' Performance in Early Warning Dissemination in Emergency Response in Bangladesh

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Abstract Millions of people living along coastal Bangladesh are at risk from cyclones, and timely dissemination and social acceptance of effective early warnings could significantly save their lives. In recent years, the Cyclone Preparedness Programme (CPP) volunteers have gained considerable popularity among local community as the most reliable source for early warning and emergency assistance for evacuation during coastal cyclones. The sustainability of the CPP is threatened not only by limited funding but also by the difficulty of attracting and retaining committed and efficient volunteers. The purpose of this study is to identify factors that affect the activities of Cyclone Preparedness Programme volunteers regarding early warning dissemination during emergency responses. The research design of this study integrated both qualitative and quantitative approaches. The questionnaires were complemented by face-to-face interviews and Focus Group Discussion with 177 residents of the Koyra and Ukhiya sub-districts (Upazila) to investigate the respondents' responses to early warning information. In addition, a total of 23 CPP volunteers' opinions were collected through a questionnaire survey, to identify the factors influencing CPP volunteering performance. The obtained results also show that both of the study-area communities did not properly understand the cyclone early warning signal system delivered by CPP volunteers. Approximately 49% of the community said that they could not interpret the warning message. The low level of community contact with CPP volunteers also hinders trust in warning messages and evacuation decisions. The findings also concluded that the factors related to the effectiveness of volunteering were found to be individual volunteer's experience, training opportunities, lack of equipment and materials due to lack of budget, the social class of individual volunteers and in the absence of proper coordination. Maintainace of CPP volunteers engaged throughout the year is very challenging.

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These limited engagement features affect the cyclone preparedness and early warning activities of CPP. The government needs to implement policies that enable the mobilization of adequate resources and awareness campaigns to be mobilized toward the volunteers.

Keywords: Cyclone Preparedness Program (CPP), Community Engagement, Early Warning, Volunteerism, Disaster Volunteer

1. INTRODUCTION

Recently, the nature of cyclones in Bangladesh has changed in terms of frequency and intensity. On November 12, 1970, a strong cyclone struck the coastal area with a storm surge of six to nine meters high and more than 300,000 people died (Uclg 2019). According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, more cyclones will occur in the future, making Bangladesh the most vulnerable country (IPCC 2007). Recent catastrophic weather events the west coast has recently experienced Cyclone Sidr in 2007, Cyclone Aila in 2009, Cyclone Bulbul in 2019, and Cyclone Amphan in 2020. Despite the fact that the country is attacked by almost the same category of cyclones every year, the number of people killed by natural disasters remains low. For example, Cyclone Sidr claimed 4234 lives in 2007, but 138958 lives in 1991(Haque *et al.* 2012). The improvement in the early warning system in Bangladesh and the community-based cyclone preparedness program (CPP) volunteers are believed to play an important role in significantly reducing the number of deaths caused by tropical cyclones, courtesy the dissemination of early warnings to the population.

In 1973, the Bangladeshi government introduced a community-based disaster management method through CPP (Habiba and Shaw 2012). The goal of the CPP is “to minimize the loss of lives and properties in cyclonic disaster by strengthening the capacity of the coastal people of Bangladesh in disaster management.” A joint management mechanism operates the Program through the “Policy Committee” program and “Implementation Board” program comprising of representatives from the Bangladesh Government and Bangladesh Red Crescent Society (BDRCS). The local government manages the administrative part and BDRCS has the mandate to manage the operational aspect of the CPP, which includes volunteer training, equipment, and distribution of manuals for operations.

CPP has a head office, under which there are seven zonal offices. The zonal offices are divided into Upazila (sub-district) offices, the Upazila offices are divided into unions, and the unions are divided into units. The "unit" committee consists of 15 volunteers (10 males and 5 females) divided into five groups. Each unit covers an area of 2.5 square kilometers and has a population of 2000 to 2500 people. A unit committee under a team leader is responsible for the dissemination of early warning information, rescue and relief operations, first aid, and evacuation shelter management. The BDRCS is responsible for recruiting volunteers for the

Unit committee in accordance with the 13 criteria; age between 18-30, strong commitment and attitude to serve people, permanent resident of the locality, ability to read and write and manically independent and self-supporting, *etc*. The CPP program covers 13 coastal districts of Bangladesh. A total of 55,250 volunteers, including 18,410 women and 36,840 men, are currently working in 3684 units (CPP 2021). CPP Volunteers are not paid. The Unit committee under the CPP program collaborates with local governments, NGOs, and communities in order to effectively implement early warning and evacuation plans and programs.

However, owing to the ongoing natural catastrophe crisis in Bangladesh and the circumstances surrounding CPP volunteers, the system does not appear to be working efficiently (Amin 2012; JICA 2013). Despite this, disaster response efforts and community training and awareness initiatives in Bangladesh have been insufficient. (Ahsan *et al*. 2016; JICA 2013; Mahmud 2013).The CPP does have a limitation and does not cover all the cyclone-prone districts in Bangladesh, especially the isolated islands (CPP 2020; JICA,2013). In addition, the poor road networks in rural areas have made volunteers delay the early warning information. Mahmud (2013) reported that the local people have spoken about the low workforce of CPP volunteer and their incapability to provide logistical support. As a result, the evacuation rates during cyclone disasters remain low in the coastal areas of Bangladesh. Scholars argued the importance of cyclone preparedness program volunteer activities, which are related to conducting the evacuation of people to a safe place. For example, Paul (2009) found a high positive correlation between the rate of evacuation and the understanding of a hazard warning disseminated by CPP volunteers, which indicates that, if warnings are heard and trusted, they are highly likely to result in evacuation. Based on this perspective, hazard warnings can be considered as a social process consisting of interconnected activities: warning messages, information dissemination, message reception, previous experiences, preparedness, and response (Mileti and Sorensen 1990). During Cyclone Komen that hit in 2015, Chakma and Hokugo (2020) found some residents to not receive any cyclone warning information from the CPP volunteers. Amin (2012) in his work with the CPP volunteers in the southwest part of Bangladesh, which mainly focused on the factors affecting the motivation of volunteers. His research found that, there is a difference between males and females in physical formation, which sometimes indicates the negative position of the female volunteers during disaster time, and that social factors also affect motivation.

Studies have shown that training affects the motivation of volunteers, and differences between men and women have been identified in a number of areas, such as ethical behavior, social problem-solving (Goddard *et al.* 1998; Caplan *et al.* 1997). For the CPP, it was found that women were not involved in financial matters, such as relief work, which involves money. This is due to both gender power relations and gender stereotyped work divisions(Tanjeela and Rutherford 2018). CPP program facing some organizational problem such as equipment's problem, training *etc*. (JICA 2013). However, volunteers try to provide early warning information to the community. Since the CPP volunteers come from the community, and they are aware of their locality and can reach the community before any other organization, it is clear that CPP is effective to some extent and work can be put to draw higher potency from it.

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2. CPP'S EARLY WARNING OPERATIONAL SYSTEMS IN BANGLADESH

The Hyogo Framework for Action progress reports highlight the success of developing early warning systems that correspond more closely to local needs. Early warning systems can save people's lives and reduce economic damage from natural disasters, such as cyclones, floods, landslides, and other events (United Nation Volunteer 2007). In Bangladesh, once a warning is issued by the Bangladesh Meteorological Department, the CPP headquarters collects information from the Bangladesh Meteorological Department, which is then transmitted to zonal offices and sub-district offices. The sub-district offices transfer this information to the unions (at the village level) through a very high-frequency radio and telephones. Unit teams then disseminate these cyclone warnings throughout the villages. The CPP's volunteers disseminate cyclone warning information to communities, assist with the evacuation of people, sheltering, and rescue operations, and provide first aid to the injured (ADRC 2020, JICA 2013).

Table 1. CPP's cyclone warning propagation process

Communication flow	Communication tools
Headquarters to the Zonal offices & Sub-districts	High-Frequency Wireless system (HF)
Sub-district to the Union level	Very High-Frequency Wireless system (VHF)
Union to the Unit leader	Cell phone
Unit leader to the CPP Volunteers	Cell phone
Volunteers to the Community	Door-to-door visits, using a microphone or megaphone, hoisting two/three flags, by walking, boat, or bicycle.

2.1 CPP's Flag Warning System

The Bangladesh Meteorological Department tracks cyclone movement and communicates with CPP via cell phone or wirelessly when it detects a cyclone formation that can affect the coastal areas. CPP volunteers then use a three-flag warning system (Figure 1) to inform the public of the level of risk. The figure below shows the meaning and use of each flag.

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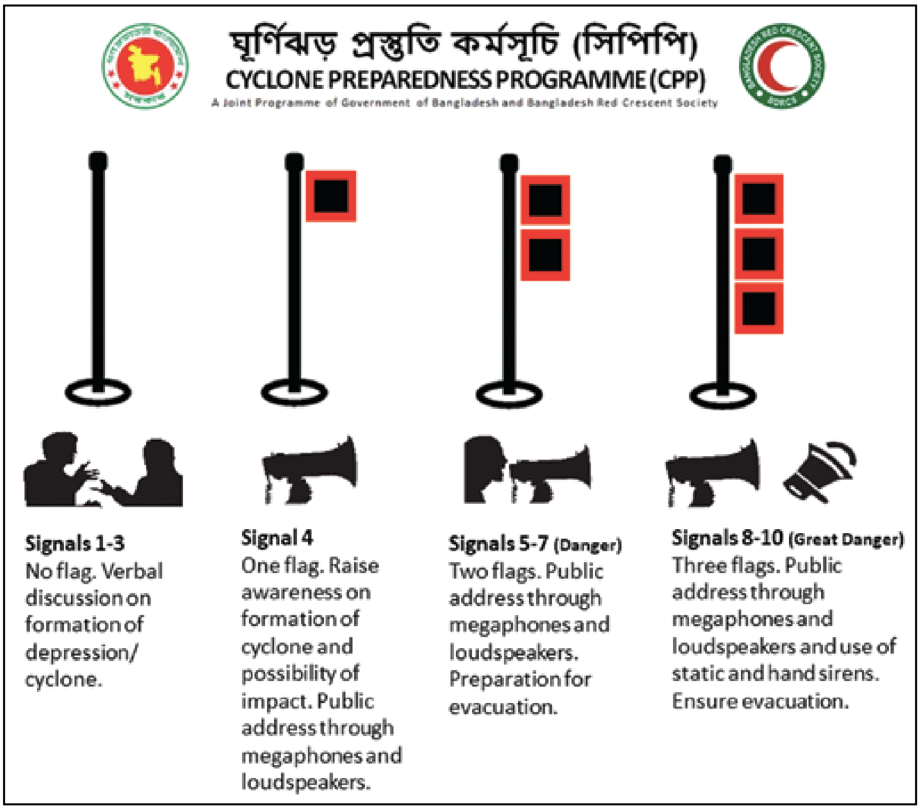

Figure 1. Use of flags in the CPP's warning system

- *Flag-1 (Warning Signal) A storm has formed with the potential to turn into a cyclone. No megaphone will be used to play warning messages*.
- *Flag -2 (Danger Signal) A cyclone has formed and may come to this area. You have approximately 24 hours until the cyclone arrives. A megaphone will be used to play early warning messages.*
- *Flag-3 (Great Danger Signal) A cyclone has formed and will impact this area soon. You have approximately 10 hours until the cyclone arrives. A siren will sound, and megaphones will play early warning messages* (CPP 2021).

3. RESEARCH OBJECTIVES AND METHODOLOGY

This research aims to examine the factors that affect the activities of Cyclone Preparedness Programme volunteers regarding early warning dissemination during emergency responses in Bangladesh. The specific objectives of this study are as follows:

1. To examine the current framework of CPP in Bangladesh and explore the strengths and weaknesses of CPP volunteers.
2. To understand the coastal community's perceptions of early warning information delivered by CPP volunteers

3.1 Methodology

The research plan used both primary and secondary data in order to achieve the objectives. Primary data were collected using a combination of approaches that included open, close-ended, and semi-structured interviews and focused group discussion (FGD). To identify the factors, challenges, and limitations of CPP volunteers in providing early warning dissemination, a total of 23 CPP volunteers' opinions, including both male and female volunteers, were collected through questionnaires. A total of 177 households were surveyed in the study areas (Koyra and Ukhiya sub-districts) using random sampling to assess the performance of the CPP volunteers in their community. Primary data collection by personal visits to the field from community people of the selected areas. If the randomly selected household was absent during the survey, then the neighboring household was interviewed. The questionnaire consists of 5 sections and a total of 30 questions. Questionnaire sections are 1. General Information, 2. Experiences of Cyclone 3. Early Warning information 4. Communication with CPP volunteers and 5. Conclusion. At the beginning of the interview, the researchers explained to the respondents the purpose and goals of the research. With their consent, the interviews took place in the respondents' homes during their free time. On average, each interview took half an hour. One FGD was conducted at the community level to get the qualitative data of the study because participants were free to express their view under this process. Ten participants have attended the discussion. The participants were CPP volunteers, students, household wives, fisherman and day labors. The secondary data used different types of literature, Government and Non-Government Organizations (NGOs) documentations, assessment reports, reports of community-based volunteerism, disaster volunteer, early warnings, scholarly articles, journals, and books. Furthermore, information regarding the CPP activities, policies, and challenges has been gathered from relevant expert bodies using an unstructured questionnaire to gain new or additional insights on the issues being studied, which is also not available in the literature as well as in the primary documents. The relevant expert bodies were the Operation Manager, Documentation and Logistic manager from CPP headquarter, District Rehabilitation and Relief officer, and team leaders from Bangladesh Red Crescent Society, in total 8 key informants were interviewed.

3.2 Description of the study areas

Historically, the coastal areas of Bangladesh have been recognized as a venue for disasters (Chowdhury *et al*. 1993). The sub-districts mentioned below are the most vulnerable areas and are under high-risk zones for cyclones. As cyclones frequently affect these areas, volunteer practices should be developed in these areas. The study areas were selected based on the CPP volunteers' activities and performance during the disaster. Further, there has been no specific research conducted in those areas previously. The Koyra and Ukhiya study areas were considered as study areas for a few reasons.

(1) The selected study area's geographical location is different. Koyra Upazila and Ukhiya

Upazila are located in the southwest and southeast regions, respectively.

(2) Both the areas are severely affected by cyclone SIDR 2007, AILA 2009, Komen 2015, and Bulbul 2020.

(3) In Ukhiya sub-district, it is the local and indigenous people who live in this area. People in this area use different dialects.

(4) In Koyra (sub-district), a CPP's unit was established after Cyclone Aila (May 2009). The Ukhiya CPP unit was under the Cox's Bazar District, which was established in 1973. Subsequently, the Ukhiya Upazila unit was separated from the Cox's Bazar Sadar unit.

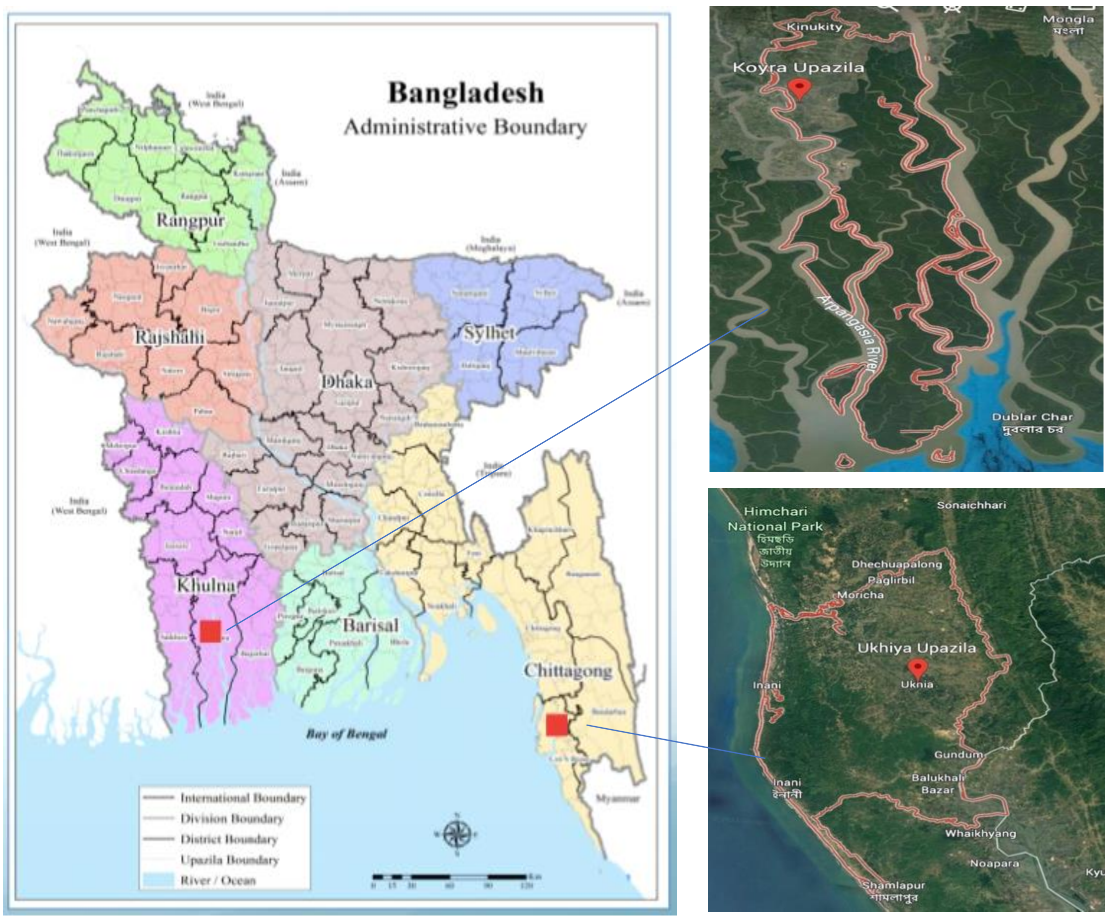

Figure 2. Map of the study areas

4. RESULTS

The results of the survey were classified into two main categories: (4.1) Identifying the challenges, and limitations of CPP volunteers in providing swiftly disseminating early warning, and (4.2) Assessment of the volunteer performance of CPP from a community's viewpoint.

4.1 Identifying the challenges, and limitations of CPP volunteers in providing swiftly disseminating early warning

4.1.1 Characteristics of the respondents (CPP Volunteers)

The respondents included 39% female and 61% male CPP volunteers who resided in their community. Only 9% had obtained a higher secondary qualification. The male volunteers (30%) were farmers and fishermen. More than 35% of female volunteers were housewives. The average age of the volunteers was 30.5 years.

4.1.2 Early warning information to the community

Table 2. Advantages and limitations of different early warning systems and other methods used for raising awareness of people at risk

Early warning methods	Advantages	Limitations
Early warning from radio and television	Alert the community and provide the latest information to prepare for evacuation.	Without electricity and battery, both assets do not work, especially in remote rural areas.
CPP volunteers' early warning information (face-to-face in every household)	Helps those who did not receive the evacuation order from any sources to evacuate to safe places.	Due to storm surge, wind, and poor road network, volunteers are unable to deliver information to remote areas in a face-to-face manner in time
CPP volunteers display a warning flag	The flags are easily visible in the coastal areas.	It is difficult to understand the meaning of each flag and see it from a distance.
Use of a hand siren by CPP volunteers	It is easy to understand and is able to alerts the community faster.	It is heavy to carry and it may function only toward the wind direction.
Use of a Megaphone by CPP volunteers	It is easy to communicate and provides clear-cut evacuation orders.	It has limited coverage and battery capacity.

Early warning helps in evacuating people to a safe place before the cyclone makes landfall to minimize the loss of life and property. The CPP has provided different early warning equipment: sirens, megaphones, and other devices that volunteers can broadcast as early warning signals (CPP 2021). Moreover, CPP volunteers are trained to operate an alarm system.

They receive early warning messages via wireless/mobile/radio/television; and organize preparatory meetings at the unit, union, and sub-district levels. They then start broadcasting warning messages, alerting people to actions based on the signal level, and listening to weather forecasts on the radio. This was followed by the door-to-door information provided to communities in remote rural areas.

Table 2 shows five early warning sources that have been used to notify people threatened by previous cyclones. The various sources include the CPP volunteers' actions, such as radio and television warning messages; warning information from governments and NGOs; and the use of flags, sirens, and megaphones.

4.1.3 Difficulties faced by the CPP volunteers during the operational time

The road network in coastal areas is not well-connected, and evacuees usually go to the nearest public cyclone shelter (Ahsan *et al*. 2016). Volunteers also note that there are no designated CPP for the char (isolation) areas (JICA 2013). According to the volunteers, the road network in the Koyra region is worse than that in the Ukhiya region. CPP volunteers typically visit each home to provide evacuation information and suggest evacuations to the nearby public cyclone shelters. At Koyra, 58% of the volunteers said that it took longer to disseminate early warning information due to poor road networks, and lack of manpower and equipment made it difficult to communicate information at night. They said that the community was not reachable at night due to storm surges, heavy rains, and winds.

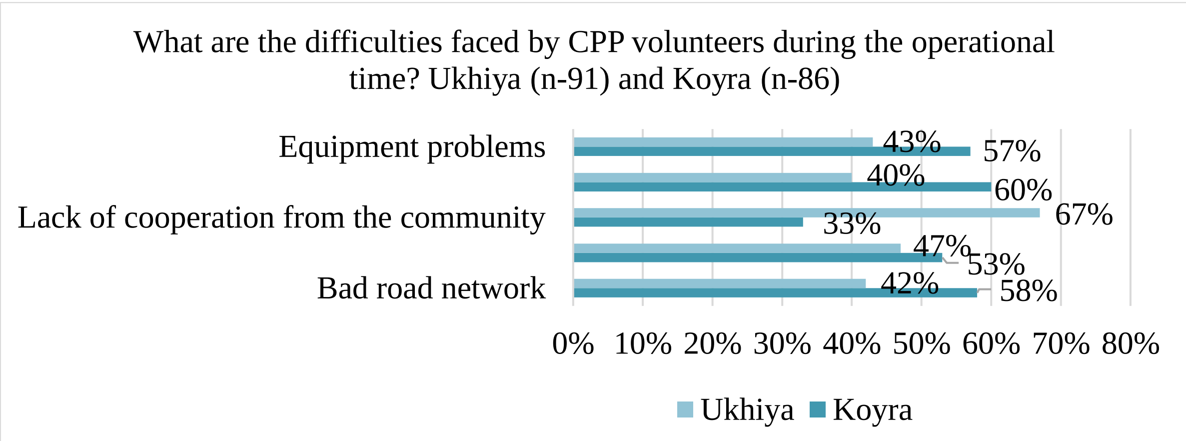

Figure 3. Difficulties during the operational time

Volunteers also pointed out that it is very difficult to deliver an early warning to fishermen who venture offshore. Even if fishermen have cell phones and walkie-talkies, communication offshore is impossible because of the limited mobile communication network signals. JICA (2013) reported that 25% of the deaths caused due to cyclone Aila in 2009 were of fishermen.

CPP volunteers distributed early warning signs and other materials for first aid and rescue operations by providing volunteers with early warning equipment such as megaphones and sirens. However, 57% and 43% of the Koyra and Ukhiya respondents, respectively, said they do not have sufficient equipment in case of an emergency. Some equipment is very old and unusable. For example, a high-quality battery is required to use a loudspeaker. This equipment is not updated sometimes, which leads to malfunctions in emergencies. In this case, the volunteers buy new batteries with their own money, although this is not their responsibility. Additionally, many volunteers did not receive personal items such as helmets, rubber boots, raincoats, life jackets, flashlights, and other necessary equipment. First, the CPP provides priority equipment to the warning and first aid teams. Dissemination of disaster information downstream of sub-districts is delayed due to CPP's lack of equipment. However, CPP volunteers are prepared to perform their duties even without appropriate experience and equipment. Volunteers also state that mobile phones helped speed up early warning information dissemination rates, especially during Cyclone Aila in 2009. However, mobile networks do not cover all coastal areas in Bangladesh. According to the results of the interview survey, 60% of the volunteers from Koyra and 40% of the volunteers from the Ukhiya sub-districts stated that intense winds and rains caused the phones systems to go down sometimes. They have difficulty communicating with other volunteers if the phone towers are damaged. Even though they receive the information from other sources, it slows down the dissemination of information to the community.

4.1.4 CPP training during the normal time

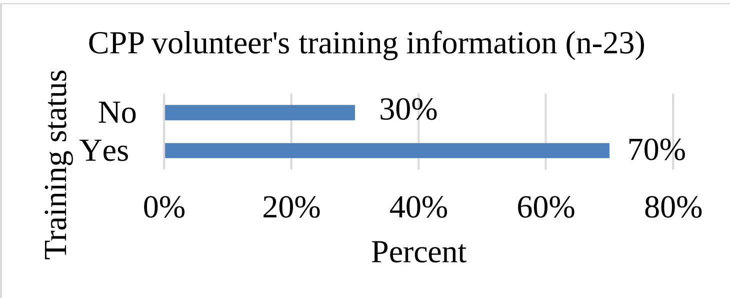

Figure 4. CPP volunteer's training information

Training of the CPP volunteers takes place twice a year, in April and September respectively (CPP 2021, JICA 2013). However, the training has not been conducted regularly, due to a lack of funding. Training of new CPP volunteers is conducted once a year before April, which has not yet been fully implemented (CPP 2021). Figure 4 shows that approximately 70% of the CPP volunteers have received basic training. However, 30% of the participants were not trained. Volunteers said that they took refresher courses without any basic training knowledge.

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Additionally, some volunteers received the same training more than once. Early warning dissemination is one of the most important tasks of CPP volunteers, in addition to search and rescue, evacuation, sheltering, and first aid when a cyclone strikes. Volunteers who have not received training in search and rescue and first aid are members of the search and rescue teams. Therefore, these volunteers must be able to perform the assigned tasks in the areas for which they are responsible with minimal training.

4.1.5 Factors related to CPP volunteer motivation and volunteering

Table 3. Factors associated with the motivation for the performance of CPP volunteers'

Characteristics	Gender (Volunteers)			P values
	Male (n-14)	Female (n-9)	N-23 (%)	
Age (in years)				
20-39	9 (53%)	8 (47%)	17 (100%)	0.005*
40-50+	5 (83%)	1 (17%)	6 (100%)	
Knowledge about emergencies				
Yes	13 (72%)	5 (28%)	18(100%)	0.034*
No	1 (20%)	4 (80%)	5 (100%)	
Past experiences of working as a CPP volunteer				
0-4 years	1 (14%)	6 (86%)	7 (100%)	0.029*
Over 3 years	13 (81%)	3 (19%)	16 (100%)	
Received training				
Yes	12 (86%)	2 (14%)	14 (100%)	0.036*
No	4 (44%)	5 (56%)	9 (100%)	
Attended any awareness campaigns over the past years				
Yes	9 (100%)	0 (0%)	9 (100%)	0.002*
No	5 (36%)	9 (64%)	14 (100%)	
Individual equipment				
Yes	9 (90%)	1 (10%)	10 (100%)	0.012*
No	5 (36%)	8 (64%)	13 (100%)	
Insurance coverage				
Yes	3 (100%)	0 (0%)	3 (100%)	0.019*
No	5 (100%)	0 (0%)	5 (100%)	
No Idea	6 (40%)	9 (60%)	15 (100%)	
Recognition of responsibility				
Yes	9 (82%)	2 (18%)	11 (100%)	0.04*
No	5 (42%)	7 (58%)	12 (100%)	

*The chi-square test statistic was significant at the 0.05 level.

A socio-cultural approach is applied to explain the variation in volunteer participation and motivation as a volunteer. Focused group discussion and Key Informant Interviews were conducted based on the study objectives. The activities and motivation of the CPP volunteers are considered to have a significant influence on the process of disaster volunteerism. The characteristics are gender, age personal experience, training, personal equipment, awareness campaigns, awareness of liability, and insurance. The participation and motivation of male and female volunteers were positively related to previous disaster experience, training, personal equipment, disaster drills, awareness programs, insurance, *etc* ($P > 0.05$, Table 3).

Volunteers (male and female) stated that helping their community is their main motive behind volunteering. Most of the interviewees said that male and female volunteers make the same warning signals. Typically, while female volunteers broadcast the warning messages indoors, while men provide information outdoors and in remote areas. At the village level, due to religious practices and cultural sensitivities, the male volunteers are unable to enter some houses, while female volunteers can easily enter the houses and help to evacuate to a safe place. Women tend to listen to female volunteers rather than male volunteers. However, this changes from region to region and from community to community. Male and female volunteers do not see joint participation as an issue; rather, they see it as a complementary force. These emotions help improve the volunteers' motivation levels. It is also found that female volunteers had relatively less knowledge of their roles and responsibilities than their male counterparts. Many female volunteers work without having received any training. Gender issues should be addressed, and women's participation in disaster risk reduction should be increased to reduce the vulnerability of women.

4.2. Assessment of the volunteer's enactment of CPP from the community's viewpoint

4.2.1 Characteristics of the respondents (Community)

Of the total respondents were 59.9% males and 40.1% females. The average age of the respondents was 35 years. While most respondents were farmers, fishermen, and business owners, although 21.5% were housewives. Notably, their education level was not high. Of the respondents, 41.8% were uneducated. Furthermore, 48%, 9%, and 1.1% of the respondents attended primary and secondary schools, colleges, and universities respectively.

4.2.2 Communities' primary source of early warning information

In order to raise awareness about disaster risk reduction, communities need to be aware of the early warning systems and have easy access to early warning sources. CPP operations, such as the use of flags and sirens, are effective in coastal areas. Locals depend almost entirely on CPP for early warning of tornadoes. As shown in Figure 5, 43% and 37% of the Koyra and

Ukhiya respondents, respectively, received cyclone warnings and evacuation orders from CPP volunteers who disseminated the information via door-to-door visits. Radio is the main source of early warning for people living in the coastal areas of Bangladesh. Nearly 25% of those interviewed in Koyra and 29% in Ukhiya received an evacuation order on the radio. This is because there is no electricity in remote rural areas where battery-powered radios can be used. Nearly 28% of the respondents received warnings from their Neighbor and loved ones. In particular, women share information within their communities. People have also received warnings from the Bangladesh Meteorological Department, NGOs, elected members, television, religious sources, and more. However, NGOs can only provide information to their beneficiaries/stakeholders, which is a major limitation.

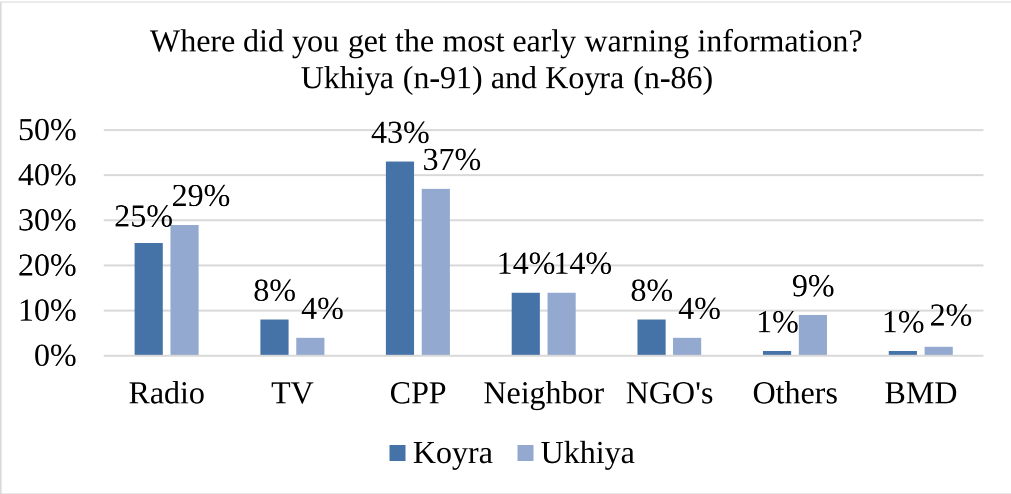

Figure 5. Early warning information

4.2.3 Understanding the signal disseminated by CPP (Flag System)

CPP volunteers use the "three flag system" to inform the community of the level of risk. In November 2018, the disaster warning system was revised following the amended Disaster Management Act (UNDP 2018). Research has shown that 42% of the community members understand the flag warning signals propagated by CPP volunteer. The cyclone warning signals in Bangladesh range from one to ten, depending on location, storm surges and wind speed. They divided these ten signals into three flag systems for easy understanding by the residents. The results show in the study areas, only 42% of both male and female respondents were aware of the national flag warning system. On the other hand, 37% and 21% of the male and female respondents were unaware of the flag warning system. The education level of the householders showed a high correlation with the awareness and understanding of the early warning system ($p>0.05$, Table 4). This factor is an important reason for disaster preparedness and evacuation. It also shows that the socioeconomic factors play an important role in understanding the flag early warning system used by CPP volunteers. This question is especially important for fishermen. Excluding radio, the flag warning system is the only source of cyclone early warning information for fishermen fishing in the offshore.

Table 4. CPP disseminated warning signal (Flag System)

Understanding of the CPP disseminated warning signal (Flag System)					
Characteristics	Yes (%)	No (%)	No idea (%)	n	P value
Gender					
Male	58 (55%)	31 (29%)	17 (16%)	106 (100%)	*P*=.000*
Female	16 (23%)	34 (47%)	21 (30%)	71 (100%)	
Total	74 (42%)	65 (37%)	38 (21%)	177 (100 %)	
Education level					
Not educated	16 (22%)	30 (41%)	28 (37%)	74 (100%)	*P*=.000*
Primary & secondary	41 (48%)	35 (41%)	9 (11%)	85 (100%)	
College	15 (94%)	0 (0%)	1 (6%)	16 (100%)	
University	2 (100%)	0 (0%)	0 (0%)	2 (100%)	
Total	74 (42%)	65 (37%)	38 (21%)	177 (100%)	
Occupation					
Farmer	28 (37%)	30 (40%)	17 (23%)	75(100%)	*P*=.000*
Business and job	23 (70%)	7 (21%)	3 (9%)	33(100%)	
Housewife	10 (26%)	15 (40%)	13 (34%)	38 (100%)	
Fishermen	11 (100%)	0 (0%)	0 (0%)	11 (100%)	
Others	2 (10%)	13 (65%)	5 (25%)	20 (100%)	
Total	74 (42%)	65 (37%)	38 (21%)	177 (100%)	

* The chi-square test statistic is significant at the 0.05 level

4.2.4 Understanding the early warning message delivered by CPP using megaphones

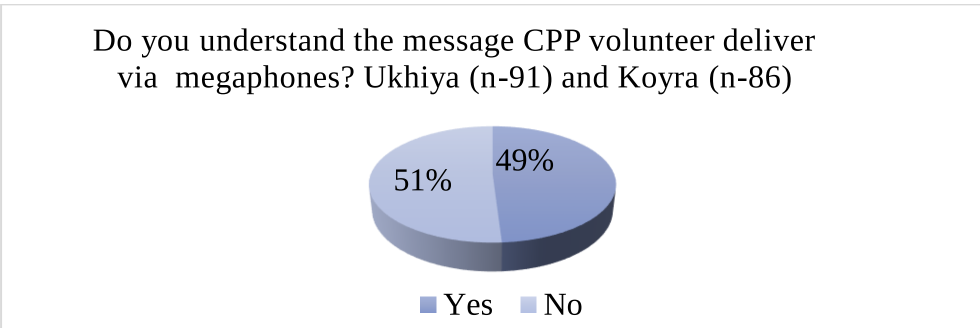

Figure 6. Understanding level of the early warning message provided by deliverers using megaphones

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Table 5. Reasons not to understand

Sub-District	Reasons not to understand				
	Message content is not clear	Sound system	It does not reach us	Language issue	Total
Koyra	31%	44%	22%	3%	36 (100%)
Ukhiya	18%	40%	12%	30%	50 (100%)

CPP volunteers use megaphones to disseminate early warning information to the community. However, as shown in Figure 6, 91 (51%) of the respondents understood the information announced by megaphones. The remaining 86 (49%) did not clearly understand the message content. The reasons for this gap in understanding are shown in Table 5; the community members could not interpret the CPP volunteers' messages delivered through megaphones. Language is one of the most important issues. Cyclone warnings are usually broadcast in the official language of Bangladesh (Bangla), which is not always understood by people in vulnerable communities. The people of Ukhiya often uses local dialects that are different from Bangla. In addition, people of different ethnicities have their own dialects. Therefore, those who are not well educated cannot interpret the warning messages. Moreover, the warning message does not always provide information about the severity of the events, preparation time, etc. This could be due to the lack of knowledge of the community members about the disaster, or the government's inability to handle it properly. Some respondents from Koyra and Ukhiya noted that the sound produced by the megaphones used by CPP volunteers only reached in the direction of the wind, whereas those on the opposite side had little chance of hearing such warnings.

4.2.5 Communication with CPP volunteers

A previous study indicated higher rates among the evacuee households in terms of both the percentage of early warning recipients and the understanding level of early warnings (Ahsan *et.al*, 2016). In addition to this scenario, the communities' low level of contact with CPP volunteers also restrains them from trusting on warning messages and decision making for evacuation, thus showing a significant positive correlation between the community members and their contact levels with CPP volunteers and evacuation decisions.

As illustrated in Figure 7, the Koyra community showed good communication skills with CPP volunteers (55%) than the Ukhiya community (45%). After 2007, many cyclones hit Koyra Upazila. Thus, the community became more aware than before. It is found that the percentage of evacuees was higher among those who participated in cyclone preparedness training before Aila. They attempted to maintain regular contact with CPP volunteers, especially during cyclone periods. It is found that, communication with CPP volunteers offers

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households preparedness, an understanding of the early warning messages, and reliability in the received warning signal.

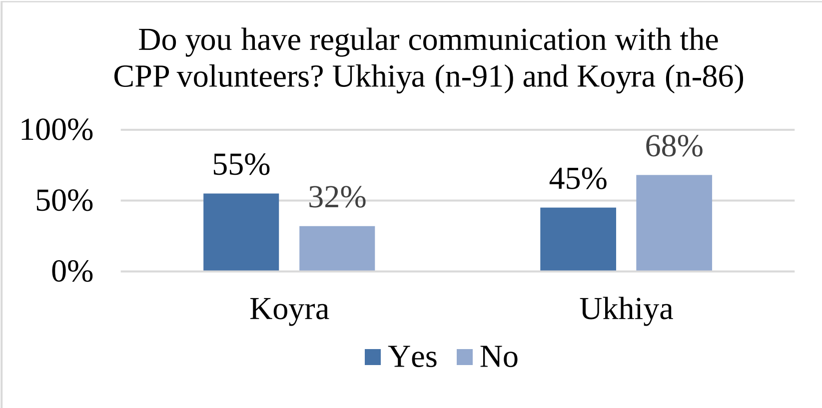

Figure 7. Regular communication with the CPP volunteers

5. FINDINGS AND DISCUSSION

This study examined the important factors that influence the scope of CPP volunteer's involvement in early warnings and the coastal resident responses to warnings. The survey results revealed that the communities in both the study areas did not properly understand the cyclone early warning messages. Accordingly, some researchers have studied the ways to improve the role of voluntary organizations in the field of disaster management from various viewpoints, such as management, participation, and organizational effectiveness (Wymer and Samu 2002, Jung and Ha 2021). However, this research acknowledges the factors affecting the volunteers' activities in early warning and communities understanding of the level of early warning methods. Besides on the results of the questionnaire survey, the key findings are discussed in the following sections.

5.1 Individual factors affecting the performance and motivation of CPP volunteers

People decide to engage in volunteering work for several reasons. People have for long been able to volunteer in traditional support networks based on the ideals of solidarity and reciprocity for a long time (Kaseke and Dhembe 2006). Evidence shows that the CPP volunteers' performance and motivation depend on factors such as age, individual work experience, education, and personal satisfaction. It has also been found that volunteer satisfaction is related to the involvement of BDRCS. During the normal times, there is no communication between the BDRCS and the CPP volunteers. According to Shi *et al*. (2018), training and education are the commonly used strategies to increase knowledge and awareness. Germany, Australia, and other countries have developed an emergency training system for emergency volunteer services. Skoglund (2006) recommended that the volunteer organizations should develop a support group and ongoing training seminars. Emergency preparedness training can help people learn more about how to be safe and make better decisions. In the case of CPP volunteers, respondents admitted that they received basic training from BDRCS; however, volunteers who have not been trained in search and rescue continue to be members of the search and rescue team. It is, therefore, undesirable for these volunteers to carry out the assigned tasks without minimal training in the field they are in charge of. The research explores that volunteer who have experience working in emergencies are more eager to participate in volunteering. Previous studies have identified 30-50 years as the most active age for volunteering. Smith believed that this may be due to an improvement in the socioeconomic status of the middle-aged people. Evidence shows that age is the most consistent and strongest determinant of CPP volunteer participation; while emergency awareness campaigns appear to be a significant factor influencing volunteering participation (Table 3). The research examining the gender differences in volunteering has brought out differences. Other studies have indicated that gender makes a difference depending on the variable being measured, such as the amount of time and frequency of volunteering. (Rosenthal *et al.* 1998; Todd, Davis, and Cafferty 1984). The results of this study show the participation in emergency volunteering to be higher for male volunteers than for female volunteers. The female volunteers were not provided with safety gear (raincoats and gumboots) during times of early warning and rescue broadcasting. As a result, female volunteers performed lower than male volunteers during search and rescue operations. Presently, 34% of the CPP volunteers are women. Despite the many factors, in this case, a positive factor is that young people are more likely to participate in CPP. McGee (1988) notes that recognition can improve morale and productivity. This reward program has a greater significance than the monetary value of the prize; it fosters a positive attitude. We found that the willingness to volunteer was significantly influenced by the degree of recognition of responsibility (Table 3). Amin (2012) claimed that there was previously a provision for awarding certificates to the volunteers, which incentivizes other volunteers to perform better. A large number of male volunteers get recognition for their relief work. However, female volunteers have expressed their powerlessness and spoken about the fewer opportunities available to them in management capacity in the area of public work (Tanjeela and Rutherford 2018). The research reveals that a lack of proper safety issues also hinders their participation in CPP. The CPP volunteers' commitment to helping others was a sacrifice that ultimately claimed the lives of 26 volunteers (Amin 2012). The BDRCS and other volunteers learned a lesson in prioritizing safety and security in the aftermath of the tragedy. Volunteers are discouraged from being provided with microphones, however they must purchase batteries for these microphones with their limited personal resources. The lack of functional equipment makes it difficult for volunteers to provide warnings. It may even lead to them leaving with their families instead of staying and helping. However, in developed countries such as Japan, volunteer fire corps (Shobo-dan) are trained in disaster management, including how to use various tools such as handheld loudspeakers, fire bells, sirens, and fire engines loudspeakers to warn communities throughout the affected areas (Ishiwatari 2012). In the United States, Community Emergency Response Teams (CERT) were established following Hurricane

Katrina in the United States. These involved local volunteers trained in disaster preparedness and response, which became more vital to make disaster management as effective and safe as possible for both survivors and rescuers (CERT 2020). Therefore, it is necessary to have appropriate equipment . Unfortunately, in CPP equipment maintenance is an issue that must be addressed via the increasing of budget. However, resources are not available to satisfy this requirement. They are needed to not only increase volunteer participation, but also ensure adequate early warning equipment to disseminate warning information to the community in time.

5.2 Community factors

Development of a community-based disaster risk management plan is also important for clarifying the role of each participant in both routine and emergency situations. CPP volunteers and community members have realized that volunteering is mutually beneficial. Previous studies conducted in several countries have shown that people who have a strong awareness of the neighborhood and a sense of belongingness to the community are the most likely to participate in community volunteering activities. Rural residents are more likely than urban residents to engage in volunteer work (Shi *et al*. 2018). In Bangladesh, rural communities have stronger bonds and a stronger sense of community than urban communities do. This is not an exception in Asian countries such as China, India, and Japan. The study explores how the Koyra and Ukhiya's local communities have some knowledge and skills pertaining to early warning systems and response strategies. However, it is difficult to access this information. Currently, information is disseminated through social media and the internet, especially in the case of disasters such as frequent cyclones and floods caused due to climate change. They may have received this information after it was translated into the local language, for the information was delivered primarily in Bangla and English. In Ukhiya, 30% of the respondents answered that they could not interpret the language announced by the CPP. This is because of the ethnic communities having different dialects. It is vital that local people understand and access information through technology; however, their knowledge of accessing technology is limited. Communication between the various local NGOs and communities on disaster preparedness issues was lacking in both Koyra and Ukhiya sub-districts. One of the important aspects of the evacuation drills was unsatisfactory in both the study areas. Both communities were found to be highly vulnerable to cyclones, as they had never received any disaster drills and had minimal community awareness about preparedness before and during the disaster. The research found the sociodemographic factors such as gender and education to impact the awareness of risk and the ability to prepare for risk reduction. In particular, education level has a considerable influence on understanding the flag warning system. Women do know about the cyclone early warning signal dissemination. Unfortunately, they could not interpret them because of the lack of proper knowledge and there being a lower level of education. The results show 55 illiterate women to not know anything about the flag warning system signals (Table 4). The correlation between the lack of education and lack of knowledge about early warning signals was highly significant (p = 0.00) (Table 4). They had to wait for someone who could disclose the existing early warnings and information regarding the preparations for evacuation. In the study areas, most of the existing access roads are made up of earthen materials, which become slippery during rainy seasons, and especially vulnerable people find great difficulty reaching the nearby shelter using these roads. It has also been noticed that most of the households are located in such a place, from where it will take approximately 20–60 minutes to reach a nearby shelter; however, it sometimes takes more time because of the unfavorable road and weather conditions that prevail during the cyclone.

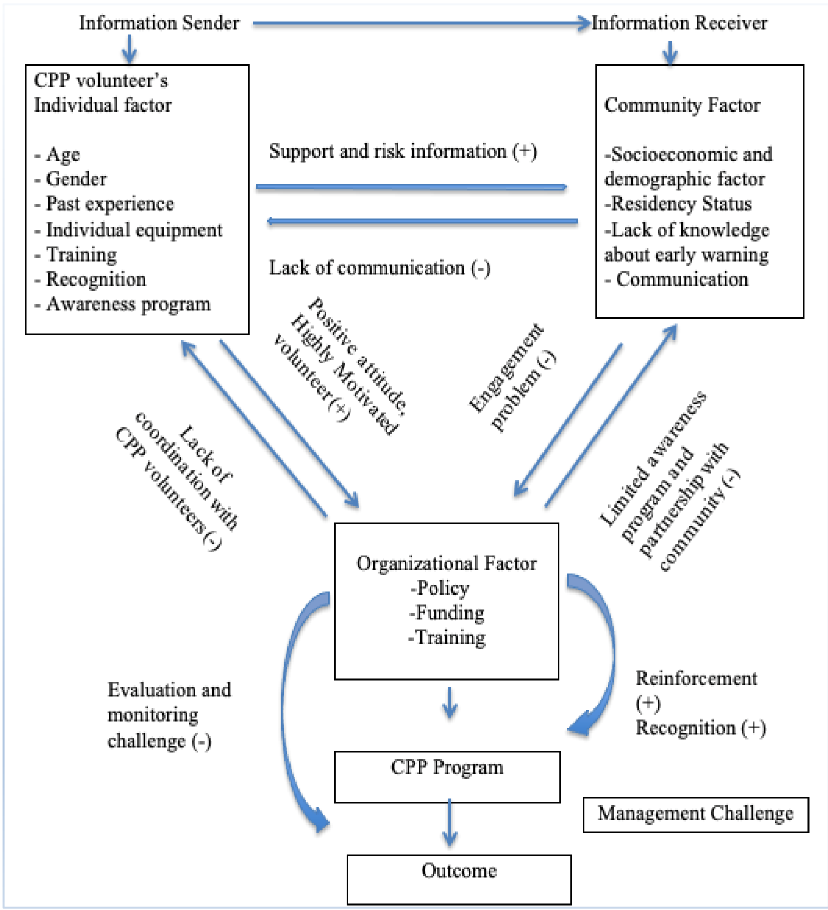

Figure 8. Framework for the factors associated with the scope of CPP volunteer involvement

5.3 Representative organizational issues

Countries with a well-established volunteer system have many volunteers. In the United States, 40% of the population is involved in volunteer services. Germany has a population of about 82 million, with 23 million volunteering and 1.8 million providing emergency volunteer services (Shi *et al*. 2018). A previous study reported that, while Bangladeshi government pays the salaries of CPP employees, there is no compensation provided to the CPP volunteers for the program operation costs they incur at the field level, including their capacity building (Amin 2012). The program's operation is entirely reliant on external funds. There is no insurance coverage for the CPP volunteer's injuries. In Japan and Germany, a sound volunteer risk management system, such as a volunteer insurance plan, is used to encourage emergency volunteer services. In Germany, the government has a legal obligation to purchase insurance for volunteers (Shi *et al*. 2018). Despite the efforts of voluntary organizations for disaster management, the activities of these organizations have not always been successful. For example, when Hurricane Katrina hit the United States in 2005, volunteers were unable to seamlessly integrate into the disaster response phase (Jung and Ha 2021). The employees of voluntary organizations did not know how to manage volunteers or the work that had to be done at that time. However, after the experience of Hurricane Sandy in 2012, volunteers help to spread the early warnings information and help to evacuate to shelters. It is found that, developed countries like Japan, Australia, and New Zealand provide strong financial support to their emergency volunteering (Mackwani and Sullivan 2016; Jung and Ha 2021). This regular emergency training can ensure that personnel with qualified skills can be effectively deployed to participate in emergency volunteer services during disasters. Training and regular communication stimulate volunteer action. Despite the fact that Bangladesh has not yet developed a community-based emergency training program, it does not have volunteers with specific knowledge and skills to respond to emergencies. According to CPP, the government has its disaster management strategies and objectives keeping with the government policy. In addition, CPP lacks a specific monitoring and evaluation system. Evaluating the program provides the ultimate justification for a volunteer program. Brudney (1996) defined evaluation as "the systematic collection of information about the processes and outcomes of a volunteer program and the use of that data to evaluate the program and hopefully improve it." The study discovered that although there is a union disaster management committee at the union level that is supposed to disseminate cyclone early warnings, it is not functional. There is a lack of accountability and insufficiency in the financial, logistical, and training resources available. To sustain the program, it is important to strengthen the accountability of volunteers by ensuring follow-ups at all levels, including from the headquarters to the CPP units at the village level.

6. CONCLUSIONS

In Bangladesh, CPP volunteers are gradually becoming the most reliable source of early warning, in addition to them assisting communities during cyclones in evacuation shelters (Ahasn *et.al*, 2016; Rahman, *et.al*, 2021.The CPP volunteers managed to significantly reduce cyclone casualties from 300,000 in the 1970s to 190 in Aila 2009 and to just 17 in Mahasen in 2013 (IFRC 2017). Volunteers are accepted by the community members in the coastal regions. However, the present study results show that the volunteers of the preparedness program are unable to disseminate warning information in a timely manner because of their limitations, such as lack of human resources, lack of modern gear, and poor transport systems to reach remote areas. Interviews with the BDRCS and CPP volunteers revealed that they faced some challenges during the operational time. First, it was difficult to take appropriate and prompt action in an emergency situation where no operational manual was available, and unexpected events occurred one after another. This is one of the reasons why some people receive timely evacuation information and some people do not. The volunteers just follow the higher level authorize the decision. It's a top-down approach. During cyclone Mahasen in 2013, an early warning and evacuation order issue from the district level was delayed by 2-3 hours, being transmitted CPP to Upazila (sub-district) level due to the time required to obtain get permission to deliver the evacuation information at each level (JICA 2013). The above framework shows that individual stakeholders (CPP, Community, and the Organizations) could make a significant contribution, but multiplier effects are still missing. The networking process, especially during normal periods, is expected to result in a shift in pre-disaster risk management. This study argues that the Bangladesh Red Crescent Society should concentrate on providing equipment and training to all volunteers so they can disseminate the warning information on time. The study also uncovers the details of gender-based involvement and issues working as a CPP volunteer that has not been widely reached in the past. The CPP program should provide equal opportunities (training, relief work) for both male and female volunteers to revive the program.

Residents of Bangladesh's coastal areas are poor and have little access to radio or television. As a result, they must rely entirely on the CPP volunteer's information. According to the findings, the community did not fully comprehend the cyclone early warning signal system. The problem that exists on the receivers’ side is that they wait until the last minute to evacuate (Paul 2009; Ikeda 1995). When the flags are displayed, people may use their view to understand that the intensity and severity of the hazard event are increasing, but they do not know the depth of the signals. The warning signals also do not provide adequate indications of when people should evacuate, seek shelter, or remain in their home. When signals are provided, they can be difficult for coastal residents to understand because knowing the wind speed is insufficient. This clarification is required to improve the effectiveness of the warning system. This could be due to community members' lack of knowledge about the disaster or to the government's failure to manage it properly. There are not enough cyclone shelters and embankments in the study areas, despite the fact that thousands of people live there. Also, the road network is very poor that's the reason CPP volunteers did not disseminate the warning information to the community on time. Finally, a large-scale awareness program among the locals, capacity building of the responsible authorities, and increasing the facilities provided to vulnerable groups can introduce a change in the current scenario and lead to the emergence of disaster-resilient communities in both study areas.

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Technical Note

Responding to Future Compound Disasters: Findings from COVID-19 Cases in Japan's Urban Areas

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Abstract The novel coronavirus (COVID-19) pandemic is a pervasive global issue. In Japan, the number of confirmed COVID-19 cases is especially greater in prefectures with, or adjacent to, densely populated cities. Hence, COVID-19 can be regarded as an urban disaster in Japan. To address current and future compound disasters in urban areas caused by pandemics and natural hazards (e.g., high-magnitude earthquakes), disaster response requires understanding that urban factors might increase the risk of infection. This study shall clarify how the COVID-19 infection in Japan might have been affected by urban factors related to population, in order to arrive at an effective compound disaster response. It employs a correlation analysis to evaluate correlations between the percentage of infection in Japan's major cities and the four indicators of population-related urban factors: population density, number of restaurants per capita, percentage of population inflow, and percentage of foreign residents. The study then uses a multiple regression analysis to estimate the impact of each of these four indicators on COVID-19 infection. It eventually considers how best to conduct disaster response activities for preventing an increased risk of infection during compound disasters. The results showed positive correlations between the percentage of COVID-19 infection and the four indicators in 43 major cities, with percentage of population inflow having the most significant impact. Japan's current disaster response policies premises a physical move to affected areas while noting COVID-19 countermeasures. Hence, disaster response activities should take greater care to limit physical dispatch and utilize remote assistance.

Keywords: COVID-19, Pandemics, Compound Disaster, Urban Disaster Prevention, Disaster Response

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1. INTRODUCTION

The COVID-19 infection is now a pervasive global issue. Other prevalent global disasters include climate change, frequently extreme weather events, and high-magnitude earthquakes. In such circumstances, comprehensive disaster response and societal preparedness for compound disasters are vital. In the recent past, COVID-19 has caused unprecedented damange across the world. Since the confirmation of the infection in 2019, several variants of the COVID-19 virus have emerged; following that of the Delta, the latest prevalence is of the Omicron variant. Current statistics state the cumulative number of COVID-19 cases in the world as 461.68 million (as of March 16, 2022); the United States has the largest number of confirmed cases at 79.59 million, followed by India and Brazil (Johns Hopkins University 2022).

In Japan, the cumulative number of positive polymerase chain reaction (PCR) tests is 5.81 million (as of March 16, 2022) (MHLW 2022a). By prefecture, Tokyo has the largest number at 1.14 million, followed by Osaka, Kanagawa, Aichi, Saitama and Chiba (NHK 2022). This indicates that there are more COVID-19 cases in prefectures with, or adjacent to, densely populated cities. Thus, COVID-19 can be regarded as an urban disaster in Japan (Kawata 2021). Hence, an elaborate up-front planning and support system is urgently needed to prepare for compound disasters, especially in urban areas. The COVID-19 infection primarily occurs through droplet transmission when an infected person coughs, sneezes, converses and so on; it could also spread through contagion and aerial infection in specific environments (NIID 2021; NCRH 2022). Therefore, in Japan, it is recommended to avoid the “3 Cs” (closed spaces, crowded places, and close-contact settings), apart from taking basic countermeasures like maintaining social distance, wearing a mask and washing hands, to avoid the spread of the disease (Kantei 2021; MHLW 2022b; NCRH 2022). In addition, envisaging the possible spread of the disease beyond a certain level, and a consequently overwhelmed medical service system, Japan has taken countermeasures for restricting people’s movements. This includes the “COVID-19 Declaration of State of Emergency” that allows prefectures to impose stay-at-home orders, restrict events, reduce business hours of restaurants, etc., and the municipal-level “Priority Preventive Measures” (CORONA 2022; NCRH 2022). Furthermore, the government started its COVID-19 vaccination drive in February 2021, and approximately 80 percent of the entire population has taken the second dose (Kantei 2022; NCRH 2022).

Since COVID-19, Japan’s Basic Disaster Management Plan, the highest-level plan which constitutes the basis for disaster management activities, has been updated such to incorporate infectious disease countermeasures, including COVID-19, into conventional disaster prevention measures. In this context, the relevant policies such as disaster responses, evacuation and sheltering have noted COVID-19 countermeasures like avoidance of the 3 Cs, as well asbasic countermeasures like maintaining social distance, wearing a mask, and washing hands. The response to the current and future compound disasters caused by pandemics in urban area, and natural hazards like high-magnitude earthquakes (for e.g., Tokyo Inland

Earthquake and Nankai Trough Earthquake) requires a physical move to the affected area, with adequate understanding of urban factors that could increase the risk of infection. COVID-19 has taught that it is necessary to ascertain the factors peculiar to urban areas where infection is pervasive. There is a positive correlation between COVID-19 infection and population density at the prefectural level (NITech, 2020; Shirabe *et al*. 2020). However, statistical analyses at the city level are insufficient in specifying the correlations and effects between COVID-19 infection and population-related urban factors. The questions that arise include: which are the urban factors that could increase COVID-19 infection and how do they do so, and, based on the key factor, how should disaster responses be conducted to prevent increased risk of infection during compound disasters. This study clarifies the effects of population-related urban factors on COVID-19 infection in Japan, to arrive at an effective compound disaster response.

2. METHODOLOGY

First, this study evaluated the correlations between COVID-19 infection in Japan's major cities, and each of the population-related urban factors, based on publicly available statistical data. A correlation analysis was conducted to measure the strength of the linear relationship between the two variables. The CORREL function and scatter diagram feature of Microsoft Excel were used to conduct the analysis. The study then estimated the impact of urban factors on COVID-19 infection, utilizing a multiple regression analysis that measures the impact of explanatory variables on a dependent variable. IBM's SPSS Statistics software (version 27) was employed for this analysis. This shows how simple statistical analyses can provide objective insights for preventing the risk of infection during disaster response activities. Moreover, they provide statistical evidence to the up-front planning and support system for addressing compound disaster responses. Based on the results, this study considered how disaster response activities should be conducted during compound disasters.

This study used "the percentage of persons infected with COVID-19" as a dependent variable of COVID-19 infections. The percentage was obtained by dividing the cumulative number of COVID-19 cases by the population of Japan's 43 major cities. These cities included 23 special wards of Tokyo, and 20 ordinance-designated cities other than Tokyo. The cumulative number of cases by city was searched at COVID-19-related websites of each city, and the number of positive PCR tests released as of May 16, 2021, was used. The population of each city was obtained from the 2015 census (e-Stat 2017).

This study assumed that three urban factors — population density due to residence, formation of temporary population density, and population inflow from outside — impacted the spread of COVID-19 infection, and applied the four related indicators (i.e., explanatory variables), as shown in Table 1. The population density of each city was obtained from the 2015 census (e-Stat 2017). The number of restaurants per capita in each city was calculated by dividing the number of restaurants per 1,000 people as per the 2016 Social Life Statistical Index (e-Stat 2016), by 1,000. The percentage of population inflow in each city was obtained by dividing the population inflow in the 2015 census by the daytime population. The percentage of foreign residents in each city was derived by dividing the number of foreign residents as per the 2020 Statistics of Foreign Residents (e-Stat 2020), by the city's population.

Table 1. Urban factors and their indicators applied

Urban factors	Indicators (explanatory variables)	Reference/Calculation
Population density due to residence	Population density	2015 census
Formation of temporary population density	Number of restaurants per capita	The number of restaurants per 1,000 people, divided by 1,000
Population inflow from outside	Percentage of population inflow	Population inflow divided by daytime population
	Percentage of foreign residents	Number of foreign residents, divided by city population

3. RESULTS

3.1 Correlation between COVID-19 infection and the four indicators

Fig. 1 shows the correlation between the percentage of COVID-19 infection in Japan's major cities, and each of the four indicators of population-related urban factors: population density, number of restaurants per capita, percentage of population inflow and percentage of foreign residents. The results showed a positive correlation between COVID-19 infection and the four indicators in 43 major cities. The correlation coefficient for population density was 0.702. However, in comparison to the population density, the percentage of COVID-19 infection was particularly high in Tokyo's Shinjuku-ward and Minato-ward. The coefficient for the number of restaurants per capita was 0.489, but in comparison to this, the percentage of COVID-19 infections was again high in Tokyo's Shinjuku-ward and Minato-ward, while being extremely low in Chiyoda-ward. The coefficient for the percentage of population inflow was 0.775, wherein the percentage of COVID-19 infections in Tokyo's Shinjuku-ward stood out again, while that in Chiyoda-ward was negligible. The coefficient for the percentage of foreign residents was 0.778, with a relatively high and low percentage of COVID-19 infection in Tokyo's Shibuya-ward and Shizuoka prefecture's Hamamatsu city, respectively. A key finding was that Shinjuku-ward was the most positively deviated in three out of four correlations, while

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Chiyoda-ward was the most negatively deviated in two correlations. As such, it is vital to explore potential factors peculiar to these cities.

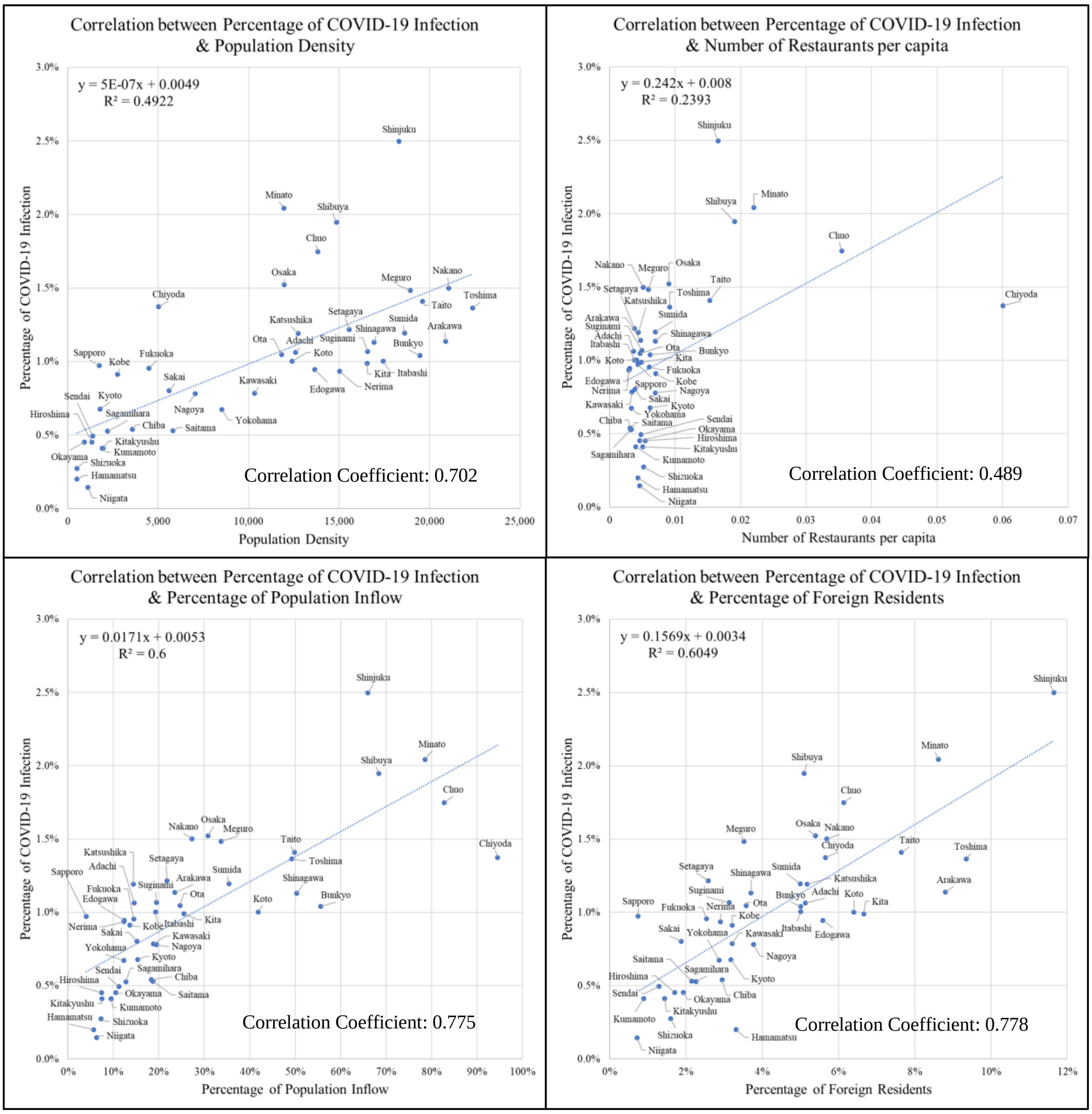

Figure 1. Correlation between the percentage of COVID-19 infection and four indicators.

3.2 Effects of the four indicators on COVID-19 infection

Fig. 2 illustrates the impact of the four indicators (explanatory variables) on the percentage of COVID-19 infections (a dependent variable), through a multiple regression analysis. The results revealed that the significance probability was 0.000. The standardized coefficients of each indicator were as follows: 0.298 for population density, 0.010 for the number of restaurants per capita, 0.451 for the percentage of population inflow, and 0.257 for the percentage of foreign residents. In other words, the percentage of population inflow had the most significant impact on that of COVID-19 infection, followed by the impact of population density.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Correlations			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	.003	.001		3.587	<.001					
	Population Density	2.101E-7	.000	.298	2.201	.034	.702	.336	.174	.340	2.945
	Number of Restaurants per capita	.005	.086	.010	.055	.957	.489	.009	.004	.206	4.861
	Percentage of Population Inflow	.010	.005	.451	2.183	.035	.775	.334	.172	.146	6.849
	Percentage of Foreign Residents	.052	.027	.257	1.912	.063	.778	.296	.151	.345	2.901

a. Dependent Variable: Percentage of COVID-19 Infection

Figure 2. The SPSS output of multiple regression analysis.

The results reveal that it is important to make efforts to avoid population inflow and density in the context of disaster response activities. It is particularly important to prevent an increased risk of infection when those involved in disaster response are dispatched to the affected areas. In Japan, the inter-municipality mutual assistance system, a centralized system for making the best use of human resources from municipalities across Japan, was established by the Ministry of Internal Affairs and Communications in March 2018 (MIC 2019). As part of this system, municipal personnel from non-affected prefectures are dispatched to the affected municipalities to support disaster response operations and manage large-scale disasters. However, this involves a physical move to the affected areas. During the heavy rainfall of July 2020, personnel who were dispatched to Kumamoto prefecture's Kuma village to assist the affected people in shelters got further infected by COVID-19, raising concerns about a cluster at the shelter (Disaster Management 2021). Hence, optimal human resource allocation through limited physical dispatch of personnel and increased remote assistance using information and communication technology (ICT) are steps towards preventing population inflow into affected municipalities when responding to compound disasters caused by pandemics.

4. CONCLUSION

This study ascertained the effects of population-related urban factors on COVID-19 infection in Japan, in order to arrive at an effective compound disaster response. Statistical evidence can be useful for preparing an elaborate up-front planning and support system to address compound disaster responses. The study used a correlation analysis to evaluate the correlations between the percentage of COVID-19 infection in Japan's major cities, and four indicators of population-related urban factors. These included the population density, number of restaurants per capita, percentage of population inflow and percentage of foreign residents. The study then estimated the impact of urban factors on COVID-19 infection through a multiple regression analysis. It eventually considered how disaster response activities should be conducted to prevent increased risk of infection during compound disasters. The results show positive correlations between the percentage of COVID-19 infection and the four indicators in 43 major cities. The percentage of population inflow had the most significant impact on that of COVID-19 infections.

Since COVID-19, Japan's Basic Disaster Management Plan has been updated to incorporate infectious disease countermeasures, including COVID-19, into conventional disaster prevention measures. In this context, the existing inter-municipality mutual assistance has noted COVID-19 countermeasures like avoidance of the 3 Cs and basic countermeasures like maintaining social distance, wearing a mask, and washing hands. However, it still premises a physical move to the affected areas. The disaster response support is being developed uniformly across Japan without emphasizing urban characteristics, which might increase the risk of infection. Thus, the findings from this study are helpful to give utmost caution to the physical move in urban areas when conducting response activities to compound disasters caused by pandemics. As such, optimal human resource allocation should be considered through limited physical dispatch of supporting personnel and higher remote assistance using ICT.

While the results are specific to Japan and use its publicly available data only, readers might find them applicable to similar situations in other countries. Moreover, this study does not consider the temporal variability of population-related urban factors on COVID-19 infection, throughout the changing circumstances. Future studies should include a time-series analysis of urban factors, pursue more relevant indicators of urban factors, and further consider how to conduct an effective compound disaster response.

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Original paper

Rapid and Accurate Detection of Building Damage Investigation Using Automatic Method to Calculate Roof Damage Rate

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Abstract In the event of a natural disaster, local Japanese governments investigate the level of damage of the buildings and issue damage certificates to the victims. The damage certificate is used to determine the content of the support provided to the victims; hence, they must be issued rapidly and accurately. However, in the past, the investigation of damage was time-consuming, thus delaying the support provided to the victims. Additionally, while investigating the roof of the damaged building, it was difficult for the investigators to look at the entire roof and calculate the damage rate accurately. Therefore, we have developed an automatic method to calculate the damage rate of a roof using image recognition from aerial photos so that building damage investigation can be more accurate and rapid. We requested the staff in the disaster management division to evaluate the estimation results of this model and confirm its effectiveness. As a result, 80 % of the roof data obtained from this method was equal to or more accurate than the investigator checking from the ground. Additionally, we have developed an efficient flow for building damage investigation using the proposed system. In the future, we aim to investigate the system usage to ensure responsibility in data estimation.

Keywords: Deep learning, roof damage, damage certificate, image recognition

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1. INTRODUCTION

In the event of natural disasters, such as earthquakes, storms, and floods, the Japanese local government investigated the level of damage to each building and issued a damage certificate to the victims to prove that the buildings were damaged by the disaster. As this certificate is used to determine the content of their support, such as temporary housing, support money, and loans, it is necessary to reconstruct their livelihoods. Moreover, until they receive the actual certificate, they are unable to make plans to reconstruct their livelihoods, especially regarding their residence. Hence, they must be issued accurately and rapidly (Disaster Management, Cabinet Office, Government of Japan 2020). After the earthquake in Great East Japan, the Basic Act on Disaster Control Measures was revised, and local governments were instructed to issue damage certificates without delay (Disaster Management, Cabinet Office, Government of Japan 2020). However, in the past, the process of building damage investigation and issuing damage certificates was time-consuming and delayed the support provided to the victims.

The building damage investigation is conducted by the staff of the local government and has three stages: first, second, and reinvestigation. The results of this investigation require the agreement of the victims. If the victims are not convinced of the results of the first investigation, they can apply for a second investigation or a reinvestigation. The first investigation is comparatively simple because it is a visual inspection. The second investigation and reinvestigation are detailed. At each stage of the investigation, the investigators check the appearance, inclination of the building, or damage degree of each part, such as walls, foundations, and roofs, to calculate the level of damage to the entire building. An overall damage rate of more than 50 % is assigned to completely destroyed structures, 40–50 % to large-scale half destroyed structures, 30–40 % to middle-scale half destroyed structures, 20–30 % to half destroyed structures, 10–20 % corresponds to semi half destruction, and less than 10 % to partially damaged structures (Disaster Management, Cabinet Office, Government of Japan 2021).

However, in the roof damage investigation, the investigators cannot investigate the entire roof. Therefore, they look at the roof from a distance and investigate it within the range of vision from the ground. In addition, they calculate the degree of damage to each roof surface and need advanced expert knowledge. These inaccurate investigations result in victims' dissatisfaction with the results, and the number of second investigations or reinvestigations increases. In past earthquakes, investigations classified as unsatisfactory to resident caused much trouble between local governments and victims (Shigekawa *et al.* 2005).

After the Kumamoto earthquake in 2016, 135,959 first investigations, 37,807 second investigations, and 2,635 reinvestigations were conducted in Kumamoto City (Department of Crisis Management, Kumamoto Prefecture, 2020). One of the previous studies (Inoue *et al.* 2018) reported that the work on building damage investigation in one city of Kumamoto Prefecture took approximately 29,000 man-days, which was the largest number after the work on the issue of damage certificates. Thus, improving the efficiency of building damage investigation may enable the local governments to allocate manpower to other tasks effectively.

In previous earthquakes in Japan, many buildings, especially wooden buildings, were damaged. Based on investigations to assess damaged buildings after the 2016 Kumamoto earthquake, 8,642 buildings were found to have been completely destroyed, 34,393 buildings were half destroyed, and 155,177 buildings were partially damaged (Department of Crisis Management in Kumamoto Prefecture, 2020). In Mashiki-town, which was the epicenter of the damage, 28.2 % of wooden buildings built before 1981 collapsed (Ministry of Land, Infrastructure, Transport, and Tourism 2016). In Japan, the ratio of wooden buildings is 56.97%, and this increases to 92.5 % for single houses (E-Stat 2018, Ministry of Internal Affairs and Communications 2018). Although changes in building standards have resulted in buildings more robust to earthquakes, many buildings may still be damaged. Traditional Japanese tile roofs tend to be damaged by earthquakes or typhoons. Many Japanese people select this tile roof for reasons such as their design, durability, and heat resistance. Prior to the change in the building standard in 1981, tile roofs of buildings did not have to be fixed to the roof base. Currently, the number of tile roofs that sustain damage in disasters is decreasing because of revised strict building standards, the use of light raw materials, and a decrease in the number of people using tile roofs. However, many old buildings, or buildings without sufficient countermeasures, may still be damaged in the future.

2. RESEARCH PURPOSE

Based on the aforementioned challenges, the problems encountered during building damage investigations are as follows:

(1). Building damage investigation is time consuming and delays the support provided to the victim’s livelihood.
(2). In the roof investigation, the investigators cannot look at the entire roof from the outside; hence, the results are not accurate.
(3). The investigators must have prior technical knowledge owing to the complexity of investigation.

Therefore, the purpose of this study is to develop a system to automatically calculate the damage rate of roofs using image recognition from aerial photos so that building damage investigation can be more rapid and accurate. Additionally, using aerial photos enable the investigators to accurately investigate the part of the roof that cannot be seen from the outside. Moreover, if image recognition can calculate the precise damage rate of the roof, prior technical knowledge is not required and people other than experts in architecture can also investigate the roof accurately.

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3. PREVIOUS STUDIES

Vetrivel *et al.* (2018) developed a damage-building detection model using deep learning and 3D point cloud features. They used high-resolution oblique aerial photos as the inputs for the model. Tu *et al.* (2017) developed a detection model to identify damaged regions using a support vector machine, which is a type of machine learning method. They used multi-temporal high-resolution remote sensing images to detect changes in the buildings owing to damage. This study uses aerial photos that are obtained by drones or aircraft at a low price. This provides easy access to training and estimation data during disasters.

Ji *et al.* (2019) estimated damaged buildings using texture analysis, which analyzes the state and pattern of the object surface, and a convolutional neural network (CNN), which is a type of deep learning for image recognition, based on differences in post-disaster and pre-disaster aerial photos. In addition, Fujita *et al.* (2017) used the information on differences in post-disaster and pre-disaster aerial photos to detect damage of buildings by tsunami using a CNN. However, the pre-disaster aerial images may be old, and the building information may be significantly different from the post-disaster images. Such buildings include not only damaged buildings but also new buildings or demolished buildings. Therefore, their system may detect buildings that are not damage. This problem was addressed in this study because only post-disaster aerial photos were used. Meloy et al. (2007) investigated the roof performance of new homes in Florida damaged by Hurricane Charley using oblique aerial photos with four angles. They used a special tool to obtain the area ratio of the damaged part by manual entry, and determined the damage level from this ratio. This study calculates automatically the damage rate of a Japanese building damage investigation from both the area ratio and type of damage. Moreover, this study does not use oblique aerial photos but ortho photos, which were taken from directly overhead. In Japan, many companies and organizations employ ortho arial photographs because it is easy to overlay them on maps, and are thus considered important by disaster response organizations. Considering their availability, ortho aerial photos are effective for this system.

Inoguchi *et al.* (2019) developed a detection system for buildings with blue sheets using a CNN for deep learning from the aerial photos captured by drones. Their data were generated from images of the roof immediately after they were captured manually. However, these methods are time-consuming during disasters. In this study, data are generated using the original trimming algorithm based on the location information of the building polygon, which is geospatial information. Miura *et al.* (2020) identified collapsed buildings and blue tarp-covered buildings using deep learning from aerial images. However, the focus was on the damage to the entire building, not just the roof.

According to previous studies, the efficiency of building damage investigations can be improved using various methods. Matsuoka *et al.* (2018) judged the level of damage to the building using a CNN from aerial photos and investigation field photos for the purpose of investigation. They also focused on the damage to the entire building and did not refer to the

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usage of their system in the actual investigation field during a disaster. Tanaka *et al.* (2008) analyzed the processes of building damage investigation and proposed a self-inspection system that can be used by a non-expert. Fujiu *et al.* (2012) developed a remote judgment system for building damage investigations using smartphones and the Internet to improve the efficiency of the investigation and issue of damage certificates. To the best of our knowledge, there is no existing research on automatically calculating the degree of damage of the damage building investigation of individual parts of buildings, particularly roofs from the aerial photos, considering usage during actual disaster response, such as obtaining aerial photos and generating image data.

4. AUTOMATIC METHOD TO CALCULATE DAMAGE RATE OF ROOF

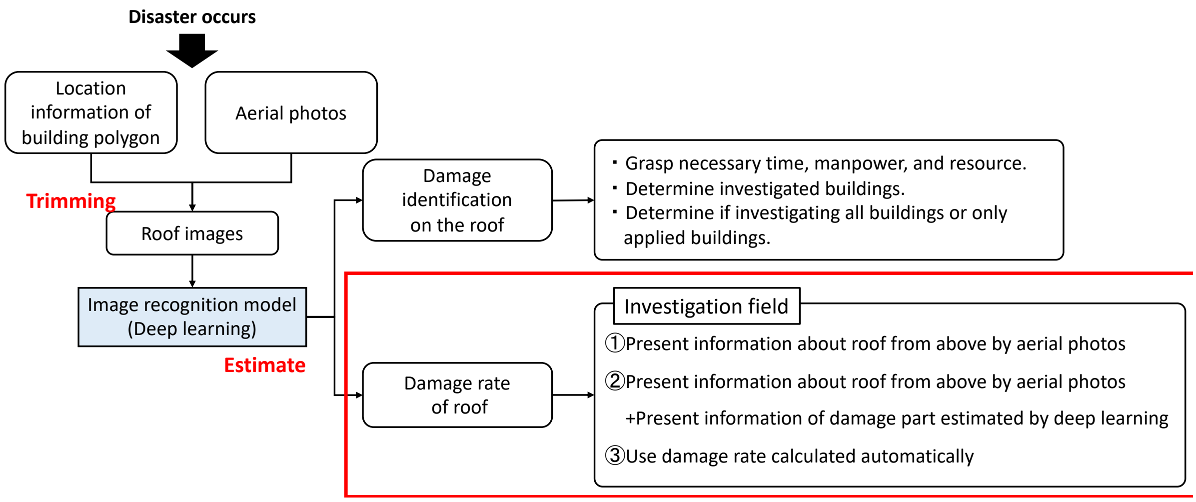

Figure 1. Overall structure of the proposed system

Table 1. Usage of the proposed system

	Use of aerial photos	Use of deep learning	Basis for judgement of investigator	Final calculation
①Present information from aerial photos	○	×	Field information +Aerial photos	Investigator
②Present information from aerial photos +Present information from deep learning	○	○	Field information +Aerial photos +deep learning	Investigator
③Use damage rate of roof by deep learning	○	○	-	Deep learning

4.1 Overall Structure of Proposed System

Figure 1 shows the overall structure of the proposed system. After a disaster occurs, the proposed system automatically generates images of the roof using a trimming algorithm, aerial

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photos and geospatial information, such as the location information of building polygons. Then, each data point of the image of the roof is fed as an input to the image recognition model to estimate the damage to the roof. In our previous study (Fujita and Hatayama 2021), this image recognition model estimated the presence of roof damage to grasp the necessary time, manpower, and resources, determine the investigated buildings, and investigate all buildings or only the applied buildings. In this study, we developed an image recognition model to calculate the damage rate of the roof so that the building damage investigation can be more rapid and accurate to address the following usages:

(1) Present information about roof parts that cannot be seen from the outside using aerial photos.
(2) Present information about roof parts with high probability of damage and advise investigation to investigators.
(3) Calculate the damage rate of the roof directly using the model for building damage investigation.

Table 1 lists the details of these usages. In this table, “O” means “use” and “X” means “do not use”. In all three usages, the investigators are in the investigation field to investigate certain parts of the building other than the roof.

4.2 Trimming Algorithm

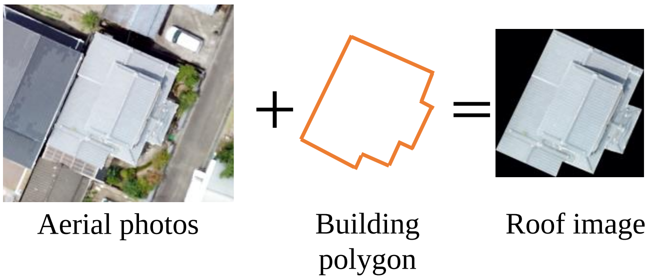

Figure 2. Trimming algorithm

The trimming algorithm can automatically generate data from the image of the roof using aerial photos and location information of the vertex of the building polygon as shown in Figure 2. Because trimming can extract each image from aerial photos, this model can reduce the time required to generate image data so that the level of damage can be estimated rapidly during a disaster. Subsequently, a large amount of training data is generated for deep learning. Moreover, this method uses building polygons; hence, the proposed model can estimate the damage not by area but by building and obtain detailed information. Moreover, painting areas of the building other than the roof with black can remove unnecessary information while calculating the damage rate of the roof, which increases accuracy.

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4.3 Method to Calculate Damage Rate of Roof in Building Damage Investigation

During the investigation, the investigator calculates the damage rate of certain parts of the building, such as the wall, foundation, and roof and, determines the level of damage of the building from the total amount of damage. The damage rate of the roof is calculated by multiplying the degree of damage by the roof surface area rate. These values are then added as in equation (1), where *Si* is the area of roof *i*, S^e is the area of the entire roof, and *Di* is the damage degree of roof *i*. The damage degree is represented as a percentage based on the damage type and position. If one roof surface has a different degree of damage, then the degree of damage is calculated by the average weight of these areas (Disaster Management, Cabinet Office, Government of Japan 2020).

$$Damage\ rate = \sum_i \frac{S_i}{S^e} \times D_i \tag{1}$$

4.4 Problem of This Study

Our previous study (Fujita and Hatayama 2021) estimated the damaged roof and the roof covered with a blue sheet using deep learning from trimming roof data. Because many victims covered the damaged part of the roof with a blue sheet to prevent wind and rainwater, we identified the roof covered with a blue sheet as a damaged roof. Consequently, the accuracy of the estimation of the damaged roof was lower than that of the roof covered with a blue sheet. Based on this result, we concluded that the challenges to be addressed were the difficulty in extracting the features of the damaged part and the lower resolution of the aerial photos captured by the aircraft. It is necessary to use abundant training data to improve the accuracy of deep learning models. However, there are insufficient high-resolution aerial photos that include roofs damaged by earthquakes. The reasons for this are the low frequency of earthquakes, short time since the invention of drones that can capture aerial photos with high resolution, and time limitation, which forced us to take aerial photos of the roof covered with a blue sheet. Thus, we concluded that the problem in the estimation from aerial photos during disasters in our study was limited training data, which is necessary for the improvement of accuracy.

4.5 Proposed Method to Calculate Damage Rate of Roof

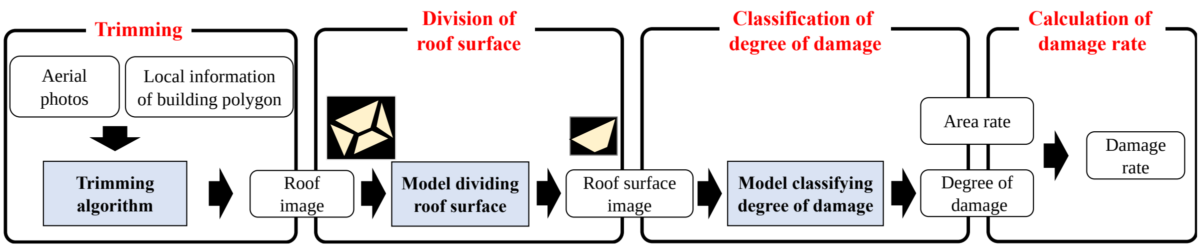


Figure 3. Flow of the proposed method to calculate damage rate of the roof

Based on the above problem, the trimming of roof images is divided into roof surfaces, thus increasing the amount of training data, as shown in Figure 3. Generating multiple roof images from one trimming roof image enables us to obtain training data several times. Then, the divided roof surface images are fed as inputs to the classification model to estimate the degree of damage. Finally, the degree of damage is multiplied by the area rate, and the values for all the roof surfaces are added to obtain the damage rate of the roof.

Ise *et al.* (2018) suggested a deep learning method using finely divided image data obtained from images as training data to classify moss and obtain a high accuracy. This shows that the division method can generate a large amount of training data from one image to improve accuracy. In terms of the building damage investigation, the proposed method follows the calculation method of the actual investigation. Therefore, the calculation result obtained in the proposed method is close to the actual result, and the skepticism of the victims regarding the accuracy of the estimated result may decrease. Moreover, this method obtains the degree of damage of each roof surface; hence, we can determine the actual damaged roof surface. Therefore, the second usage of the proposed system, which is to present information about roof parts with a high probability of damage, can be achieved. Additionally, in the third usage of our system, which is to use the damage rate of the roof directly, as calculated by the model during building damage investigation, the proposed model can indicate the basis for judging the calculation result to the investigators or victims. As mentioned above, the damage level of a building estimated during a building damage investigation determines the support content for the victims. Thus, when the victims are not convinced of the estimated level of damage or the calculated damage rate is located near the borderline position of the damage level class, many troubles with victims are likely to occur. In addition, in deep learning with high accuracy, numerous parameters act on each other. It is difficult to directly obtain an interpretation or explanation of the training or manual estimation. However, it is likely that providing a basis for judgment in addition to the high accuracy of the proposed method, will enables a smooth response without problems.

4.6 Necessary Data

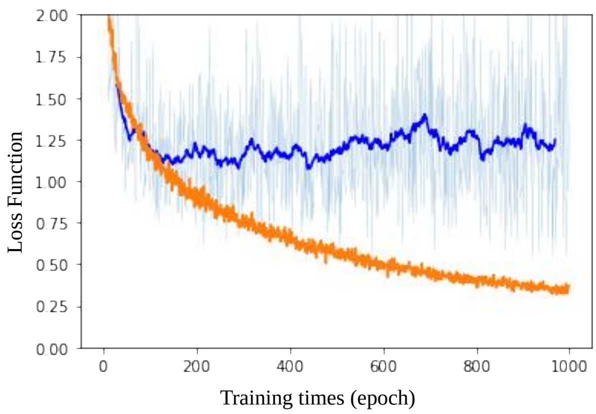
To operate this system, data such as aerial photos for estimation, location information of building polygons, and training data (aerial photos and correct labels for deep learning) are necessary. Aerial photos for estimation during a disaster can be obtained for free from the Geospatial Information Authority of Japan or a non-profit organization, such as Drone Bird. The location information of building polygons can be downloaded from Fundamental Geospatial Data in Japan or Open Street Map. The approach to training data differs based on when the model is trained, whether before or after a disaster. If the model is trained before a disaster occurs, a general model that considers the features of the region, such as the roof format, must be constructed. For example, Naito *et al.* (2020) constructed a general model to estimate building damage by deep learning using aerial photos of several regions as training data. If the model is trained after a disaster, a model that considers the features of a region can be constructed using part of the aerial photo of the estimation data as training data. However, in this case, the input of the correct answer label to the training data (annotation) must be conducted rapidly after a disaster. For example, cooperation by cloud sourcing or requesting input from outside people, such as those who are aware of the investigation process or experts is necessary.

Thus, aerial photos and location information of building polygons can be obtained from existing data, and the label for deep learning can be obtained from existing systems or staff with knowledge of the investigation. This indicates that the proposed system can be operated only by local governments, and ensures the feasibility of the system.

5. DIVISION OF ROOF SURFACE

5.1 Data Division Model

This study uses an instance segmentation model of deep learning that extracts the region of an object by classifying each pixel in an image to divide the roof surface because, a deep learning model can extract complicated features such as roof surfaces in images even with damage or dirt. In particular, this study uses Mask R-CNN (He *et al*. 2017), which is one of the most accurate instance segmentation models.



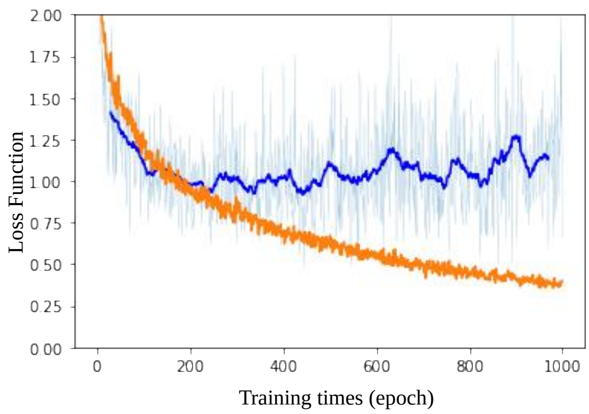


Figure 4. Left side shows transition of the loss function of the first experiment, and right side shows one of the additional experiments. The orange line represents one of the training data and blue line represents one of the validation data.

5.2 Training Method

Table 2. Result of dividing roof surface

	First experiment				Additional experiment		
	All images	Images with damage in roof surface	Images with damage in boundary	Images with leaf	All images	Images with damage in roof surface	Images with damage in boundary
Average of IoU	0.7580	0. 7341	0. 6874	0.7237	0. 7672	0. 6858	0. 7074
Average of AP	0. 6670	0. 6846	0. 5752	0. 3979	0. 6934	0. 6094	0.4628

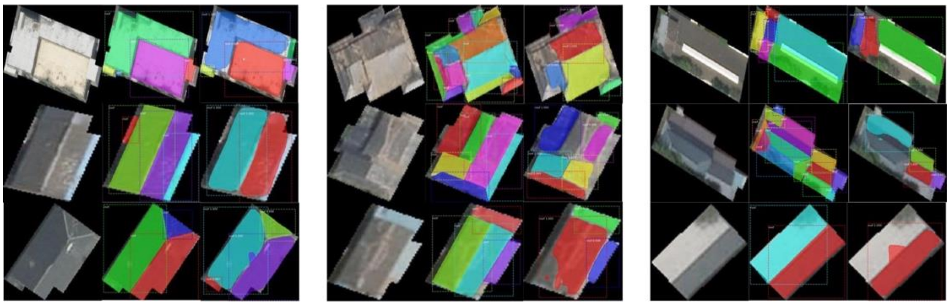


Figure 5. Left: images of the roof with damage in roof surface, center: images of the roof with damage in boundary, and right: images of the roof with leaf in them. Each row shows original image, correct region, and estimated region from left to right.

We generated images of the roof using a trimming algorithm and ortho aerial photos taken in Mashiki town of Kumamoto prefecture after the 2016 Kumamoto Earthquake. These aerial photos were taken by aircraft rather than drones, with a resolution of 20 cm and an elevation of 1396m. Although these are low-resolution photographs, they cover a very wide area in the damaged region. The location information of the building polygons was obtained from the Fundamental Geospatial Data of the Geospatial Information Authority of Japan. This annotation took approximately 1 min for one roof image and a total of 8–9 h. In this study, 2400 (300×8) images were used as training data to update the parameters, 800 (100×8) images were used as validation data to confirm overfitting, and 800 (100×8) images were used as test data to evaluate the accuracy of the model. The number of data points was increased eight times with horizontal flipping and rotation of each image. Because there is a gap between the location of the building polygon and the actual building, we excluded roof images whose gap was large or the roof surface could not be judged by observation from these datasets.

The loss function of the validation data was confirmed to prevent overfitting. When this value increased, we considered the increase to be overfitting and stopped the training. In this study, the classification classes were set to 2 (roof and background), the size of the input image to 256×256, the batch size to 2, the number of iterations in one epoch to 100, and the number of iterations in the calculation of the loss function of the validation data to 5. Tesla K40c and

GeoForce GTX 1060 6 GB of NVIDIA were used as the GPU in this experiment. The training of 1000 epochs took approximately 16 h. The left side of Figure 4 shows the transition of the loss function of the training and validation datasets. Because an increase in the loss function appeared in epoch 500, the training was stopped at epoch 500 using with the proposed model.

5.3 Result of Division in the First Experiment

The average intersection of union (IoU) by image in the first experiment was 0.7580 and the average of average precision (AP) was 0.6670, as shown in Table 2. The IoU indicates the degree of overlap between the correct and estimated regions. The AP indicates the degree of recall and precision of the regions estimated by image. As a result, images with high AP and IoU tended to have large and few regions of the roof surface in each image.

In the roof images with damaged regions, as shown in Figure 5, there is a difference between the accuracy of roof surface division between roof images with damaged regions on the roof surface (Figure 5, left) and roof images with damaged regions at the boundary of the roof surface (Figure 5, middle). Comparing the 40 image data with damage to the roof surface (five original images) with all the other images from Table 2, it was observed that the proposed model is capable of dividing the roof surface of these images as accurately as other roof images. Therefore, even if the color or texture of the roof surface is discontinuous, the model can accurately divide the roof surface. This result suggests that instance segmentation using deep learning is effective for image division. However, when the 40 images with damage at the boundary of the roof surface (five original images) were compared with all other images from Table 2, the model could not divide the roof surface of these images with the same accuracy as other roof images. Additionally, it was observed that roof images with a low average IoU and AP included roof images with leaves, as shown in Figure 5 (right).

5.4 Result of Division in the Additional Experiment

To handle images with the abovementioned features, we added 160 images with damage regions in the boundary (20 original images) and 160 images with leaves (20 original images) to train the data. The proposed model was trained using 2720 training data points, 800 validation data points, and 800 test data points. The right side of Figure 4 shows the transition of the loss function of the training and validation datasets. Because an increase in the loss function appeared at epoch 600, the training was stopped at epoch 600 with the proposed model. As a result, the average IoU of the roof images with damage regions in the boundary was lower by 0.0016, and the average AP was higher by 0.0342 compared to that in the first experiment, as shown in Table 2. The average IoU of the roof images with leaves was lower by 0.0163, and the average AP was higher by 0.0649 compared to that in the first experiment. In both roof images with damage regions at the boundary and with leaves, both IoU and AP did not increase.

However, the difference between the increase and decrease in both of these values indicates that the accuracy of the division of these images improved to some extent.

5.5 Image Processes after Division

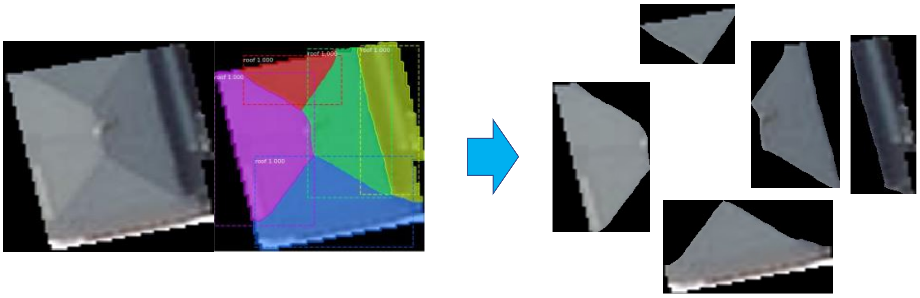


Figure 6. Example of divided roof surface data image

There were many overlapping regions with multiple estimated regions and overlooked regions that were not estimated to be roof surfaces.

In overlapping regions, many regions with large areas expanded to regions with small areas. To remove overlapping regions, we selected the smallest region of overlapping regions and excluded the others. To compensate for the overlooked regions, we expanded the estimated regions to all sides at the same speed after removing overlapping regions. Roof surface images were generated after these two processes, as shown in Figure 6.

6. CLASSIFICATION OF DEGREE OF DAMAGE

6.1 Used Data

Roof surface image data created by division of the roof surface have a low resolution because the image of the roof from which the roof surface is divided has a resolution of 20 cm. Therefore, it is difficult to determine the degree of damage of these images in detail. Thus, we have constructed a model that classifies five classes of roof surfaces: no damage, damage (-25 %), damage (25–50 %), damage (50–75 %), and damage (75%). The corresponding image data were generated as shown in Figure 7.

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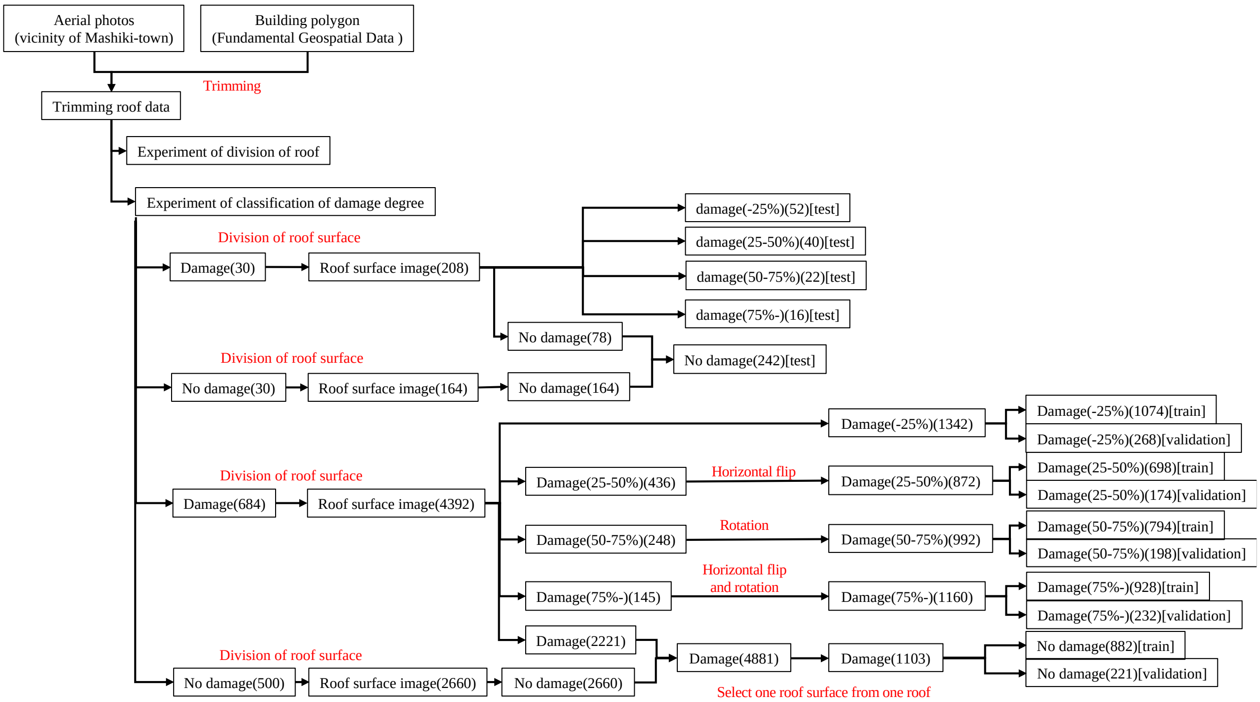

Figure 7. Breakdown of data used in classification of degree of damage

In this study, we used 30 roof images, each with and without damage, as the test data. Of the 30 roof images with damage, we selected roof images with different degrees of damage to obtain various damage types. Then, we divided the images with damage using the division model described in Section 4, and requested the staff in the Department of Crisis Management of Shimanto-town, Kochi Prefecture, who have an experience of building damage investigation, to input the correct label of damage degree to 208 divided images. In this study, 684 roof images with damage and 500 roof images without damage were used as the training and validation data. A total of 4,392 roof surface images were obtained from roof images with damage. These were fed as input labels of the degree of damage in reference to the labels of the test data and investigation manual. Consequently, this model could generate 2,171 roof surface images with damage from 684 roof images with damage, indicating that the training data could be increased by 3.174 times. In this study, the number of data points of each class in the training and validation data was equal by horizontal flipping and rotation. Additionally, in roof images without damage, we selected one roof surface from each roof to obtain various types of roof data. Figure 8 shows examples of images of damaged roof surfaces.

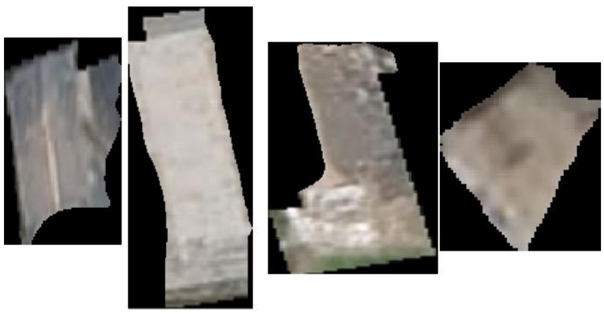

Figure 8. Examples of image of roof surf with damage (damage (-25 %), damage (25–50 %), damage (50–75 %), damage (75%) ordered from left to right)

6.2 Training Method

We used ResNet50 (He *et al.* 2015) to classify the degree of damage, which is one of the most accurate classification models. We trained ResNet50 using the data described in the previous subsection. The batch size was set to 16, the size of the input image to 256×256, and the loss function to cross-entropy loss. It took 5 h and 56 m to train this model using the GPU GeoForce GTX 1060 6 GB of NVIDIA for 200 epochs. Figure 9 shows the transition between the loss function and the accuracy. 1 epoch represents 274 times of training. This represents the total number of times training was provided to all data simultaneously. Figure 9 indicates that the training was stopped at epoch 500 when the accuracy was high and the loss function increased.

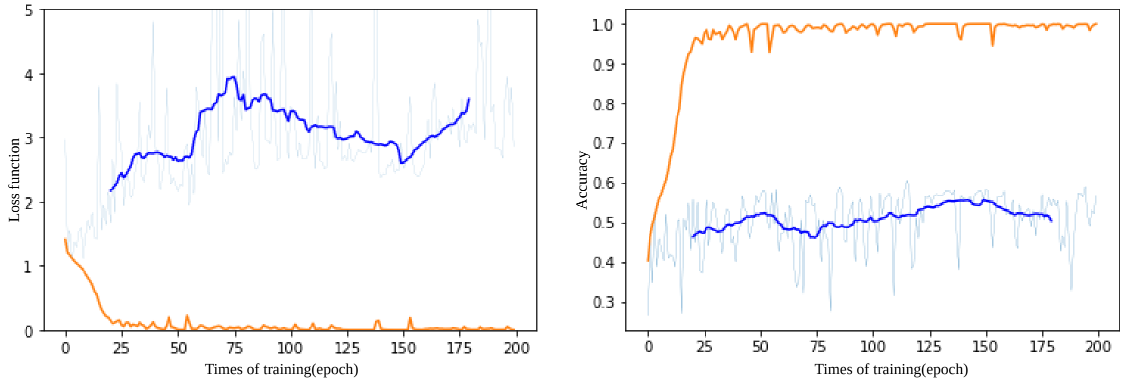

Figure 9. Left: loss function and right: accuracy. Orange line: transition of training data and blue line: transition of validation data (moving filter)

6.3 Classification Result

		True label					
		No damage	Damage (-25%)	Damage (25-50%)	Damage (50-75%)	Damage (75-%)	
Estimated label	No damage	181	15	9	4	0	
	Damage(-25%)	42	29	19	6	6	
	Damage(25-50%)	8	5	5	5	5	
	Damage(50-75%)	6	1	3	3	1	
	Damage(75%-)	5	2	4	4	4	Average Recall
	Recall	0.7479	0.5577	0.1250	0.1364	0.2500	0.3634

Table 3. Confusion matrix of classification of damage degree

Table 3 presents the confusion matrix of the estimation results of the test data. The recall of image data with damage, particularly for damage (25–50 %), damage (50–75 %), and damage (75 %), was lower than image data without damage. Additionally, degree of damage of image data with large damage, such as damage (25–50 %), damage (50–75 %), and damage (75%) were underestimated.

In these underestimated image data, there were many roof surfaces that reflected little damage in the image, but collapsed overall or reflected only the damaged part. These examples suggest that the data were judged not only from the roof surface of the target but also from other roof surfaces when the label of the damage degree of the test data was fed as input. Therefore, the model underestimated the degree of damage because it was trained and estimated based only on information from the roof surface of the target. Additionally, using aerial photos with low resolution as inputs to the label of the degree of damage probably resulted in the mixing of individual subjects in the judgment criterion. This implies that the difference in judgment criteria between the staff of the local government inputting labels of test data and training data caused low recall of image data with large damage.

7. CALCULATION OF DAMAGE RATE

7.1 Calculation Method of Estimated Damage Rate

In this study, the value of the degree of damage was assigned to each class classified in Section 5. The values of no damage was set to 0, damage (-25 %) to 0.125, damage (25–50 %) to 0.375, damage (50–75 %) to 0.625, and damage (75 %) to 0.875 as degree of damage. Then, the model multiplied these degrees of damage by the area rate and summed the values of every roof surface to calculate the damage rate of the roof. The area rate of the roof surface was calculated by dividing the number of pixels of each roof surface by the number of pixels of the entire roof.

7.2 Comparison of Correct Damage Rate and Estimated Damage Rate

The model estimated the damage rate of 30 images of the roof with damage and 30 images without damage to the test data using the above calculation method based on the degree of damage of each roof surface estimated in Section 5. The coefficient of determination between the correct and estimated damage rates was 0.3445. The coefficient of correlation was 0.6486, the average error was -5.401, and the average absolute value error was 11.07. Figure 10 shows a scatter diagram of the correct and estimated damage rates. The average error of the images of the roof with damage was -13.44 and that of the images without damage was 2.461.

For images of the damaged roof, the average error indicated that the model underestimated the damage rate. This was owing to an underestimation of the classification of the degree of

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damage in Section 6. Similarly, for the images of the roof without damage, the average error indicated that the model estimated multiple data as little damage and only 12 of 30 images as no damage. This is because, the model incorrectly calculates the damage as a whole if the classification model estimates even one roof surface without damage as damage. Therefore, the model must increase the recall of no damage in the classification of the degree of damage.

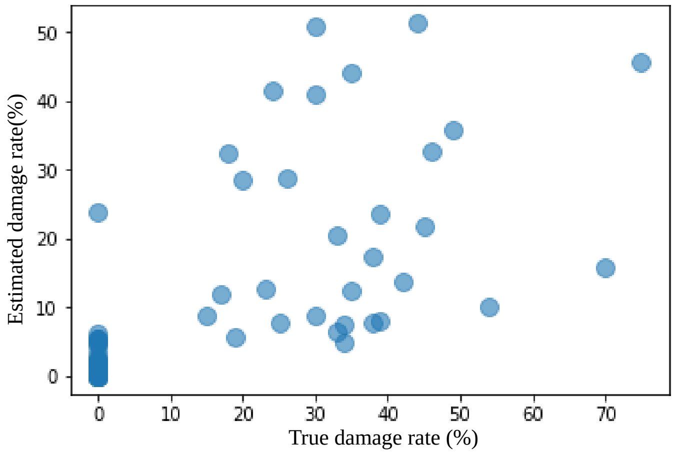

Figure 10. Scatter diagram of correct damage rate and estimated damage rate

8. EVALUATION OF SYSTEM EFFECTIVENESS

8.1 Result of Evaluation

Table 4. Question and answer to each roof data

Answer choices	It can.	It cannot.	total
By using aerial photos, can this system present the part which cannot be seen from outside?	60(100%)	0(0%)	60

Answer choices	It can advise perfectly and improve efficiency.	It can advise partially and improve efficiency.	It can estimate no damage roof to be "No damage" class.	It has too much mistaken advice and cannot improve efficiency.	total
To improve efficiency in the investigation, can this system advise to investigate the part with high probability of damage?	16(26.67%)	32(53.33%)	12(20.00%)	0(0%)	60

Answer choices	It is as accurate as investigator judging from aerial photos and the ground.	It is more accurate than investigator judging from the ground.	It is as accurate as investigator judging from the ground.	It is more inaccurate than investigator judging from the ground.	total
How accurate is it?	15(25.00%)	3(5.000%)	30(50.00%)	12(20.00%)	60

To evaluate the effectiveness of the three usages (Table 1) of the proposed system in building damage investigation, we framed three questions for the staff of the Department of Crisis Management of Shimanto-town as shown in Table 4 for each of the 60 images of the roof surface estimated by the proposed system and obtained the relevant answers. The answers were based on the images of the roof shown in Figure 11, correct damage rate, and estimated damage rate. The image on the left of Figure 11 shows the image of the roof with a width of 3 m from the trimming roof image, and the right image shows the trimming image of the roof, which visualizes the estimated degree of damage of each roof surface.

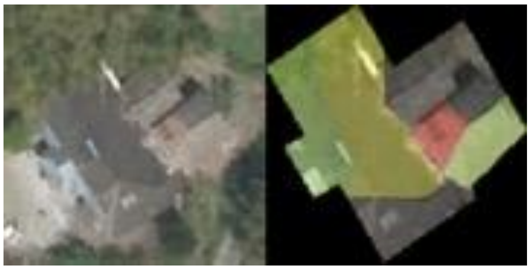

Figure 11. Roof data used for framing questions

The first question is "by using aerial photos, can this system present the portion that cannot be seen from outside?" The answer was "It can." with 100 %. Therefore, this system can present information about the part of the roof that cannot be seen from outside by using aerial photos, which is the first usage of the system. This indicates that the proposed system can improve the efficiency and accuracy of investigations. The second question is "to improve the efficiency of investigation, can this system advise to investigate the part with high probability of damage?". The answer was "the system provides incorrect advice and cannot improve efficiency" with 0 %. There were 18 roof data points without damage that the system estimated as a damage of a few percent by mistake. However, the answers of all of these 18 roof data were not "It has too much mistaken advice and cannot improve efficiency." but "it can advise partially and improve efficiency". According to the respondent, the system presented information about the roof surface without damage and could improve the efficiency of the investigation. Therefore, this system can present information about roof parts with a high probability of damage and advise investigation to investigators, which is the second usage of the system. This indicates that the proposed system can improve the investigation efficiency. In the evaluation of this model, it is desirable to quantitatively compare its accuracy with the accuracy of the investigation by an investigator who looks at the roof from the ground or from the ground and aerial photos. However, it is difficult to obtain these data. Thus, the staff were advised to classify the estimated accuracy of each roof data into four classes, such as "equal to investigators who look at the roof from ground and aerial photos," "(lower than the above and) higher than the investigator who looks at the roof from ground," "(lower than the above and) equal to the investigator who looks at the roof from ground," and "lower than the investigator who looks at the roof from ground" to qualitatively evaluate the accuracy. This indicates that the proposed model can calculate the damage rate of 30 % of roof data more accurately than the investigators who look from the ground, which is a conventional judgment method, and that of 80 % of roof data is the same accurately or more than the investigators who look from the ground.

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We asked additional questions about the overall system. First, "can this system show basis for judgment of calculation result by obtaining estimation of degree of damage of each roof surface?" The answer was "It can." Therefore, this indicates that the proposed system can interpret the estimation using a deep learning model, which is a black box model, by calculating and visualizing the degree of damage to each roof surface. Next, "under which conditions can you use the estimated damage rate as the investigation result directly?" The answer was, "We cannot use the estimation directly if the roof is damaged because we need to understand the feelings of the victim. Hence, the presence of damage must be verified manually." Another answer was that "investigating the roof in the field is necessary because it is difficult to judge damage from the data used by the system" and "estimated damage rate is useful for reference data." Therefore, these results indicate that the calculated damage rate of the roof cannot be used for building damage investigation directly without a human check; however, the damage rate estimated by using the proposed system is useful for reference data.

8.2 Usage Flow of Our Proposed System

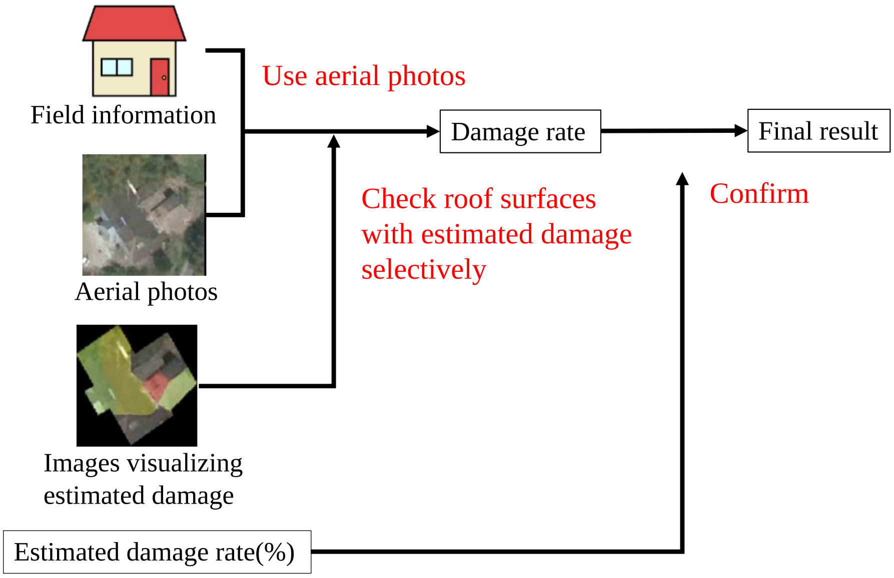

Figure 12. Usage flow of the system in the investigation field

Considering the results presented in the previous subsection, the usage flow, shown in Figure 12, incorporating the three usages mentioned in Table 1, can be considered. First, focusing on the roof parts with a high probability of having a high value of image visualizing the estimation of the system, the information from the field and aerial photos were investigated. Then, with reference to the damage rate estimated by the system, the calculated degree of damage was compared and confirmed to determine the final degree of damage. This indicates that the investigation can be more rapid and accurate in the red regions of Figure 12, using both the second and third usages as reference data.

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8.3 Map of Damage Estimation

Figure 13. Left: map of building damage (Miura *et al.* 2020) and right: map of damage estimated by this system

We estimated the damage rate of the image of the roof of 3,513 buildings around the government office of Mashiki town in Kumamoto prefecture using the proposed system and plotted it on the map, as shown on the right side of Figure 13. Let d be the degree of damage estimated using this system. The value of d≤10 % is set to light blue, 10 %<d≤20 % to yellow-green, 20 %<d≤30 % to yellow, 30 %<d≤40 % to orange, and 40 %<d≤50 % to red. The larger the damage rate, the larger the point size set on the map. The left side of Figure 13 shows the actual damage map (Miura *et al.* 2020), and the data in the area surrounded by the dotted line reflect the results of the on-the-spot investigation by the Architectural Institute of Japan. These maps were compared to identify common areas, such as areas where the damage was concentrated. Because this study focused on roof damage and Miura *et al.* (2020) focused on whole building damage, an accurate comparison of the accuracy is not possible. However, according to Figure 13, rough spatial distributions between these maps are similar.

We believe that this map is effective in grasping the necessary resources, such as manpower for investigation or deciding the method of investigation. This indicates that the map is effective in grasping the overall damage in the entire area, as well as on the roof. Additionally, it is likely that this map is useful not only for building damage investigation but also for decision-making regarding the first response after a disaster or deciding the rehabilitation plan.

9. CONCLUSIONS AND FUTURE RESEARCH

In this study, we developed a system to automatically calculate the damage rate of a roof and suggested its usage to improve the speed and accuracy of building damage investigations.

A drawback of our previous study was that the aerial photos captured were insufficient as training data for the estimation of damage using deep learning from aerial photos (Fujita and Hatayama 2021). Therefore, this study divided the roof images into roof surfaces and increased the amount of training data. We developed an automatic method to calculate the damage rate of a roof from four processes: a trimming algorithm to automatically create roof images, dividing the roof surface by instance segmentation using the deep learning model, classification of the degree of damage by the image classification model of deep learning, and calculation of the damage rate from the degree of damage and area rate.

The effectiveness of this system was evaluated based on its capability to present information of the parts that could not be seen by the investigators using aerial photos, which is the first usage, and highlight parts with a high probability of damage to the investigators, which is the second usage. Moreover, this model could calculate the damage rate of 30 % of roof data more accurately than judgment from ground and that of 80 % of roof data with the same accuracy or more than judgment from ground. We then suggested the usage flow of this system in building damage investigation based on the answers provided by the staff to the questions framed by us. Additionally, we observed that the map shown on the right side of Figure 13 for plotting the estimation result of this system was effective for estimating the overall damage. This indicates that the proposed system is effective for both the estimation of local damage, representing the damage rate of one roof, and overall damage, representing damage to the entire area.

In the future, a more accurate system can be developed based on the following improvements:

- Information around the target roof surface is added to the input value of the model to classify the degree of damage.
- Increase the recall of roof data without damage in the classification of the degree of damage.
- Generate more general training data based on the label inputs of several individuals.
- Address roof data with a gap in the building polygon and low resolution.

In addition, the use of image data of roofs damaged by typhoons may be effective as training data. There may be common features, such as dropped tile roofs, between earthquakes and typhoons. However, the presence of different features may decrease the accuracy of deep learning models. Therefore, a fine-tuned model that uses earthquake image data after training with typhoon image data may be effective. This study needs to confirm the increase in accuracy by performing fine-tuning. In addition to image information, information such as earthquake acceleration, building type, and the raw material of the roof may be effective. Because neural networks can be trained using this information as input data, this study needs to consider the development of a multimodal model.

Moreover, we found that the estimation results of this system cannot be used directly in the field of building damage investigations. This indicates that it is difficult to use a deep learning model for decision making because it lacks reliability and explainability. This is a limitation specific to deep learning or machine learning systems during disasters as well as a lack of training data. In the future, we aim to design a usage to improve the reliability and explainability of the model and ensure responsibility by combining the efforts of the systems and humans.

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