Integrating Multi-Hazard Risk Analysis into Spatial Planning for Small Island: Study Case of Sangihe Island

Atrida Hadianti1,2,*, Hilmiyati Ulinnuha1,3, Leni Sophia Heliani1,3, Ahmad Sarwadi1,2, Adhy Kurniawan1, Juswono Budisettiawan1, Latif Suhubawa1, Wiwit Suryanto1, Cecep Pratama1,3, Bachtiar Wahyu Mutaqin1, Widya Nayati1, Yosi Bayumurti1, Ridho Ilahi2, Senoaji Y Widjonarko2

1Center for Marine Resources and Technology Studies, Universitas Gadjah Mada, Jl. Hujan Mas A-4 Bulaksumur, Yogyakarta 55281, Indonesia
2Department of Architecture and Planning, Gadjah Mada University, Jl. Grafa Utara no 2, Sekip Yogyakarta, Indonesia
3Department of Geodetic Engineering, Gadjah Mada University, Jl. Grafa Utara no 2, Sekip Yogyakarta, Indonesia

atrida.h@ugm.ac.id

Abstract. Small island regions are facing disaster risks due to their exposure to various hazards, e.g. floods, landslide, and earthquake. In order to achieve long-term disaster resilience, one of the significant strategies is applying spatial planning based on disaster risk reduction. Methods for multi-hazard risk assessment and risk analysis have been broadly discussed, nevertheless, its implementation in spatial planning is inadequate. In this study, we conducted a multi-hazard risk mapping of Sangihe Island and reviewed its spatial plan. It is identified that disaster risk analysis hardly meets its standard in consequence of insufficient secondary data availability. Also, the spatial plan merely utilizes hazard maps for consideration, not yet as risk analysis, resulting in allocating vital elements in high-risk areas. Hence, secondary data support is necessary for accordance with the needs of standardized risk analysis and is updated regularly. Furthermore, integration of risk analysis into spatial planning is required to determine the direction of development, which not only reduces exposure to hazards but emphasizes more towards the capacity building to reduce vulnerability.

1. Introduction
The Sangihe Islands is one of the most active geodynamic regions in Indonesia with a very unique phenomenon, namely an archipelago with a range of volcanoes, both visible to the surface as islands and seabed volcanoes, formed due to the subduction of the Maluku sea plate under the Eurasian continental plate. Sangihe subduction zone is one of the complex subduction zones [1] and is the oldest active subduction zone in the Indonesia-Philippines region [2]. These conditions indicate that the level of plate activity is very high. It is estimated that at this time the Sangihe Islands will continue to be pushed to the southeast [3] and push the Halmahera Islands arc. This causing the Maluku sea area to become narrower from time to time. The horizontal movement of Sangihe Islands can reach 13.88 mm/year to the southeast [4]. Hence, these circumstances lead Sangihe archipelago to be very prone to natural disasters, including earthquakes, tsunamis, landslides, and volcanoes [5].
In order to carry out disaster risk management in the regions, the preparation of a disaster-based spatial planning is required, referred to Law No. 26/2007 on Spatial Planning. According to the Regulation of the Minister of Agrarian and Spatial Planning No. 1/2018, analysis of disaster risk reduction (DRR) is an embedded part of the analysis that obligatory to be carried out in a Regional Spatial Plan (Rencana Tata Ruang Wilayah/RTRW). Spatial planning, which is manifested in spatial structure, spatial patterns, and strategic areas, becomes a key instrument to regulate land use and in the context of disaster management, it plays an important role as a mitigation measure by minimizing the exposure to hazard, allocating socio-economic activities and infrastructures [6]. In the current document of Spatial Plan of Sangihe Islands Regency, the disaster aspect is discussed only refers to hazard-based information which focuses more on the physical aspects, so that there is a lack of congruence in land use and elements at risk. Meanwhile, disaster risk analysis methods have pretty much been formulated in the scientific domain and applied by international and national organizations concerned with disaster issues in the standardized technical guidelines for implementing risk assessment and risk analysis [7]. The National Disaster Management Agency (Badan Nasional Penanggulangan Bencana/BNPB) as the agency responsible for disaster management in Indonesia has compiled this instrument in Disaster Risk of Indonesia. However, these instruments have not been applied in the process of spatial planning.

To date, local authorities have set up strategies in the Sangihe Islands to develop the region as an area of tourism and fisheries as well as achieve a disaster-resilient region. Considering the potential of the occurrence of multiple hazard disasters due to geodynamic phenomena in Sangihe archipelago, it is important to develop a disaster risk analysis model that depicts the disaster risks spatially. This model comprises the elements of risks; hazard, vulnerability, and capacity of each potential hazard to provide an integrated assessment of multiple risks and contributing aspects that might increase risk [7]. The multi-hazard disaster risk analysis approach aims to comprehensively visualize the level of disaster risk faced by the region. Then, the risk analysis must be integrated into spatial planning, thus it not only directs the development of the area by “keeping it away from threats” but also emphasizes capacity increase to reduce vulnerability. Thus, the regional development agenda can go hand in hand with disaster risk reduction.

In this study, a disaster risk analysis was carried out on Sangihe Island, the main island, and a review of the spatial plan documents. Disaster risk analysis was carried out to map the level of disaster risk in each sub-district on Sangihe Island using available secondary data. So that it is known how to carry out a multi-hazard disaster risk analysis and identify the availability of secondary data in the area to support this analysis. A review of the spatial planning document was carried out to the Regional Spatial Plan of Sangihe Islands Regency by identifying the level of disaster risk in the areas contained in the spatial structure plan, spatial patterns, and strategic areas. The mismatch between multi-hazard disaster risk and the spatial plan is reflected in the location of vital elements in areas with a high level of risk.

2. Method

The study takes place in Sangihe Islands Regency, an integral part of North Sulawesi Province with the capital city Tahuna. Geographically, Sangihe Islands District is bordered by the Republic of the Philippines and Talaud Islands Regency in the north, Sitaro Regency in the south, the Pacific Ocean and Maluku Sea in the east, and the Sulawesi Sea in the west. Sangihe Island is located on an active tectonic plate and a trans-pacific volcanic area that makes this region prone to natural disasters, one of which is earthquakes with a magnitude of 4.5 SR annually [5].

Risk is a function of hazard, vulnerability, and capacity of a population exposed to the hazard [8]. In this case, the level of risk (R) is directly proportional to the level of hazard (H) and the level of vulnerability (V), but inversely proportional to the level of capacity (V). This mathematical model is then used in mapping using the three variables based on the scores at each level, namely 1 for low, 2 for medium, and 3 for high. Mapping was carried out for 4 (four) types of hazard, namely flood run-off, tidal flood, landslide, and earthquake. From the mapping, a risk map of each hazard type is generated which is then overlaid to produce a multi-hazard risk map. The multi-hazard risk map then becomes the basis for reviewing the existing spatial planning (RTRW) maps.
The hazard map is generated using the data provided by inaRisk BNPB service, for each of the earthquakes, tidal floods, flood runoffs, and landslides. The level of the hazard was measured by considering the magnitude and physical characteristics of the area using the Digital Elevation Model (DEM) raster data. The hazard mapping method uses Analytical Hierarchy Process (AHP) based on these criteria. Vulnerability and capacity mapping were done through an aggregation process by weighting indexes between dimensions for each hazard, the dimensions comprise social, economic, physical, and environmental [9]. Data for vulnerability and capacity mapping was gathered from secondary data provided by the local government. Risk map of each hazard generated through the overlay of hazard map, vulnerability map, and capacity map. Then, the respective risk maps are combined into a multi-hazard risk map.

A review of the current spatial plan was done through comparison towards the multi-hazard risk map and maps of Spatial Plan of Sangihe Islands Regency 2014-2034. Maps on spatial structures, spatial patterns, and strategic areas were analyzed to identify the locations of vital elements (settlements, community activity centers, and network of facilities and infrastructure) and compare them with the risk level based on the multi-hazard risk analysis reflected on the map.

3. Results and Discussions

3.1. Multi-hazard risk analysis and mapping

3.1.1. Hazard. Hazard mapping generates 4 (four) maps, namely flood runoff, tidal flood, landslide, and earthquake. Each hazard shows a different distribution of hazard levels due to different physical criteria for each hazard. Based on Figure 2, the red color represents the areas with high disaster potential, the yellow color represents the areas with moderate disaster potential, while the green color represents the areas with low disaster potential. Due to the terrain of Sangihe Island with 2 highlands, namely in the northern and southern parts of the island, areas that have a high runoff flood threat level support the results of the landslide hazard map. Based on the inaRISK map, the tidal flood hazard map is only at risk around coastal areas (or close to the coast), however, usually, these tidal floods could occur in the central area of the island. Areas that have a high level of landslide threat are in the northern and central-western areas. This area appears to be highly threatened because it is located around a plateau, allowing a large percentage of slopes to form. This area is not considered as a high-hazard area due to the lack of detail in the modeling scenario (considering that Sangihe Island is relatively small compared to other islands in Indonesia), thus this map is modeled in general mode. The earthquake threat area spreads along Sangihe Island. There is an area with a small area in the middle of the island which has a high
hazard risk level. The area with the highest hazard level is at the southern tip of the island (Tabukan area).

![Hazard maps of Sangihe Island](image)

**Figure 2.** Hazard maps of Sangihe Island, in clockwise: runoff flood, tidal flood, landslide, and earthquake.

From the hazard mapping, several issues occurred during the process that affects the result. The secondary data availability and variables used in hazard mapping. Landslide hazard map and runoff flood hazard map from secondary data need to be cross-checked with field data. Cross-check can use the addition of the latest slope data and soil types scattered in the Sangihe Islands. The scenario of making a tidal flood hazard map needs to add the influence of water discharge on rivers connected to the coast and analysis of river paths along Sangihe Island. Earthquake hazard maps need to include the location of plate faults on Sangihe Island because most earthquakes occur near plate fault locations. In addition to plate location data, geological and geomorphological data on Sangihe Island are also needed in making a more representative earthquake hazard map. Meanwhile, the results of the map are still dispersed because they have not included the location of the fault and detailed geological information in the process of making the hazard map.

Sangihe Islands have many potential disasters, multi-disaster analysis of this area is needed for a more accurate disaster risk assessment. This assessment is carried out by incorporating all hazard maps in the risk analysis process. The accuracy of multi-disaster risk assessment is also influenced by the accuracy of hazard maps. The hazard map used has the smallest scale at the sub-district level, so that the multi-hazard risk map produced will also be at the sub-district level.

3.1.2. **Vulnerability.** The vulnerability maps generated in this study are in accordance with vulnerability dimensions, such as social vulnerability, economic vulnerability, physical vulnerability, and
environmental vulnerability. Social vulnerability parameters based on population density and population of vulnerable groups. Physical vulnerability parameters based on the number of public facilities and critical facilities. Economic vulnerability parameters are based on the percent of productive land and Gross Regional Domestic Product (Produk Domestik Regional Bruto/PDRB). Furthermore, environmental vulnerability parameters are based on the densest natural elements in the studied area.

According to economic vulnerability maps, most of the Sangihe Islands have a high level of economic vulnerability. The physical vulnerability tends to have a moderate vulnerability, except in the manganitu sub-district and parts of Tahuna sub-district which have a high physical vulnerability. This high vulnerability is caused by the high proportion of spatial use as a residential area and the location of the airport in Tahuna district. Meanwhile, environmental vulnerability and social vulnerability have a low level of vulnerability.

The vulnerability index on Sangihe Island is affected by population and development, which is reflected in the high vulnerability index in the capital city of Tahuna, especially in the social and physical dimensions. On the other hand, more developed areas are less vulnerable in economic and environmental dimensions. This is consistent with the concept that the higher the number of populations exposed to the hazard, it increases the vulnerability index. Furthermore, the high population density in developed areas makes it difficult to mobilize people in the evacuation process which increases the risk [10] Higher economic levels can be considered as capacity, in this term, it could help the community to bounce back from the catastrophe, hence it decreases vulnerability index. The high physical vulnerability index in the built-up area since public facilities and critical facilities in the area are determinants of loss [7] although functionally it can be considered as capacity. However, the availability of public facilities in the area that is exposed to hazard makes it more vulnerable because of the possible losses caused by the necessity to repair the physical structure of the building and restore its normal function.
Figure 3. Vulnerability maps of Sangihe Island based on the vulnerability dimensions, in clockwise: social, economic, environmental, and physical.

Assessment of vulnerability based on dimensions cannot stand alone distinctively, and on a relatively small island scale such as Sangihe Island, the type of data and its depth affects the mapping results. In terms of social vulnerability, population density and the number of vulnerable populations are still too broad to map the community vulnerabilities accurately so that the dependency ratio and unemployment rate assessments can be added to reflect the social conditions of the community [11]. Moreover, in the economic dimension, the financial characteristics of the population based on livelihoods such as income and disparity at the household scale can be significant parameters [12]. The fact that there is a concentration of vulnerability in the surrounding area of the capital city requires further analysis on the pressure on the environment in the environmental dimension [13] in this case, related to the development of urban areas, such as urbanization and land conversion. Besides, institutional vulnerability assessments need to be carried out by analyzing disaster management and policies at each level of
government [11].

Table 1. Vulnerability Weighting Index based on the type of hazard.

|                | Social | Physical | Economic | Environment |
|----------------|--------|----------|----------|-------------|
| Earthquake     | 40     | 30       | 30       | -           |
| Flood          | 40     | 25       | 25       | 10          |
| Flash flood    | 40     | 25       | 25       | 10          |
| Landslide      | 40     | 25       | 25       | 10          |

The vulnerability maps for each dimension are then combined by adjusting the predetermined weightings based on the type of hazard [9]. The result indicates that, in general, the level of vulnerability on Sangihe Island is medium to high, areas with a high level of vulnerability are in the vicinity of the capital city of Tahuna. Thus, an area with a high level of vulnerability indicates that it has a high potential to cause more casualties, damages, losses, disturbances, and difficulties in recovering from the event of a natural disaster. On the maps, it can be seen that the vulnerability to earthquakes is more than that of floods and landslides, this is due to the differences in weighting on the physical and economic dimensions.

Figure 4. Result of the overlay process between vulnerability map and hazard map.

3.1.3. Capacity. Capacity is an aspect that balances vulnerability, in which if the vulnerable area that has sufficient capacity is considered as resilient to cope with the disturbance. The capacity analysis comprises resilience in social, community, institutional, physical and economic. However, due to the limited availability of secondary data, the capacity index in this study was solely assessed by the use of electricity and [11] and the sufficiency of health services [13]. It is highlighted that, among others, the Manganitu Selatan area is considered to have the low capacity in terms of dealing with natural disasters. In the area around the capital city of Tahuna, although the level of vulnerability is high, the level of capacity is also high. Several areas in Tabukan Utara are at a high level of vulnerability with a moderate level of capacity, this needs to be emphasized due to its contribution to the level of risk in this area. Thus, the capacity in the area needs to be increased to overcome its vulnerability. In addition, an in-depth analysis of capacity should also be carried out by including other aspects of capacity. Capacity data is dynamic and changes from time to time so that each parameter in the capacity analysis requires updating, in this case, the provision of secondary data by the responsible agency.
3.1.4. Risk. The multi-hazard risk map generated in this study is an overlay result of hazard, vulnerability, and capacity map using the functions of UNISDR [8]. Multi-hazard approach is a depiction of the total potential hazards that may occur in the administrative area [14] within Sangihe Island, therefore the multi-hazard risk depicts the total risks of potential hazards, namely runoff flood, tidal flood, landslide, and earthquake. When viewed separately for each hazard, the level of risk in a particular hazard of Sangihe Island is varied. The risk of flooding, both runoff and tidal flooding, is relatively low and moderate only spread over areas with mountainous topography. Areas with a high-risk level for landslides are in the vicinity of the Mount Awu area, while other areas at moderate levels are caused by a high percentage of slopes on the plateau stretching from north to south. The vulnerability to earthquake hazards shows an interesting variation such as the height in the Tahuna area and some areas in North Tabukan. Regarding earthquake hazard, the area in the south of Sangihe Island is high, with a relatively low capacity. Also relatively, only a few communities are exposed to the hazard, therefore the risk level is in the moderate category.
Figure 6. Risk map of each hazard of Sangihe Island.

From the four risk maps for each hazard above, an overlay is then carried out to generate a multi-hazard risk map (figure 7). In this study, the mapping was carried out at a scale of 1: 250,000 with data obtained from the sub-district level. Small islands have their own characteristics in various aspects that are not reflected on this scale so that they appear only in general, therefore a more detailed scale is needed to show the variation in the level of risk. Results of the mapping require field confirmation to check the accuracy of information from secondary data with reality, both physical and socio-economic aspects. In the long term, this must be supported continuously by the provision of updated data as part of regional disaster management. Integrating multi-hazard risk analysis into spatial planning requires the integration of high-quality data related to disaster risk into the regional database system and the use of technology and tools that support access to data, as well as a decision-making system [15]. Assessment parameters in risk analysis need to consider more detailed aspects, therefore variables from the data at the village or household level need to be included in the calculation to provide a better picture towards risk assessment.
Figure 7. Multi-hazard Disaster Risk Map of Sangihe Island.

3.2. Review of the current spatial planning of Sangihe Island Regency

The Tahuna area (Tahuna District) is the capital of the Sangihe Islands Regency, which is designated as the National Strategic Activity Center. This area is located in an area with a high earthquake hazard. The development of population and facilities in this area is a factor that causes a high vulnerability in the region. So, this makes the risk level too high. Meanwhile, the Tona Satu area (Tahuna Timur District) is also an area with high disaster risk, this is due to the density of the population and the number of facilities built in this area. There are Naha Airport (North Tabukan District) and Coal Gasification Power Plant (PLTGB) in South Tabukan District which are high-risk multi-disaster areas (especially earthquakes). Settlement centers and population activities contribute to the high-risk index because they are the population centers, so their vulnerability scores are also high. In the Tahuna and Tona Satu areas, the high capacity index still could not balance the level of vulnerability because the hazard index is also high. Development of the spatial structure, in addition to the analysis of existing spatial structure, needs to consider the risk of disasters in the region.

Most of the areas on Sangihe Island that are planned in the existing RTRW are at a moderate risk level. However, Tahuna Subdistrict is the capital of the district which is located in an area with high disaster risk due to the high threat of earthquakes and high levels of vulnerability. The spatial pattern can be a regulatory tool to develop and, at the same time, hinder the development of space in certain areas. Therefore, spatial allocation arrangements taking into account disaster risk can be carried out by establishing a spatial pattern in areas with a high-risk level caused by a high hazard level as a protected area, on the other hand, limited or conditional rules are imposed for development utilization.

Table 2. Current spatial plan of Sangihe Island and level of multi-hazard risk.

| Level of Multi-Hazard Risk | Remarks |
|----------------------------|---------|
| Low                        | Moderate| High |

1) Spatial Structure

- National Strategic Activity Center (PKSN) | v | High: Tahuna
- Environmental Activity Center (PKL) | v | Moderate: Mala, Manalu
- Environmental Activities Promotion Center (PKL-P) | v | High: Mala, Manalu

- Moderate: Tamako, Dagho
Low Moderate High

Area Service Center (PPK) v v v Low: Kendaha
Moderate: Pintareng, Salurang, Kolongan Mitung
High: Lapango, Tona Satu

Environmental Service Center (PPL) v v v Moderate: Kalinda, Binebas High: Kaluwatu, Kalurae, Kalasuge, Mohongsawang

2) Spatial Patterns

Protected Area

Protected areas for its subordinate areas v v v
Local protected areas v v v
Natural reservation, nature preservation, cultural heritage & science areas v v
Natural disaster areas v v
Geological protected areas v v

Development Area

Agricultural area v v v None
Livestock area v v v Salurang, Manalu, Tamako, Dhago, Kuma, Tahuna
Mining area v v
Industrial area v v v

Tourism area None
Fishery area None
Residential area v v v Tahuna area is the most populous and the high-risk area

Other designated areas v v v Naha Airport is located in the high-risk area

3) Strategic Area

Economic Growth Aspects v v v
Social & Cultural Aspects v v v
Environmental Function & Carrying v v v

Disaster risk identification, in contrast to hazard identification, focuses on possible consequences in the form of losses resulting from threats, vulnerability, and lack of capacity [16]. Identification that emphasis on disaster risk assessment allows for a harmonious and effective basis for consideration in the government's efforts to achieve protection for people's lives and livelihood. The hazard approach exclusively in spatial planning only illustrates how to keep people away from hazards, while in fact, the community has lived in areas that are considered disaster-prone for generations. With a risk approach, disaster management-based spatial planning does not only settle the communities in "harmless" locations but lives in harmony with disasters by remaining aware of the hazard and also improving their
livelihoods in order to increase their capacity. The space utilization for disaster mitigation facilities using the latest technology and the development of activity centers that could increase community capacity can be accommodated through spatial planning. In the practical context of spatial planning for small islands, detailed planning is more suitable to its physical and socio-economic characteristics and applicable, through detailed spatial planning or building and environmental planning.

4. Conclusions
In purpose to implement a standardized risk analysis instrument requires adequate secondary data support and is in accordance with the data needs of each variable. In this case, the disaster management agency (BNPB) must be supported by relevant agencies in providing secondary data, so that the national scale disaster risk map (InaRISK) can have a level of detail up to the village level, even the environment, and be updated (annual data series). Thus, it can support DRR-based spatial planning and reach out to the outermost small islands. Integration of risk maps in spatial planning is not only based on hazard analysis but with risk analysis by taking into account the aspects of vulnerability and capacity. The consequences in the form of severity caused by a hazard are not always tied to the magnitude of the hazard. The existence of capacities and vulnerabilities also play a role in the magnitude of the consequences caused by a phenomenon that presents a hazard. The higher the value of vulnerability or the lack of capacity to deal with these hazards could result in the possible consequences of quite severe losses. In this regard, spatial planning emphasizes more on strategies to increase capacity and reduce vulnerability, not only reducing exposure to hazards but more on capacity building to reduce the level of risk.

References
[1] Di Leo, J. F., et al. (2012). Deformation and mantle flow beneath the Sangihe subduction zone from seismic anisotropy. *Physics of the Earth and Planetary Interiors*, 194–195, 38–54.
[2] Jaffe, L. A., Hilton, D. R., Fischer, T. P., & Hartono, U. (2004). Tracing magma sources in an arc-arc collision zone: Helium and carbon isotope and relative abundance systematics of the Sangihe Arc, Indonesia. *Geochemistry, Geophysics, Geosystems*, 5(4).
[3] Ulinnuha, H., et al. (2019). GPS Technology Implementation for Sangihe Islands’ Movement Monitoring in 2017 - 2019. *Journal of Geospatial Information Science and Engineering*, Vol 2 No 2, p. 206-211.
[4] Nugroho, K.F and Heliani LS. 2019. Analysis of Sangihe Islands Movements derived from Recent GPS Observation. *Journal of Geospatial Information Science and Engineering*, Vol 2 No 2, p. 220-227.
[5] Heliani LS, Kurniawan A, Swastiko FA, Kurniawan MG. Networks for purposes of Geodynamics study of. In: 2018 4th International Conference on Science and Technology (ICST). IEEE; 2018. p. 1–4.
[6] Sutanta H, Rajabifard A, Bishop ID. Disaster risk reduction using acceptable risk measures for spatial planning. J Environ Plan Manag. 2013;56(6):761–85.
[7] Gallina V, Torresan S, Critto A, Sperotto A, Glade T, Marcomini A. A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment. J Environ Manage [Internet]. 2016;168(1):123–32. Available from: http://dx.doi.org/10.1016/j.jenvman.2015.11.011
[8] UNISDR. (2004). Living with Risk: A Global Review of Disaster Reduction Initiatives. 2004 Version, Inter-Agency Secretariat of International Strategy for Disaster Reduction. Volume 1, Geneva, UNISDR.
[9] Amri MR, Yulianti G, Yunus R, Wiguna S, W. Adi A, Ichwana AN, et al. RBI (Risiko Bencana Indonesia). BNPB, 2016.
[10] Rana, I.A., Routray, J.K. Multidimensional Model for Vulnerability Assessment of Urban Flooding: An Empirical Study in Pakistan. Int J Disaster Risk Sci 9, 359–375 (2018).
[11] Kusumastuti RD, Viverita, Husodo ZA, Suardi L, Danarsari DN. Developing a resilience index towards natural disasters in Indonesia. Int J Disaster Risk Reduct [Internet]. 2014;10(PA):327–
40. Available from: http://dx.doi.org/10.1016/j.ijdrr.2014.10.007

[12] Welle T, Birkmann J, Krause D, Suarez DC, Setiadi NJ, Wolfertz J. The WorldRiskIndex: A concept for the assessment of risk and vulnerability at global/national scales. In: Birkmann J, editor. Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies. Tokyo: United Nations University Press; 2013. p. 219–50.

[13] Bell H, Bausch D, Morath D, Livengood J. The ASEAN Regional Risk and Vulnerability Assessment (RVA) Guidelines for Implementation. United States Agency for International Development (USAID); 2017.

[14] Kappes, M., Keiler, M., Glade, T., 2010. From single- to multi-hazard risk analyses: a concept addressing emerging challenges. In: Malet, J.P., Glade, T., Casagli, N. (Eds.), Mountain Risks: Bringing Science to Society. Proceedings of the International Conference, Florence. CERG Editions, Strasbourg, pp. 351e356.

[15] Ran J, Nedovic-Budic Z. Integrating spatial planning and flood risk management: A new conceptual framework for the spatially integrated policy infrastructure. Comput Environ Urban Syst [Internet]. 2016;57:68–79. Available from: http://dx.doi.org/10.1016/j.compenvurbsys.2016.01.008.

[16] Simmons, D.C., Corbane, C., Menoni, S., Schneiderbauer, S., Zschau, J., 2017. Understanding disaster risk: risk assessment methodologies and examples. In: Poljanšek, K., Marin Ferrer, M., De Groeve, T., Clark, I. (Eds.). Science for disaster risk management 2017: knowing better and losing less. EUR 28034 EN, Publications Office of the European Union, Luxembourg, Chapter 2, doi: 10.2788/688605.

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