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Developing Improvements to Multi-Hazard Risk Assessments

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***Abstract*—**This paper outlines the approaches taken to assess multi-hazard assessments. There is currently confusion in assessing multi-hazard impacts, and so this study aims to determine which of the available options are the most useful. The paper uses an international literature search, and analysis of current multi-hazard assessments and a case study to illustrate the effectiveness of the chosen method. Findings from this study will help those wanting to assess multi-hazards to undertake a straightforward approach. The paper is significant as it helps to interpret the various approaches and concludes with the preferred method. Many people in the world live in hazardous environments and are susceptible to disasters. Unfortunately, when a disaster strikes it is often compounded by additional cascading hazards, thus people would confront more than one hazard simultaneously. Hazards include natural hazards (earthquakes, floods, etc.) or cascading human-made hazards (for example, Natural Hazard Triggering Technological disasters (Natech) such as fire, explosion, toxic release). Multi-hazards have a more destructive impact on urban areas than one hazard alone. In addition, climate change is creating links between different disasters such as causing landslide dams and debris flows leading to more destructive incidents. Much of the prevailing literature deals with only one hazard at a time. However, recently sophisticated multi-hazard assessments have started to appear. Given that multi-hazards occur, it is essential to take multi-hazard risk assessment under consideration. This paper aims to review the multi-hazard assessment methods through articles published to date and categorize the strengths and disadvantages of using these methods in risk assessment. Napier City is selected as a case study to demonstrate the necessity of using multi-hazard risk assessments. In order to assess multi-hazard risk assessments, first, the current multi-hazard risk assessment methods were described. Next, the drawbacks of these multi-hazard risk assessments were outlined. Finally, the improvements to current multi-hazard risk assessments to date were summarised. Generally, the main problem of multi-hazard risk assessment is to make a valid assumption of risk from the interactions of different hazards. Currently, risk assessment studies have started to assess multi-hazard situations, but drawbacks such as uncertainty and lack of data show the necessity for more precise risk assessment. It should be noted that ignoring or partial considering multi-hazards in risk assessment will lead to an overestimate or overlook in resilient and recovery action managements.

***Keywords*—**Cascading hazards, multi-hazard, risk assessment, risk reduction.

I. Introduction

PEOPLE all over the world have suffered from natural hazards. Recently, climate change and human made hazards have added severity and caused more disruptive events. While many people have faced with one hazards, more than 100 million people (2.6% of the total world population) are exposed to three or more hazards simultaneously [1]. In 2008, a 7.9 magnitude earthquake occurred in Beichuan city, China. Even though this earthquake affected 100% of the built area and caused fatalities, 60% of the city also faced three cascading hazards, which were, landslide, dam-breaching flood, and debris flood, respectively. Although there were engineering efforts to reduce the casualties, unfortunately, a quarter of the casualties resulted from these cascading hazards triggered by the main earthquake [2]. Studying 25 events causing damage and fatalities in New York City, [3] showed that although the main hazard, such as coastal flooding, causes high damages to the community, cascading hazards such as failure of critical infrastructures could arise within the next few days, causing more damages. Cascading hazards have added a catastrophic impact on communities and economies. In addition, human-made hazards, in conjunction with natural hazards are more destructive [4]. Considering multi-hazard in risk management can be a solution for reducing the negative impacts of disasters. Numerous studies have been undertaken to develop a better strategy in risk management [1], [5]. Like any other new method, multi-hazard assessment is not fully mature and an understanding of the strengths and disadvantages of using these methods in risk assessment is required as a first step to reaching maturity.

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II. Methodology

A systematic methodology for reviewing articles has been implemented. Articles from conferences and international journal papers were investigated through science research engines such as Google Scholar, Science Direct, Scopus. The article search was done by using keywords such as multi-hazard, multi-risk, risk assessment, cascading hazards. A total of 69 articles were identified from different sources. During the preliminary review, according to the relevance to this study, the number of articles for a full review was narrowed down to 40 papers. In addition, some government documents, as well as news reports, were used to identify the knowledge gaps for the case study.

First, the current multi-hazard risk assessment methods were described. Next, the drawbacks of these multi-hazard risk assessments were outlined. Finally, the improvements to current multi-hazard risk assessments to date were summarised. Based on the scientific literature review and the study area's characteristics and real hazard data, future research directions were found.

III. Result and Discussion

A. Current Multi-Hazard Risk Assessment Methods

There are two main approaches to assessing multi-hazards. Fig. 1 illustrates these two approaches.

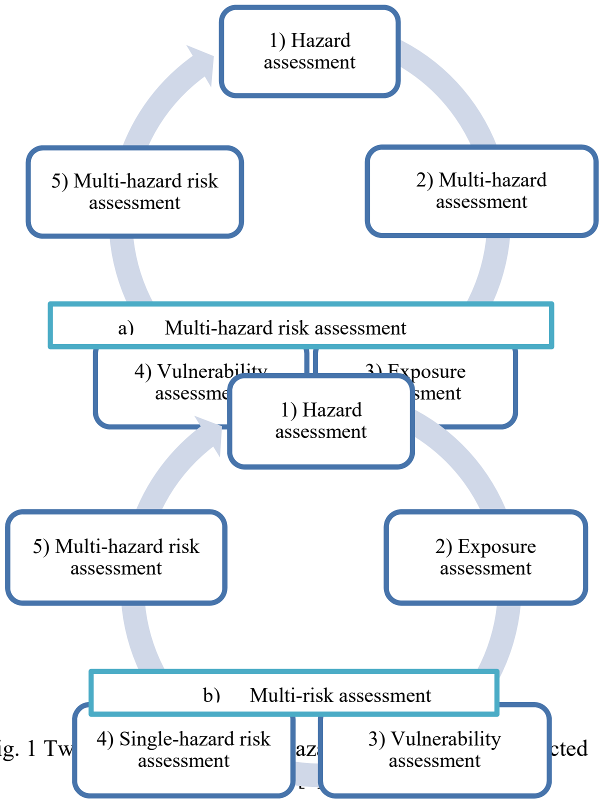

Fig. 1 Tw ... az ... cted

1) Multi-Hazard Risk Assessment

As Fig. 1 (a) shows, for achieving multi-hazard risk assessment, there are five stages. The first stage contains the evaluation of potential hazards. The second stage comes after the aggregation of the potential hazards identified in the previous stage. In this stage, a Multi-Hazard Index (MHI) is developed. This index is used to come up to an exposure assessment of different elements in the system which forms the stage three. At stage four, the vulnerability of each part is assessed. The methodology used in this stage is independent of hazards and the vulnerability is defined according to the MHI. Finally, by combining the last two stages, the multi-hazard risk assessment is achieved in stage five.

Following the five stages developed by [5], studies have been undertaken to extend the methodology of each stage [6], [7]. The following paragraphs describe the development of this approach according to the stage it has improved.

a) Stage 1

To identify the indicators of risk assessment, in 2012, Marzocchi et al. provided a method for assessment of multi-hazards. This approach can consider both simultaneous and cascading hazards. The Bayesian statistic approach was used to combine scenario-based methods and probabilistic-based techniques' to achieve the multi-hazard assessment [8].

b) Stage 2

One outcome for evaluating multi-hazard assessment stage was developing the MHI [9]. Araya-Muñoz et al. [10] utilized a logical fuzzy approach for improving the accuracy of the MHI. This methodology provides more standardized and aggregated indicators for multi-hazard evaluation. Additionally, it estimates the interactions of several indicators, simultaneously influencing the MHI.

c) Stage 3

In further research, in order to produce an exposure map, Rahmati et al. [11] used new intelligent technologies such as machine learning to add more accuracy in the data mining process.

d) Stage 4

One of the most recent researches has provided a new methodology for mapping multi-hazards vulnerability, considering a combination of Multi-Criteria Decision Making (MCDM) and Artificial Neural Network (ANN) methods providing a fuzzy system that can significantly improve the qualitative results [12].

2) Multi-Risk Assessment

Fig. 1 (b) illustrates the steps of the alternative approach which is known as multi-risk assessment. This approach is quite similar to the multi-hazard risk assessment. The first stage is similar to the potential hazards that are identified in this stage. The main difference between these two approaches is in the next three stages, wherein multi-risk assessment, the risks of each hazard is estimated and after that, the compound will be the multi-risk assessment. To achieve this objective, according to the hazard, the exposure (stage two), vulnerability (stage three) and risk (stage four) are assessed. By combining different results in stage four, the multi-risk assessment will be provided in stage five. Recent developments have been made at stage 4 and 5. The following paragraphs describe the development of this approach according to the stage it has improved

a) Stage 4

Skilodimou et al. [13] provided a multi-hazard map with GIS tools. AHP method was used as the methology in stage four (Fig. 1 (b)) to evaluate every factor's weight involving in each particular hazard risk assessment.

b) Stage 5

The accuracy of this approach depends on the last stage, where the risk of each hazard has been assessed based on a standardized unit so that the hazards can be combined or compared precisely [14]. They figured out that according to real historical data when more than one hazard is occurring, the interaction between the hazards will intensify each other so that the weights evaluated will be no longer valid. Therefore, Earthquake was assigned as the principal hazard since the case study has a rich history of earthquakes that caused secondary seismically induced phenomena. Then other hazard's weights were adjusted according to the main hazard. Finally, with a developed AHP evaluation, the importance of factors emerged to become more reliable. Also, by reviewing previous geophysical environment studies that give rise to natural hazards, Liu and Siu [15] classified the relationships of the hazards to four groups: independent, mutex, parallel and series relationships to establish a framework to consider multi-hazards interactions in risk assessment processes in Yangtze River Delta zone, China. To compare these two methods, the principal difference is regarding the dependency of exposure to the hazard. It is known that the latter approach (Fig. 1 (b)) is more complicated [16]. This method considers both hazards and vulnerability. Thus the interactions between hazards can be considered in stage four. Moreover, the analysis methodology varies in these two approaches, wherein the multi-risk assessment the input data can be more detailed and more related to the physical aspects of nature.

B. Drawbacks of Current Multi-Hazard Risk Assessment

1) General Drawbacks

Regardless of the approach used for multi-risk assessment, the efforts of providing a precise multi-hazard risk assessment are not completely achieved. As a holistic view, the main drawback comes from inadequate data from previous hazards which may provide more uncertainty as the assumptions made in stage one (multi-hazard analysis) would be inaccurate. For instance, a recent study provided a multi-hazard exposure map in a regional scale. Although the number of data from 3 hazards including flooding, snow avalanche, and rockfall was 133, 58, 101 respectively, the lack of information was regarding the absence of data before 2010. Therefore the model training process and accuracy evaluation cannot be accurate [11].

To consider the climate change impact in risk assessments, Islam et al. [17] undertook a multi-hazard vulnerability study in a coastal region. He developed a Coastal Vulnerability Index (CVI) to consider the dynamic physical and locational variables of climate change on the terrain. However, it seems that some parameters' effects have not been adjusted correctly since the sea-level rise has shown less contribution to the CVI calculation. Hence improvement in the original methodology is negligible [17]. Moreover, the conventional risk assessment methodologies for human-made earth dams overestimate the risk of landslide dams. Thus, it is essential to find an optimum assessment for such unexpected events [18].

One main problem was regarding considering all possible hazards. Some cascading events occur after hazards such as fire, toxic element release and these hazards are not inherently natural hazards but can be considered as post-hazards or even part of the multi-hazards. The main drawback of assuming these in the risk assessments is the lack of obtaining sufficient data from industries as well as their relationships with other natural hazards. Considering NaTechs amplifies the uncertainty in decision makings; and so NaTechs are mostly neglected in studies [19]. For an all-embracing risk assessment, this uncertainty should be reduced, and this important hazard should be considered.

The drawbacks above are relating to stages of the risk assessment, which are similar in the two approaches. Another main drawback is related to the last stage in the two approaches.

2) Drawbacks in Stage Five of Multi-Risk Assessment

Although the multi-risk assessment (Fig. 1 (b)) can provide a more realistic result, researchers mostly avoid considering them since hazard interactions have caused unexpected destructive events. A New York City project data collection led to misleading results, where evidence shows that other parameters have an impact on the risk of multi-hazard disasters which were disregarded [3]. To achieve a better multi-risk assessment, a comprehensive view of interaction indicators between consequent hazards is necessary [3], [20].

Davoudi et al. [21] pointed out that the outcome of the adaption in the resilience process is not necessarily completed since the outcome of the risk assessment is not with clarity on providing information on the real weight of each hazard. A recent study [23] was undertaken to develop the indicators of a semi-quantitative risk assessment approach previously used by Menoni et al. [22]. Pilone et al. [23] took binary interactions into account in the risk assessment. In this study, three significant factors were used to identify the interactions,: (1) the local characteristics, (2) the historical and recent incidents and (3) the protection measures that were implicated in the area. Although these factors are logical and have produced a meaningful response, the impact of climate change on the interactions of hazards was missing.

3) Drawbacks in Stage Five of Multi-Hazard Risk Assessment

Likewise in multi-hazard risk assessment, researches (Fig. 1 (a)) mostly provide maps of vulnerable areas and leave the hazards in them unlinked [24], [25]. For instance, in New Zealand, Christchurch City, liquefaction has led to flooding but their link was not identified in the vulnerability maps [26]. Nevertheless, the main problem is that previous studies have relied on static vulnerability and are not time-dependent. Furthermore, all the methods require large amounts of historical data, which are often not available. Additionally, tools provided by different organizations are often based on questionnaires and are not based on reasonable future scenarios [27].

Another shortage in the multi-hazard risk assessment area is the lack of having an exhaustive tool. Gallina et al. [16] reviewed the existing tools such as Hazus, Riskscape. These tools are entirely reliable when the aspect is solely to analyze one risk, but when it comes to these days' multi-hazards events these tools should be developed to become more intelligent.

C. Improvements to Current Multi-Hazard Risk Assessment

A number of studies have been done [5], [27], [28] to tackle the drawbacks of risk assessments in different stages. The following paragraphs provide detailed improvements in each stage.

1) Stage 2

a) Improvements in Stage 2 of Multi-Hazard Risk Assessment

For making the multi-hazard risk assessment more practicable, Kappes et al. [5] provided a classification of hazards so that they can be compared and combined qualitatively. Also, a semiquantitative approach was used to consider different hazards in a single overall framework [23].

b) Improvements in Stage 2 of Multi-Risk Assessment

Recent research in Costa-Rica has developed a qualitative approach for natural multi-hazard analysis in the multi-risk assessment approach. The benefit of this study is that it dedicates the importance of each hazard by considering the frequency of occurrence. Thus, when incidents are occurring far apart in the time, the event will have a decreasing weight. Moreover, the interaction of hazards was considered by summation of the weight of two simultaneous hazards which are occurring in a finite spatial space. This weighing will somehow prevent the overestimation of considering multi-hazards [14]. Therefore, providing a quantitative approach is the primary step to be taken for having a more reliable multi-hazard risk assessment.

2) Stage 4

Therein the context that cascading hazards can provide more damages, the database, and GIS-based tools cannot comprehensively respond to decision making. In [27], a mapping tool was expanded to bring a useful multi-hazard vulnerability tool by using interpretation and GIS overlay techniques. Although this method was successful to some extent, as they could illustrate the multi-hazard vulnerable zone, still lack of unexpected scenarios can be seen in it. All the data used in this methodology are based on historical data and remote sensing technics while intensifying factors such as climate change have not been considered [27]. Within this concept, in 2018, a study was done to provide a more precisely ascertained CVI as there was a concern about the increase of the Power Dissipation Index (PDI) due to climate change in the past decades. Climate change has led to multiple hazards such as sea-level rise, and storm surges in conjunction with inundation during the landfall of tropical cyclones. In this regard, the ArcGIS tool was used to determine the pattern of likely scenarios and quantify the vulnerability. More indicators were used to achieve a precise vulnerability assessment which can be used for risk assessment [28].

3) Stage 5

Although Skilodimou et al. [13] have used an updated AHP method to reduce the uncertainty and adjust the coefficients used within the multi-hazard risk assessment stage, more attempt in order to reduce the uncertainty is not neglectable.

This paper will present Napier city's historical hazards data and potential risks. Also, it provides some suggestions for reaching a comprehensive multi-risk assessment for this coastal city.

IV. Case Study

Napier is a coastal city located in the eastern part of the North Island, New Zealand, geographically located on 39°28′ 59″ S latitude and 176°55′00″ E longitude. Napier city is bounded by the main outfall channel in the north and the Tutaekuri River in the south. Also, the city's elevation is 57 m above sea level, and currently the annual average precipitation is 879 mm. Having a mild climate, generally warm and temperate, with a population of 62,800 according to 2018's population statistics [29], Napier is vulnerable to various natural hazards such as liquefaction, earthquake, flooding, volcanoes, and tsunami. Therefore, as this coastal city has the potentiality of having multi-hazards it was chosen as this research's case study. The significance of multi-hazard assessment can be understood by comparing the historical hazard data and the risk assessment researches published due date.

A. Historical Hazards Data

Napier city, which is not only confronting with coastal issues, also is located on a fault. Therefore, it is highly vulnerable to many disasters such as sea-level rise, inundation, flood, erosion, as well as earthquake. Recent disasters which Napier has faced are given in Table I.

TABLE I
Main Hazards of Napier City

Year	Main hazard	Secondary hazard	Problem	Reference
1931	earthquake	Fire	The fire destroyed the majority of the business district (lack of water after the earthquake intensified the situation), More than 1000 people excavated	[29], [30]
1935	flood	-		
1960	earthquake	tsunami	A 4.6 m tsunami, Crashed many dwellings	[31]
2004	thunderstorm	flood	people excavated, and the electricity failure	[32]
2017	Heavy rainfall	flood	Sewage was released into Ahuriri Estuary	[33]

As shown in Table I, most of the hazards are caused by a foregone hazard. The main hazard is mostly, flood and earthquake as this city is both on a fault as well as being on the coastline. These two geographic characteristics amplify the city's vulnerability to multi-hazards. As Table I has shown, recently, climate change impacts such as heavy rainfalls have caused cascading hazards. Hence, assuming multi-hazards for this city is vital. It should be mentioned that there are more cascading hazards which have not been estimated or even identified. The main problem for assuming these cascading hazards is the absence of sufficient data.

B. Risk Assessment Studies in Napier City Region

Although there are few studies revolve around Napier city hazards, which are summarised in Table II, still lack of information around the likelihood of multi-hazards and their interactions is obvious.

TABLE II
RISK ASSESSMENT STUDIES IN NAPIER CITY REGION

Hazard	Location	Reference
Volcanic	Hasting Bay	[34]
Earthquake	Napier, Hasting Bay, Waria	[35]
Earthquake (resilient)	Napier	[36]
Tsunami inundation due to local earthquake sources	Napier	[37]
tsunami	Napier	[38]
Coastal risk assessment (erosion, inundation, tsunami)	Hawke's Bay	[39]
liquefaction	Hawke's Bay	[40]

C. Lack of Knowledge

Comparing the hazard information with the risk assessments done to date, it can be understood that while the occurrence of multiple hazards has been accepted [39], neither the interactions between these cascading or simultaneous hazards have been assessed, nor the future's catastrophic events have been anticipated.

The concept of data collection for cascading data has not been standardized and the methodology of gaining data is not clear. Even though there was a methodology to assume cascading hazards, the interactions between them and the weighting in the final stage of multi-risk assessment are not yet assessed.

For a more precise risk assessment in Napier City, features of the potential hazards (including climate change factors) should be predicted and measured. As mentioned, the future scenarios might differ with current scenarios due to climate change, thus anticipating new events features and characteristics of the hazards plays an essential role in multi-risk assessment. Afterwards, the interactions between cascading and simultaneous hazards should be identified. This stage might cause uncertainty [11]. Therefore, using modern technologies to reduce the uncertainty of the interactions' occurrence can eliminate uncertainty.

V. CONCLUSION

In Napier city, the primary attention and concern of researchers are revolved around disasters such as tsunami. Tsunami, a sequential disaster occurring after an earthquake, is highly distractive due to the shortage of notice time. By assuming four different scenarios, Fraser et al. [37] evaluated that the notice time for evacuation in Napier city is as short as 30 minutes.

It is strongly believed that Napier city can face multi-hazards and tsunami should be evaluated with the interaction with other disasters. According to the aforementioned aspects of multi-hazards, it seems to have a more reliable risk assessment by considering all emerging disasters simultaneously. Definitely, a multi-hazard assumption will cause some uncertainty, but by using new technologies, it is possible to reach a sufficient reliable factor and make a safer city for all citizens.

Above all, the necessity posed by climate change has made multi-hazards occurrence more often. Interactions between different disasters emerge an extreme overall accident which is incomparable with individual disaster's consequences. Ignoring multi-hazard risk assessment might be an overestimate or would be an overlook.

To conclude, the multi-risk assessment in Napier city has to be developed. According to the descriptions of the two approaches for risk assessment, the multi-risk assessment can provide a better risk assessment for Napier City. However, according to the stages illustrated in Fig. 1, this approach should be developed in three stages. First, cascading hazard should be identified. Next, the methodology to evaluate and anticipate these hazards should be provided. Finally, the interactions between them have to be estimated and implicated in the final risk assessment.

REFERENCES

[1] M. Dilley, Chen R. S., Deichmann U., Lerner-Lam A. L., Arnold M. Natural disaster hotspots: a global risk analysis: The World Bank; 2005.
[2] L. Zhang, Zhang S., Huang R. J. E. g. Multi-hazard scenarios and consequences in Beichuan, China: the first five years after the 2008 Wenchuan earthquake. 2014; Vol.180, pp. 4-20.
[3] Y. Depietri, Dahal K., McPhearson T. J. N. H., Sciences E. S. Multi-hazard risks in New York City. 2018; Vol.18(12), pp. 3363-81.
[4] M. Pelling, Blackburn S. Megacities and the coast: risk, resilience and transformation: Routledge; 2014.
[5] M. S. Kappes, Keiler M., von Elverfeldt K., Glade T. J. N. h. Challenges of analyzing multi-hazard risk: a review. 2012; Vol.64(2), pp. 1925-58.
[6] N. Komendantova, Mrzyglocki R., Mignan A., Khazai B., Wenzel F., Patt A., et al. Multi-hazard and multi-risk decision-support tools as a part of participatory risk governance: Feedback from civil protection stakeholders. 2014; Vol.8, pp. 50-67.
[7] J. C. Gill, Malamud B. D. J. R. o. G. Reviewing and visualizing the interactions of natural hazards. 2014; Vol.52(4), pp. 680-722.
[8] W. Marzocchi, Garcia-Aristizabal A., Gasparini P., Mastellone M. L., Di Ruocco A. J. N. h. Basic principles of multi-risk assessment: a case study in Italy. 2012; Vol.62(2), pp. 551-73.
[9] T. Lung, Lavalle C., Hiederer R., Dosio A., Bouwer L. M. A multi-hazard regional level impact assessment for Europe combining indicators of climatic and non-climatic change. *Global Environmental Change*. 2013; Vol.23(2), pp. 522-36.
[10] D. Araya-Muñoz, Metzger M. J., Stuart N., Wilson A. M. W., Carvajal D. J. S. o. t. T. E. A spatial fuzzy logic approach to urban multi-hazard impact assessment in Concepción, Chile. 2017; Vol.576, pp. 508-19.
[11] O. Rahmati, Yousefi S., Kalantari Z., Uuemaa E., Teimurian T., Keesstra S., et al. Multi-Hazard Exposure Mapping Using Machine Learning Techniques: A Case Study from Iran. 2019; Vol.11(16), pp. 1943.
[12] H. R. Pourghasemi, Gayen A., Panahi M., Rezaie F., Blaschke T. Multi-hazard probability assessment and mapping in Iran. *Science of the total environment*. 2019; Vol.692, pp. 556-71.
[13] H. D. Skilodimou, Bathrellos G. D., Chousianitis K., Youssef A. M., Pradhan B. J. E. E. S. Multi-hazard assessment modeling via multi-criteria analysis and GIS: a case study. 2019; Vol.78(2), pp. 47.
[14] G. J. N. H. Barrantes. Multi-hazard model for developing countries. 2018; Vol.92(2), pp. 1081-95.
[15] B. Liu, Siu Y. L., Mitchell G. J. N. H., Sciences E. S. Hazard interaction analysis for multi-hazard risk assessment: a systematic classification based on hazard-forming environment. 2016; Vol.16(2), pp. 629-42.
[16] V. Gallina, Torresan S., Critto A., Sperotto A., Glade T., Marcomini A. J. J. o. e. m. A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment. 2016; Vol.168, pp. 123-32.
[17] M. A. Islam, Mitra D., Dewan A., Akhter S. H. J. O., Management C. Coastal multi-hazard vulnerability assessment along the Ganges deltaic coast of Bangladesh–A geospatial approach. 2016; Vol.127, pp. 1-15.
[18] M. Peng, Zhang L. J. L. Breaching parameters of landslide dams. 2012; Vol.9(1), pp. 13-31.
[19] S. Girgin, Necci A., Krausmann E. J. I. J. o. D. R. R. Dealing with cascading multi-hazard risks in national risk assessment: The case of Natech accidents. 2019; Vol.35, pp. 101072.
[20] D. E. Hart, Giovinazzi S., Byun D.-S., Davis C., Ko S. Y., Gomez C., et

al. Enhancing resilience by altering our approach to earthquake and flooding assessment: multi-hazards. 2018, pp.
[21] S. Davoudi, Brooks E., Mehmood A. J. P. P., Research. Evolutionary resilience and strategies for climate adaptation. 2013; Vol.28(3), pp. 307-22.
[22] S. Menoni, Galderisi A., Ceudech A., Delmonaco G., Margottini C., Spizzichino D. FP6 Armonia Project—Applied Multi-Risk Mapping of Natural Hazards for Impact Assessment. Deliverable 51, Harmonised Hazard, Vulnerability and Risk Assessment Methods Informing Mitigation Strategies Addressing Land-Use Planning and Management 2006.
[23] E. Pilone, Demichela M., Baldissone G. J. S. The Multi-Risk Assessment Approach as a Basis for the Territorial Resilience. 2019; Vol.11(9), pp. 2612.
[24] D. E. Hart, Hawke K. A. Multi-Hazard Flooding Interactions in the Ōpāwaho Heathcote Catchment, Christchurch, New Zealand. 2016, pp.
[25] D. Todd, Moody L., Cobby D., Hart D., Hawke K., Purton K., et al. Multi-Hazard Analysis: Gap Analysis Report. 2017, pp.
[26] C. Davis, Giovinazzi S., Hart D., editors. Liquefaction induced flooding in Christchurch, New Zealand. *ISSMGE Technical Committee TC203 Proc 6th International Conference on Earthquake Geotechnical Engineering, Christchurch, NZ Nov*; 2015.
[27] R. Mahendra, Mohanty P. C., T Kumar S., Shenoi S., Nayak S. R. J. I. J. o. R. S. Coastal multi-hazard vulnerability mapping: a case study along the Coast of Nellore District, East coast of India. 2010; Vol.42(3), pp. 67-76.
[28] B. Sahoo, Bhaskaran P. K. J. J. o. e. m. Multi-hazard risk assessment of coastal vulnerability from tropical cyclones–A GIS based approach for the Odisha coast. 2018; Vol.206, pp. 1166-78.
[29] G. Thomas, Schmid R., Cousins W., Heron D., Lukovic B., editors. Post-earthquake fire spread between buildings–Correlation with 1931 Napier earthquake. *Proc New Zealand Society for Earthquake Engineering Annual Conference, Napier*; 2006.
[30] D. Dowrick, Rhoades D., Babor J., Beetham R. J. B. o. t. N. Z. N. S. f. E. E. Damage ratios for houses and microzoning effects in Napier in the magnitude 7.8 Hawke's Bay, New Zealand, earthquake of 1931. 1995; Vol.28(2), pp. 134-45.
[31] H. s. B. E. Management. 1960 tsunami: Hawke's Bay Emergency Management; Available from: https://www.hbemergency.govt.nz/hazards/tsunami/.
[32] Reporter. Residents evacuated as streets turn into rivers 2004 Available from: https://www.nzherald.co.nz/hawkes-bay-today/news/article.cfm?c_id=1503462&objectid=10915535.
[33] M. Sharpe. Hawke's Bay flooding cuts off village and overloads Napier's wastewater system 2018 Available from: https://www.stuff.co.nz/dominion-post/news/106848300/school-and-roads-closed-as-heavy-rain-batters-hawkes-bay.
[34] D. Paton, Johnston D., Bebbington M. S., Lai C.-D., Houghton B. F. J. A. J. o. E. M., The. Direct and vicarious experience of volcanic hazards: implications for risk perception and adjustment adoption. 2000; Vol.15(4), pp. 58.
[35] K. Ronan, Johnston D., Paton D., editors. Communities' understanding of earthquake risk in the Hawke's Bay and Manawatu-Wanganui regions, New Zealand. *NZSEE 2001 Conference*; 2001.
[36] D. McIvor, Paton D. J. D. P., Journal M. A. I. Preparing for natural hazards: normative and attitudinal influences. 2007; Vol.16(1), pp. 79-88.
[37] S. A. Fraser, Power W. L., Wang X., Wallace L. M., Mueller C., Johnston D. M. J. N. H. Tsunami inundation in Napier, New Zealand, due to local earthquake sources. 2014; Vol.70(1), pp. 415-45.
[38] N. Horspool, Cousins W. J., Power W. L. Review of tsunami risk facing New Zealand: a 2015 update: GNS Science; 2015.
[39] T. Taylor. Hawke Bay Coastal Strategy. Report. Hawke's Bay Regional Council 2016.
[40] M. R. Elkortbawi. Insights into the Liquefaction Hazards in Napier and Hastings Based on the Assessment of Data from the 1931 Hawke's Bay, New Zealand, Earthquake: Virginia Tech; 2017.