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Thematic and Country-Specific Characteristics of Research on the Great East Japan Earthquake: An Analysis Using Data Science Methods

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Abstract

The Great East Japan Earthquake of 2011 had profound impacts in various ways because it was a complex disaster. In addition to the earthquake itself, the tsunami and nuclear accident were even more severe for human lives, health, economy, and the environment. Researchers around the world responded to the disaster. The study topics spanned from natural sciences to social sciences. In this study, we analyzed over 20,000 academic records concerning the Great East Japan Earthquake from a data science perspective. As a result of text mining, the characteristics of many research fields were elucidated. By collecting the studies in terms of country and research subject, we found characteristics of countries that conducted studies on the disaster. We found that countries in the same Asian region as Japan and countries prone to frequent earthquakes and tsunamis have a high research interest. With the possibility of such a catastrophe in the future in mind, we should prepare ourselves by learning from previous studies to take better countermeasures next time.

Keywords

Great East Japan Earthquake, Data Science, Text Mining, Academic Study, National Policy

1. Introduction

The Great East Japan Earthquake (GEJE) that struck the Tohoku region of Japan on March 11, 2011, was one of the most significant natural disasters of the 21st

century. The magnitude of the earthquake itself was so great that even western Japan, more than 1000 km from the epicenter, felt the tremors clearly. Many buildings collapsed due to the tremors, and many people were killed or injured. The death toll from the tsunami and earthquake was 15,900, with 2523 people missing (as of March 1, 2022). Moreover, 3784 people were certified as earthquake-related deaths due to aggravation of chronic illnesses or suicide during the prolonged evacuation. In major cities such as Sendai, lifelines such as electricity and water supply were interrupted for an extended period, and it took several months for railroads and highways to be fully restored. However, even more devastating than the quake's tremors was the massive tsunami it triggered. Approximately 120,000 buildings were destroyed by the tsunami, whereas 10,000 buildings collapsed due to the earthquake tremors.

To make matters worse, the tsunami caused critical damage to the Fukushima Daiichi Nuclear Power Plant, triggering the nuclear reactor meltdown. The radiation leakage forced ca. 470,000 people to evacuate. In particular, the radiation disaster led to the abandonment of cities and farmlands near the nuclear power plant for many years, sometimes over a decade, restricting people's access to them. Furthermore, the earthquake and tsunami affected not only people's lives but also natural ecosystems. Thus, GEJE was characterized by the combined and widespread effects of the earthquake, tsunami, and nuclear accident.

Researchers from Japan, the country involved in the disaster, and from all over the world have paid attention to this disaster, and a great deal of research has been conducted. Studies were conducted from a wide range of perspectives, such as the impact of the earthquake on the local economy (Carvalho et al., 2021) and the impact on the local natural ecosystem (Horiguchi et al., 2016). The impact of the radiation disaster on the mental health of the victims (Oe et al., 2021; Maeda & Oe, 2017) and the health effects of the impact of the complex disaster (Ripoll Gallardo et al., 2018). There is also a study analyzing the tsunami's impact with special sensors onboard satellites (Sato et al., 2012) and a mathematical model of the movement of evacuees during an impending tsunami (Troncoso Parady & Hato, 2016). There is also a review on the dynamics and effects of radioactivity released into coastal waters due to the accident at the Fukushima Daiichi Nuclear Power Plant (Buesseler et al., 2017). Positive effects of exercises such as yoga on victims' mental health were also reported (Murakami et al., 2022). As can be seen, the topics were diverse, and many results were brought to light. At the same time, however, no study has been conducted to date to summarize the overall picture of the academic community's interest in GEJE. GEJE is unique regarding the disaster's scale, severity, and diversity. More than 10 years after the occurrence of the disaster, it is hoped that a comprehensive picture of the research will be compiled.

Previous studies showed how researchers worldwide have reacted to natural disasters. For example, one study monitored Armenia's long-term health and livelihoods after the country experienced a major earthquake in 1988 (Demirchyan et al., 2013). A study has systematically reviewed the literature to analyze the role

of big data in natural disasters (Yu et al., 2018). Another article provides an overview of the various processes of post-earthquake data collection (Fan et al., 2019) and analysis for the Chilean earthquake that occurred off the coast of Mauri in February 2010, the year before GEJE (de la Llera et al., 2017).

Thus, researchers worldwide have studied and reviewed disasters in their own and other countries to learn lessons and develop future countermeasures. However, exhaustive and objective reviews have been challenging to conduct regarding research review methods. Lafortune et al. (2021) provided a meta-analytic review of the effects of natural disasters. However, their interest did not cover the whole picture of the effects of disasters but was limited to prenatal maternal stress. Carrington et al. (2021) also conducted a literature review, but their study was restricted to emergency department resources. Mawardi et al. (2021) reported the importance of primary health care in disasters. However, their study did not provide the relative importance of primary health care against other aspects of disaster response and recovery. These studies show that a review study that spans various academic fields was not yet carried out.

The difficulty of the comprehensive review is especially pronounced for research on GEJE, where many issues were involved, and the conventional method was considered difficult to apply. It was especially difficult for researchers, who had to rely on subjectivity and experience, to objectively evaluate and compare research in multiple fields, including natural sciences, humanities and social sciences, medical and pharmaceutical sciences, environmental sciences, and applied engineering.

Therefore, in this study, we analyze a wide variety of studies on the Great East Japan Earthquake (GEJE studies) from around the world from the perspective of data science, such as text mining. Using the concept of data science, where computer-based analyses are conducted, it may be possible to perform an objective review of complex subjects. We expect to discover intriguing facts that the researchers did not previously assume. In this study, 1) we will conduct data collection and scraping from a database of research articles to examine the diversity of research fields handled by research articles on GEJE and the particularly active research fields. 2) We will then examine the temporal trends in the number of studies by country and research field during more than 10 years that have passed since the occurrence of the disaster. 3) Next, we will investigate what countries are interested in what kind of research and which countries showed particularly strong interest in research on GEJE. This way, we will compare various research topics equally and objectively and clarify the academic community's reaction to GEJE.

2. Methods

In this study, we used Clarivate's Web of Science (WoS) research article search service to obtain GEJE studies exhaustively. The search term was "Japan and (earthquake or tsunami) and 2011-2022." Since GEJE occurred in March 2011, this search term was intended to cover all GEJE studies. The term "Great East

Japan Earthquake" has other names, including "Great East Japan Earthquake," "Tohoku Earthquake and Tsunami," "Tohokuoki Earthquake," and "Tohoku Kanto Great Earthquake disaster." Therefore, the search term was set to include these names. As a result, 21,259 studies were found. However, it should be noted that the search results may include research that is not directly related to GEJE. Because there were many earthquake and tsunami events in Japan, a hot spot of these disasters, some research results found with the search term may deal with other disaster events.

The search results were downloaded in Microsoft Excel format, and the data were processed using the statistical software R 4.2.0 (R Core Team, 2022). To assess the country where the study was conducted, we extracted the name of the country where the first author's address existed. The year in which the study was published was also extracted.

Text mining was used to explore trends in the academic fields of GEJE studies. For text mining, the R package tm (Feinerer & Hornik, 2020) was used: words were converted to lower case, and punctuation and numbers were removed for the "Article title" of the GEJE studies. English common stopwords were removed. Stopwords are words such as prepositions like "at" and "of," articles like "a," "an," and "the," and pronouns like "I," "he," and "she" that is widely used in general and are not considered to have a direct effect on the meaning of the sentence. The tm library contains such built-in stopwords. In addition, stopwords specific to GEJE studies have been added. Words such as "study," "effect," "observe," "analysis," "data," and "method" were excluded because they frequently occur in research regardless of the field. In addition, words such as "disaster," "earthquake," "great," "east," "Japan," "Tohoku," "seismic," and "Fukushima," which are closely related to this study, were also excluded. The word "tsunami" was not excluded because its frequency of occurrence varied greatly among research fields, as described below, and it characterized each research field.

WoS Categories are category names assigned by the Web of Science. Many categories have been set, encompassing research topics from the natural sciences to the humanities and social sciences. In this study, we applied text processing in R to aggregate the categories into 20 major categories by taking the first word of each category and grouping them according to that word. Text mining was then performed for each of the 20 major categories to capture the characteristics of the studies in each category. In this study, the name of each category is used with additions and modifications to make it easier to read, such as "Area" as "Area Studies" and "Green" as "Green & Sustainable."

GEJE studies were aggregated by country, category, and year to determine whether there was a change over time. The temporal change was visualized for the top 10 countries and the top 10 categories. By ranking the relative abundance in the research category per country, we estimated what each country showed particular interest in.

A matrix was created for the top 20 countries and top 20 categories, and the number of GEJE studies was compiled. In addition, the relative percentages of

the top 20 categories for all countries combined were calculated and compared to the percentages for each country to visualize what type of research each country is particularly interested in.

In addition, by obtaining R & D expenditure data for each country from the OECD (2022) and the World Bank (2022) and calculating the number of GEJE studies per billion dollars of R & D expenditure, we estimate the extent to which each country is interested in GEJE. We found that some countries, even those with relatively small research budgets, are uniquely active in academic research on GEJE. If OECD data for R & D expenditures were available, we prioritized them; if not, we obtained the data from the World Bank. In each case, we obtained the latest data as of September 2022.

3. Results

Using the WoS article search service, a search was performed using the search terms "Japan and (earthquake or tsunami) and 2011-2022" (run on September 5, 2022). Using the WoS Categories assigned to each GEJE study, the top 20 most frequently occurring categories were selected. For each category, the top 10 most frequently occurring words were indicated by text mining on the titles of the academic results (Table 1). GEJE studies spanned various research fields. The research was conducted in the natural sciences, humanities and social sciences, medical sciences, applied engineering, and environmental sciences. In addition to the fact that earthquakes and tsunamis are important research subjects as natural phenomena, it is also crucial to study their effects on humans and society. In particular, the nuclear power plant accident and the resulting radiation disaster caused health hazards, impacts on the natural environment, socioeconomic disruption and losses caused by the loss of human habitation, and psychological effects of losing one's hometown due to long-term evacuation. Thus, GEJE raised issues that should be the subject of many research fields. In the clinical neurology category, we found that issues related to the mental health of disaster victims, such as sleep and stress, were addressed. Interdisciplinary research was also seen. Thus, trend analysis by text mining was particularly effective in highlighting the characteristics of each category rather than examining category names alone.

Based on the text mining results, we found that there were very many studies on tsunamis. Both in the natural sciences and the humanities and social sciences, the phenomenon of the tsunami itself and the wide variety of effects it caused was an important research topic. On the other hand, some categories in which tsunamis did not appear in the top 10. This will be discussed in a later section.

Next, temporal changes in GEJE studies by research category and country were analyzed. GEJE occurred in 2011, and there have been 12 years in 2022. The changes in the number of studies during this period were visualized by research category and country (Figure 1). The results show that Engineering, Geosciences, and Geochemistry & Geophysics research were always the top 3 research categories (Figure 1(a)); Environmental Studies, Computer Science, Multidis-

ciplinary, Construction, Astronomy, Geography, and Public Health formed the next group. These rankings did not show much variation over time.

Table 1. The result of text mining of studies related to the great east Japan earthquake by research category. Top 10 words in the article titles are presented.

| Categories	Academic Fields	Rank									
		1	2	3	4	5	6	7	8	9	10
Area Studies	Human and Social Sciences	tsunami	nuclear	reconstruct	econom	tokyo	lesson	region	post	nation	cultur
Astronomy	Natural Sciences	search	measur	decay	icecub	neutrino	ionospher	wave	bell	telescop	array
Chemistry	Natural Sciences	evalu	nuclear	power	system	isotop	monitor	structur	accid	tsunami	plant
Clinical Neurology	Medical Sciences	tsunami	health	psycholog	sleep	patient	mental	survivor	area	year	stress
Computer	Applied Sciences and Technology	system	network	simul	base	model	tsunami	evacu	inform	detect	emerg
Construction	Applied Sciences and Technology	structur	build	steel	concret	bridg	respons	perform	frame	ground	system
Ecology	Environmental Sciences	tsunami	impact	communiti	caus	popul	pacif	coast	intertid	bay	coastal
Economics	Human and Social Sciences	natur	impact	evid	risk	nuclear	econom	power	case	tsunami	energi
Engineering	Applied Sciences and Technology	tsunami	model	structur	system	build	respons	damag	base	ground	evalu
Environmental	Environmental Sciences	tsunami	nuclear	accid	risk	case	model	assess	power	landslid	health
Geochem. & Geophys.	Natural Sciences	tsunami	fault	model	subduct	zone	sourc	slip	structur	wave	estim
Geography	Human and Social Sciences	tsunami	coast	deposit	central	area	pacif	coastal	landslid	fault	sediment
Geology	Natural Sciences	tsunami	deposit	fault	tohokuoki	subduct	zone	sendai	coastal	sedimentari	sediment
Geosciences	Natural Sciences	tsunami	fault	model	volcano	zone	structur	slip	estim	system	subduct
Green & Sustainable	Environmental Sciences	case	sustain	tsunami	urban	energi	resili	region	hous	develop	nuclear
Medicine	Medical Sciences	health	tsunami	nuclear	medic	associ	accid	survey	manag	follow	longterm
Multidisciplinary	-	tsunami	slip	nuclear	fault	tohokuoki	zone	chang	subduct	activ	slow
Nuclear Science	Applied Sciences and Technology	nuclear	power	accid	daiichi	plant	reactor	unit	system	station	model
Other Studies	-	tsunami	impact	nuclear	japanes	system	respons	health	model	area	follow
Physics	Natural Sciences	decay	search	model	time	measur	icecub	neutrino	jparc	bell	statist
Public Health	Natural Sciences	health	tsunami	nuclear	follow	social	survey	impact	year	plant	associ
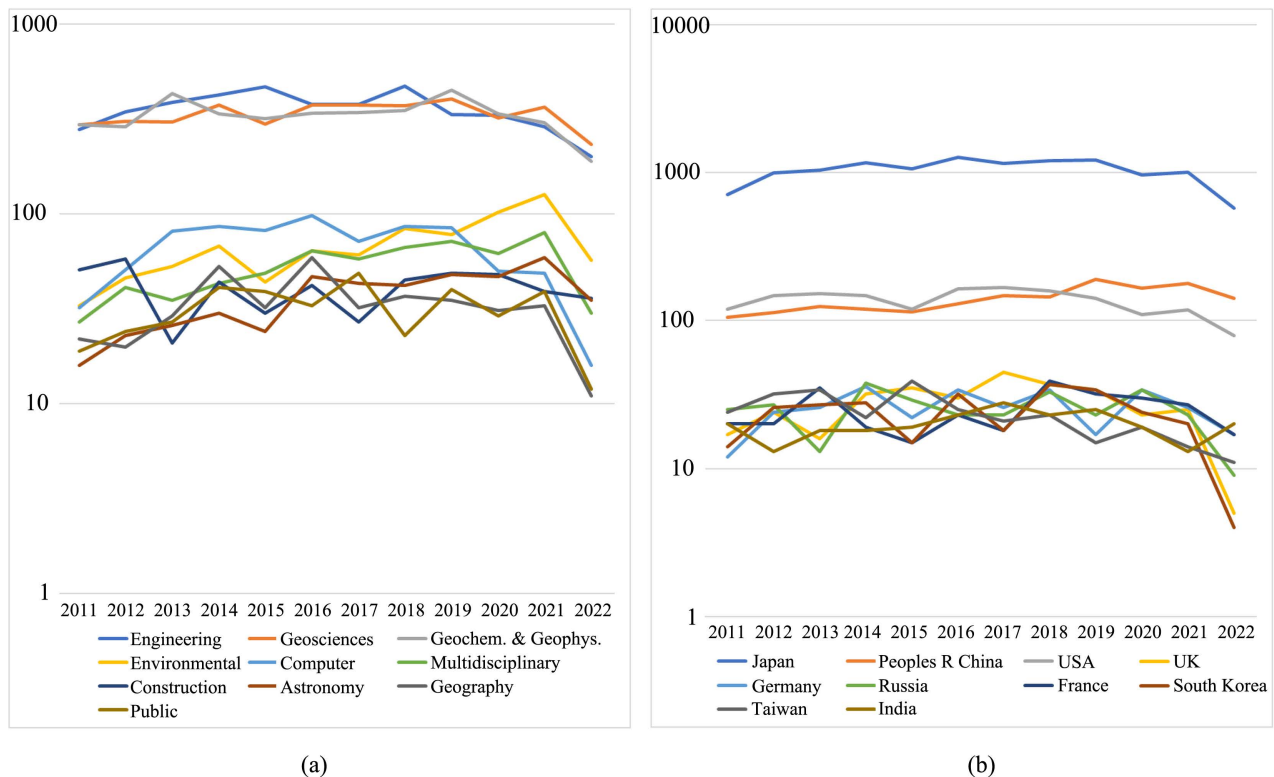
Figure 1. (a) The time series of research numbers in top 10 research topics concerning the great east Japan earthquake; (b) The time series of research numbers in top 10 countries that conducted studies concerning the great east Japan earthquake.

We visualized the change in the number of studies per country over time (Figure 1(b)). As a result, the number of studies from Japan, the country involved in GEJE, constantly occupied the top position. Next, China and the U.S. were the second and third largest countries. The following groups were the UK, Germany, Russia, France, South Korea, Taiwan, and India. The absolute number of studies from these countries did not fluctuate significantly, and there was no significant change in their rankings.

The number of GEJE studies was then organized on a matrix consisting of the top 20 countries and the top 20 research categories (Figure 2). In addition, we calculated the fraction of research categories for the global average and visualized the degree of deviation from that ratio for each country. For example, the number of engineering studies in Indonesia (70) accounts for 29% of this country's total number of studies (241). The number is marked in orange in Figure 2 because the fraction was significantly higher than the global average of engineering (20%). On the other hand, the number of engineering studies in Spain (9) accounts for 5% of the country's GEJE studies, well below the global average of 20%, and is marked in dark blue. Thus, this figure infers the characteristics of the research categories in each country.

For example, the percentage of clinical neurology is very high in Japan, indicating that Japanese researchers were highly interested in the mental health of disaster victims as the country was deeply affected by the disaster. In South Korea,
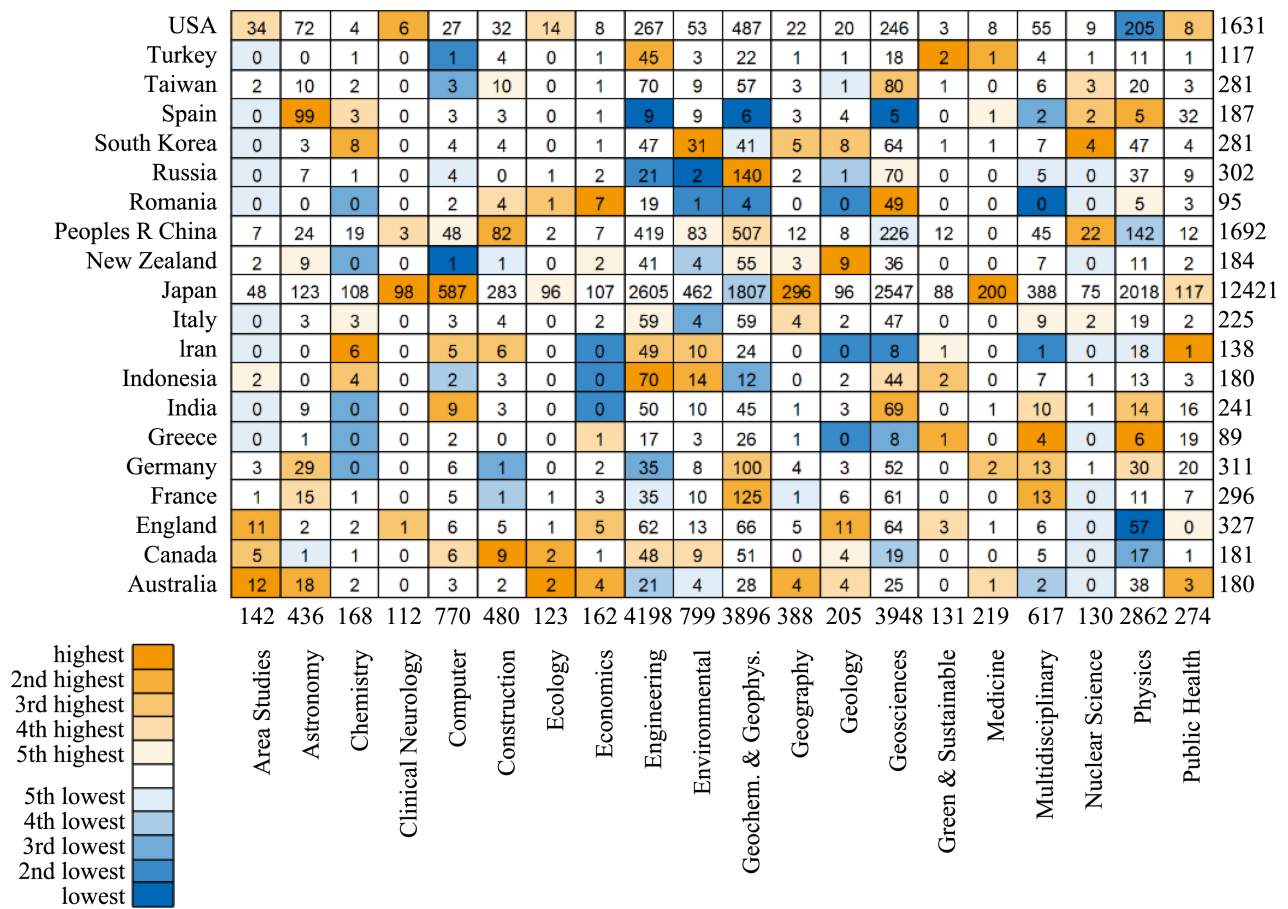
Figure 2. The number of studies concerning the Great East Japan Earthquake in the matrix of top 20 countries and research topics. The color shows the relative strength or weakness of research topics for each country.

due to the worry about the contamination of radioactive substances, the distrust of Japanese products remained strong, as the Korean public and media reacted strongly to the radiation disaster after the nuclear accident. Japan lost a reversal of a lawsuit filed with the World Trade Organization over a ban on seafood imports by Korea after the nuclear accident (Yomiuri, 2019). In Korea, it should be noted that this is manifested not only in public opinion but also in the number of studies in environmental and nuclear sciences. It can also be seen that India is strong in Science and low in Humanities. Furthermore, English-speaking countries (USA, UK, Canada, and Australia) had a higher percentage of area studies and more research from a humanities perspective.

In addition, we obtained the total budget spent on research and developments (R & D) by each country from OECD (2022) and World Bank (2022) and calculated the number of GEJE studies per million US dollars of R & D budget (Table 2). As a result, an inclination emerged among countries with a large number of GEJE studies per unit budget.

First, it was found that many of the countries are in Asia. Countries that are historically, geographically, and geopolitically related to Japan tend to have an exceptionally high level of academic interest in GEJE. In addition, countries that

Table 2. The number of studies related to the great east Japan earthquake per 1 million USD R & D expenditure.

Rank	Country	Number of GEJE Studies per R & D Expenditure (1 M USD)	Asia	Vulnerable
1	Mongolia	0.204	✓	
2	Nepal	0.184	✓	✓
3	Sri Lanka	0.091	✓	✓
4	Myanmar	0.082	✓	✓
5	Japan	0.074	✓	✓
6	Georgia	0.071	✓	✓
7	Iran	0.068	✓	✓
8	Bermuda	0.061		✓
9	Indonesia	0.054	✓	
10	Peru	0.053		✓
11	Pakistan	0.049	✓	
12	Chile	0.043		✓
13	Romania	0.040		
14	Cambodia	0.031	✓	
15	Azerbaijan	0.025	✓	✓
16	Iraq	0.024	✓	
17	Philippines	0.023	✓	✓
18	Greece	0.022		
19	Costa Rica	0.021		✓
20	Cote D'ivoire	0.020		✓

are vulnerable to natural disasters such as earthquakes and tsunamis tend to be of high interest. Specifically, countries located in the Pacific Rim orogenic belt and the Alpine-Himalayan orogenic belt were more likely to be interested. Alternatively, island nations and regions facing the open ocean (e.g., Bermuda, Sri Lanka) were included in the ranks. Meaningfully, Latin American countries (Peru, Chile, and Costa Rica) are on the opposite side of the Pacific Ocean, far from Japan, but have periodically suffered from tsunami damage and showed strong interest in GEJE studies. Thus, the relative importance of GEJE studies may be affected by the relationship with the affected country and the probability of the occurrence of similar natural disasters.

Regarding the number, China and the US have many GEJE studies, but these countries are not strongly focused on GEJE studies because their numbers of GEJE studies per unit budget are not particularly high. There have been many GEJE studies in Japan since it has been directly involved and suffered from the

disaster. However, meaningfully, there are countries with relatively more GEJE studies than Japan.

In summary, we successfully obtained a list of academic studies related to GEJE from a widely used database. These academic studies spanned a wide variety of research fields, including physical, medical, and social sciences. Researchers in many countries published their studies. This study analyzed the characteristics of research categories and nationalities of GEJE studies. We believe this analysis is valuable because GEJE has had a profound and unprecedented impact, including nuclear disaster.

4. Discussion

In this study, we obtained data on more than 20,000 GEJE studies from the research article database and 1) examined their diversity and the research categories in which they are particularly active. 2) We examined whether there is a trend in the number of studies by country and by research category in the more than 10 years since GEJE. 3) We looked into what kind of countries are interested in what kind of research, which countries showed substantial interest in research on GEJE, and why. This way, we could compare the various research topics equally and objectively and clarify the academic community's reaction to GEJE. Data science methods effectively and objectively evaluate such a large volume of research across multiple fields. The analysis can be done more efficiently than by organizing a group of experts who can understand all these.

Compared to past disasters such as earthquakes, tsunamis, and volcanic eruptions, GEJE is unique in that a natural disaster was involved in the human disaster of a nuclear power plant accident and long-term damage, which is also evident in the distribution of research themes. The fact that GEJE was a complex disaster made it possible to see the characteristics of academic circles worldwide, with different emphases on tsunamis, nuclear power plants, medicine, and so on. In particular, we could extract the characteristics of countries that emphasize GEJE studies. We found that countries in the same Asian region as Japan and countries prone to frequent earthquakes and tsunamis have a high research interest.

However, since more than 20,000 research papers were selected mechanically, the degree of relevance to GEJE is unclear. In other words, there is a possibility that articles that hardly dealt with GEJE were inappropriately selected. In future similar text mining studies, a sample survey should be conducted to quantify the probability that studies with little relevance to the subject will be extracted.

In particular, the research category "Astronomy" may manifest the limitations of this study. The text mining results showed that this category frequently contained words such as "neutrino" and "ionosphere," which are considered to have little relevance to GEJE. These studies may have become noise in the analysis. In the future, it may be necessary to manually screen titles to verify the text mining results.

5. Conclusion

This study analyzed a wide variety of GEJE studies from a data science perspective, including text mining. Since the approach from data science was applied, meaningful facts were sometimes discovered that the researcher had not anticipated beforehand. For example, we could estimate the research fields that are particularly important for each country. Since as researchers we cannot individually be familiar with all research fields, it was difficult to assess the relative importance of a wide range of research, including natural sciences, humanities, social sciences, and medical and pharmaceutical sciences. However, the data science methods used in this study were effective in objectively analyzing trends in the academic world without being bound by the researcher's subjectivity. We believe this study contributes to academia because it has shown the methods and results of how we obtained text data automatically and systematically and how the data were treated to find characteristics. Since many of the issues surrounding us, such as the pandemic and global climate change, are interdisciplinary, the methods introduced here can be applied to many research topics in the future.

GEJE was a disaster of unprecedented scale. For that reason, we researchers need to learn many lessons. With the possibility of such a catastrophe in the future in mind, we should prepare ourselves by learning from previous studies to take better countermeasures next time.

Acknowledgements

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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