Geotagging and Multi-Hazard Assessment of Evacuation Centers in the Philippines

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Abstract

The Philippines is one of the most at-risk countries to disasters in the world, ranking 8th out of 181 countries in the 2021 World Risk Index (Bündnis Entwicklung Hilft, 2021). Information on evacuation centers (ECs) is crucial for disaster risk reduction and management planning and disaster response as these serve as places for community members to stay in during disasters to minimize injuries and the loss of lives. At present, consolidated geospatial data of ECs at the national level is not yet available. In order to address this gap, through the GeoRiskPH Initiative, this study geotagged ECs in the Philippines based on the lists provided by government agencies like the DILG and DSWD, and evaluated the spatial distribution and hazard assessment of the ECs. The number of ECs that are safe from and prone to seismic, volcanic, and hydrometeorological hazards per susceptibility level, as well as EC-to-population ratios, were calculated for each province. ECs were also categorized according to their actual structural/building use such as schools, covered courts, multi-purpose halls, and daycare centers. Hazard-specific mitigation measures and the re-evaluation of the locations and number of ECs per city/municipality is highly recommended to ensure the safety and accessibility of these facilities.

I. Introduction

The Philippines is one of the most at-risk countries to disasters in the world. Given the Philippines' geographic location in the Pacific Ring of Fire and Typhoon Belt, a region where most of the world's earthquakes, active volcanoes, and cyclones form and occur, the country experiences a wealth of seismic, volcanic, and hydrometeorological hazards. The 2021 World Risk Index (WRI), which ranks countries by their risk of experiencing disaster as a result of natural hazards such as tropical cyclones, floods, and earthquakes, placed the Philippines 8th out of 181 countries in terms of the highest disaster risk (Bündnis Entwicklung Hilft, 2021). The threat of these hazards along with a warming planet, persistent environmental degradation, urbanization, and high population growth entails greater potential human and economic losses to disasters unless appropriate and adequate preparedness and mitigation measures are properly planned and enforced.

One of the crucial strategies in reducing exposure to hazards and managing risk is the evacuation process. Safe, accessible, adequate, and operational evacuation centers (ECs) are keys to protecting lives, reducing economic losses, and ensuring immediate recovery in times of disasters and other emergencies. Information on the location of ECs is vital in disaster risk reduction and management planning and response. At present, consolidated geospatial data of ECs at the national level is not yet available. It is therefore imperative to have information on the available evacuation centers in the country for data-informed planning and decision-making by the national and local governments and the public alike.

Hence, this study aims to address this gap by geotagging ECs in the Philippines based on lists provided by local government units (LGUs) and national government agencies like the Department of Interior and Local Government (DILG) and the Department of Social Welfare and Development (DSWD), as well as service learning and research outputs by students of the University of the Philippines Diliman. Through the GeoRisk Initiative and using geographic information system (GIS) workflows and processes, the spatial distribution of these ECs will be evaluated and the number of ECs that are deemed safe from and prone to seismic, volcanic, and hydrometeorological hazards per susceptibility level will be assessed and identified based on hazards information from the Philippine Institute of Volcanology and Seismology (PHIVOLCS) and the Mines and Geosciences Bureau (MGB), and administrative boundaries from the Philippine Statistics Authority (PSA). The geotagged ECs will be categorized according to their actual structural or building use such as purpose-built evacuation centers, schools, covered courts, multi-purpose halls, open areas, health centers, and day care centers. The EC-to-population ratios will also be calculated for each city/municipality. As a result of this study, it is expected that hazard-specific mitigation measures will be implemented and the locations of these ECs will be re-evaluated to ensure the safety and accessibility of these critical facilities.

II. Research Methodology

The geotagging of ECs is mainly based on the nationwide masterlist provided by the DILG, which contains the addresses of identified ECs in textual format. Using available online location information, GIS data shared by the DSWD and partner LGUs, Google StreetView, satellite imageries, and data from the Department of Education (DepEd) and Department of Health (DOH) in the GeoRiskPH database, the researchers have been geotagging ECs since July 2021.

Students taking the Civic Welfare and Training Service offering from the UP Diliman Department of Computer Science (CWTS 2 Engg CS) also geotagged ECs in the National Capital Region (NCR) using data sourced through a Freedom of Information (FOI) request. In addition to this, authors of the paper entitled

"Evaluation of the Spatial Distribution of Evacuation Centers in Metro Manila, Philippines" (Cajucom, et al.) also contributed the geotagged ECs used in the analysis for their research manuscript.

Out of the 28,083 ECs listed by DILG, a total of 17,042 ECs have been geotagged so far. While the building of the ECs database is still ongoing, it can be noted that duplicate entries, wrong addresses, and incomplete or insufficient information on the location and/or name of ECs in the masterlist hindered some entries to be geotagged. The list contains entries whose date of last update ranges from June 2018 to March 2014, hence only ECs with sufficient information that can be located on a map were geotagged. Three geotagging confidence levels were indicated for each EC mapped. ECs whose location is validated through Google StreetView are tagged as "Certain". ECs with no StreetView available, but validated through Google Maps and/or DepEd schools or DOH health facilities data are tagged as "High Confidence." Lastly, ECs mapped purely based on satellite imagery interpretation are tagged as "Moderate Confidence."

Using filters in the EC name and with validation in Google StreetView if available, ECs were categorized according to their building/land use. The following categories were used: evacuation center, school, barangay/municipal/multi-purpose hall, covered court/sports complex, church/chapel, day care, health center, other government facility, market/mall, open areas, and private facility.

The geotagged ECs were then assessed for the following seismic, volcanic, and hydrometeorological hazards only: ground rupture, liquefaction, tsunami, lahar, pyroclastic density current, lava flow, flood, and rain induced landslide hazard. Since the geometry of the ECs dataset is point-based, a buffer of 300 meters from the nearest active fault was used to assess exposure to ground rupture hazard. In this report, the terms "prone", "susceptible" and "exposed" to hazards generally mean the likelihood or the possibility for particular hazards to occur. All ECs are considered prone to ground shaking and severe wind hazard.

DATA	SOURCE
Active Faults	PHIVOLCS, 2022
Liquefaction	PHIVOLCS, 2006-2020
Tsunami	PHIVOLCS, 2006-2020
Lahar, Pyroclastic Density Current, and Lava	PHIVOLCS, 2009-2018
Flood	MGB, 2018
Rain-Induced Landslide	MGB, 2018
Administrative boundaries	Philippine Statistics Authority, 2020

Table 1. List of data sources used in the hazard assessment

$$F_{haz} = F_{loc} \cap H$$

$Where:$

$F_{loc} = Facilities\ in\ location$

$F_{haz} = Facilities\ prone\ to\ hazard$

$F = Facilities\ layer$

$H = Hazard\ layer$

$And:$

$F_{loc} = L \cap F$

Figure 1. Formula used to calculate the evacuation centers prone to hazards

The total number of ECs prone to a particular hazard is computed by first obtaining the total number of facilities within a particular location by intersecting the facilities layer with the location's administrative boundary. A detailed list of the results are in the Annex. The values presented may change overtime if there will be updates in input parameters,

especially related to administrative boundaries and hazards information, which may be refined as new data for analyses become available. Mapping methodologies employed for the generation of hazard information may be accessed from the hazard maps of the government agencies. Detailed hazard assessments may be required should site-specific projects be pursued.

III. Results and Discussion

3.1 Spatial Distribution of ECs

The spatial distribution of geotagged ECs is highly influenced by the availability of Google StreetView and Google Maps search results, and the availability and accuracy of DepEd and DOH data in the area, and the location of government facilities.

The region with the highest number of geotagged ECs is Region 1 (Ilocos Region), with 1,768 ECs tagged, closely followed by Region 7 (Central Visayas) with 1,659 ECs tagged, and Region 4A (CALABARZON) with 1,646 ECs tagged. Meanwhile, the regions with the least number of geotagged ECs are Region 12 (SOCCSKSARGEN) with 304 ECs tagged, Region 11 (Davao Region) with 380 ECs tagged, and Region 9 (Zamboanga Peninsula) with 456 ECs tagged. The figure and map below shows the number of geotagged ECs and their distribution per region.

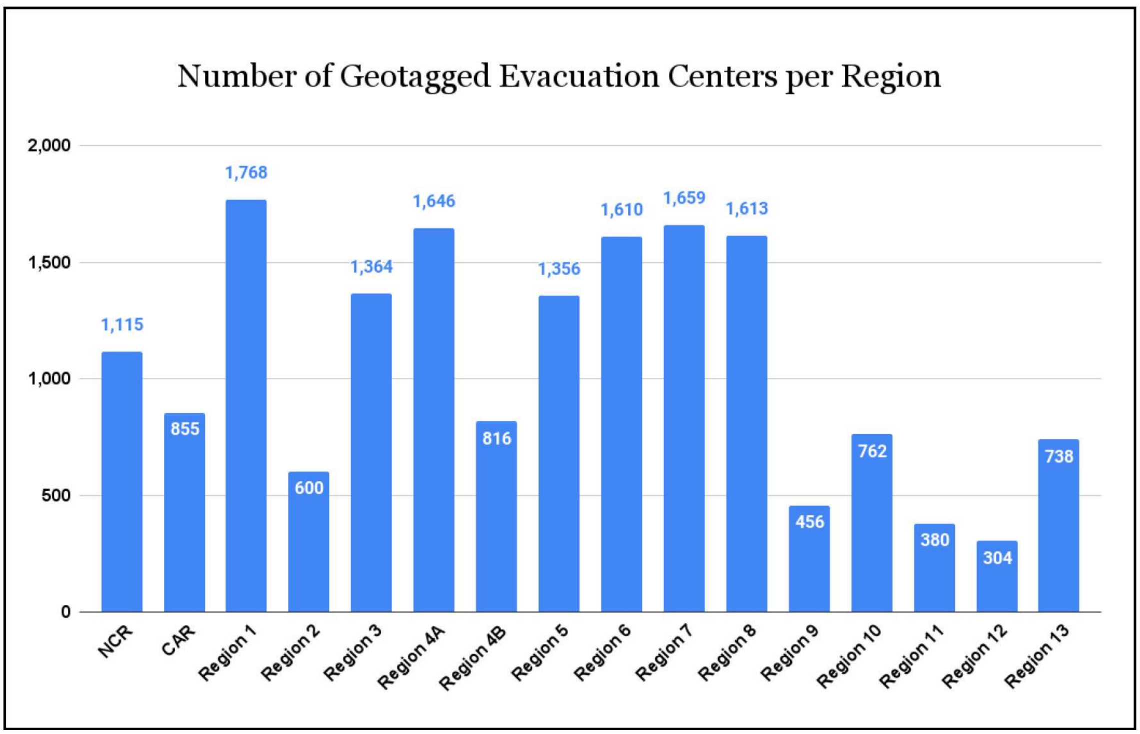

Figure 2. Number of geotagged evacuation centers for each region in the Philippines

Distribution of Geotagged Evacuation Centers

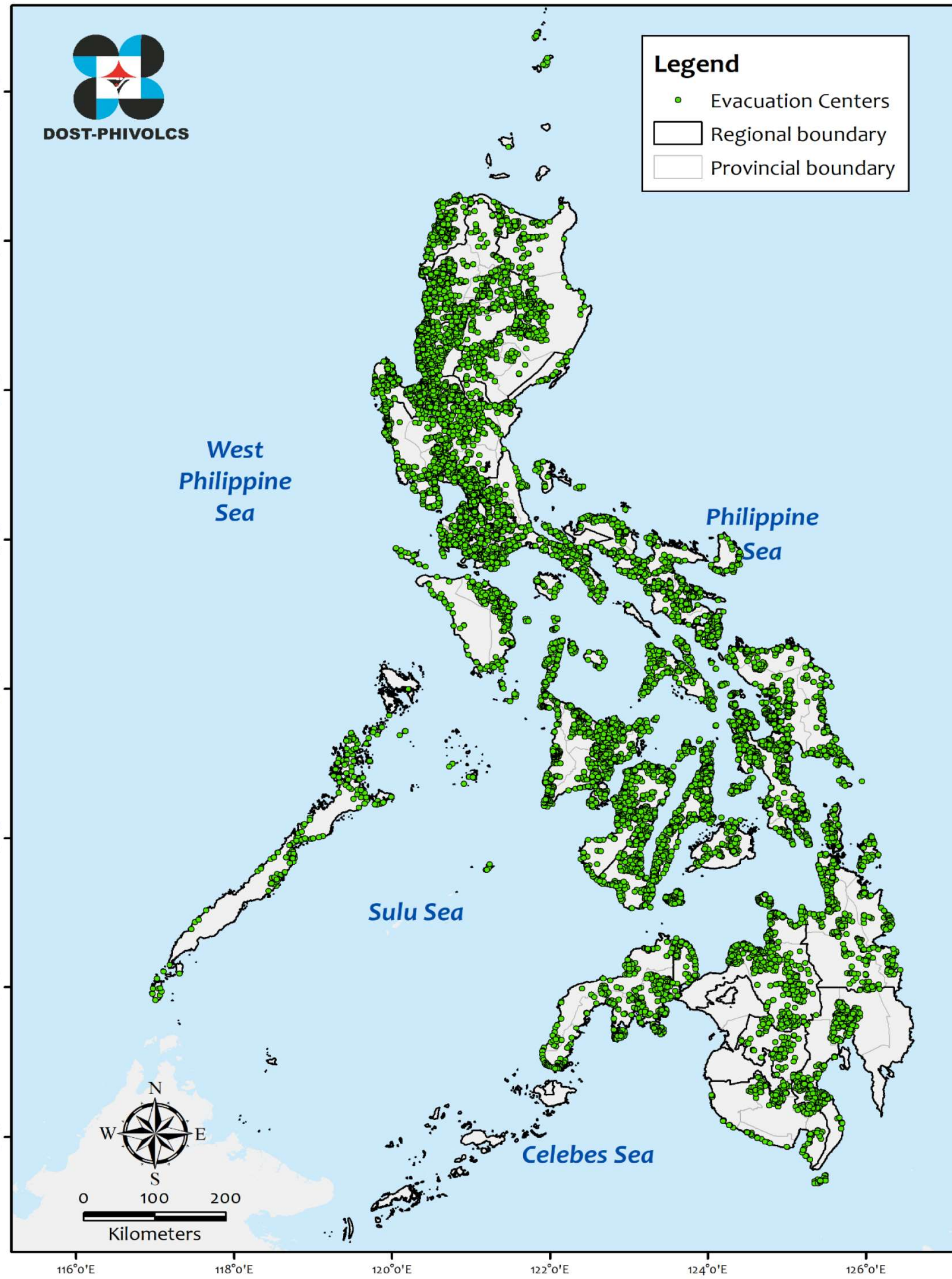

Figure 3. Distribution of geotagged Evacuation Centers in the Philippines

3.2 Building Use of ECs

The ECs were categorized according to type based on the evacuation center name indicated on the list and as validated in Google StreetView.

The eleven (11) categories and the number of geotagged ECs per category are shown in the table below.

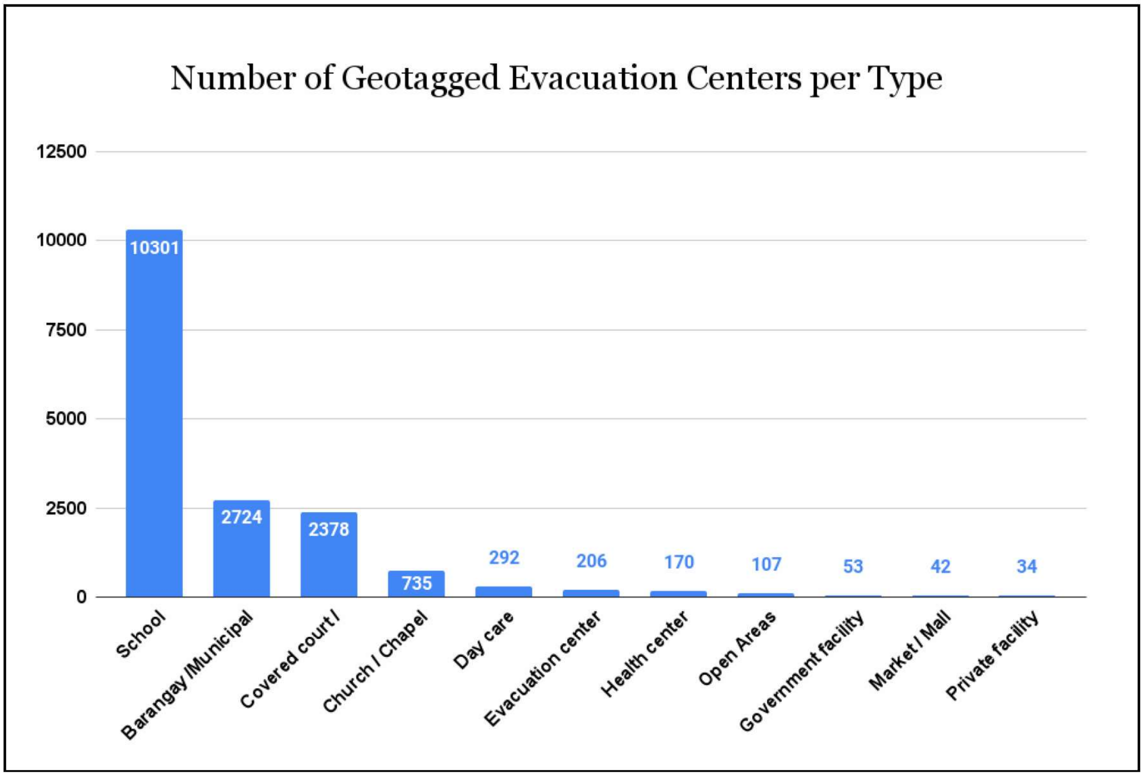

Figure 4. Number evacuation centers for each category based on observed building use

The results show that schools remain as the top site identified as potential evacuation centers with 10,301 tagged, a common practice in the country which, as a consequence, causes the disruption of classes and other school activities. Barangay, municipal, and multi-purpose halls were grouped together, adding to a total of 2,724 tagged as ECs. This is followed by covered basketball courts and/or sports complex buildings, with 2,378 tagged. There were only 206 purpose-built evacuation centers geotagged. This indicates that the majority of the areas identified as ECs are designed for other uses and only converted as such when the need arises before, during, and after disasters.

3.3 Susceptibility to Hazards

All 17,042 ECs were subjected to hazard analysis in terms of ground rupture, liquefaction, tsunami, lahar, pyroclastic density current, lava flow, flood, and rain induced landslide hazard.

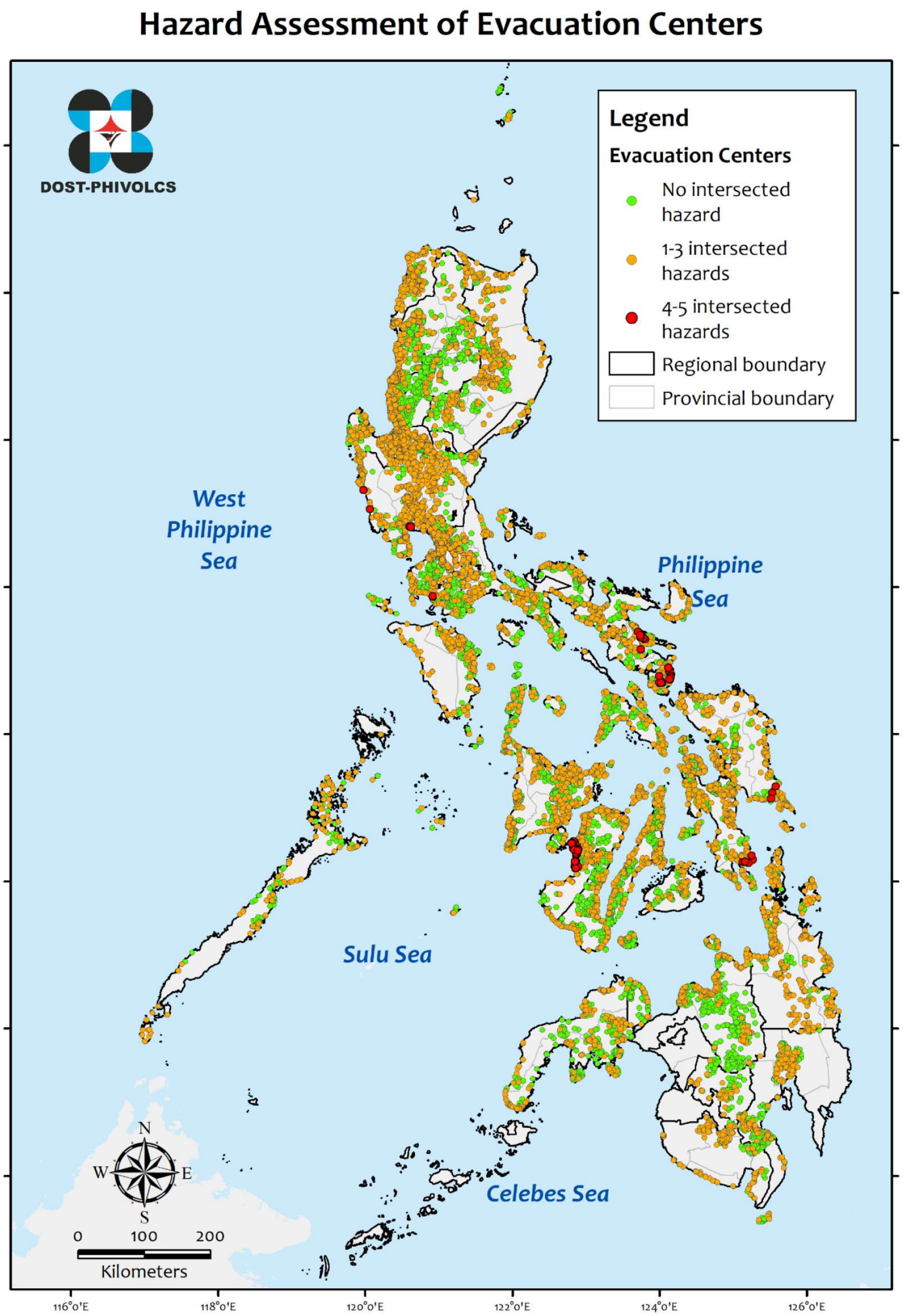

Figure 5. Hazard Assessment of the Evacuation Centers of the Philippines

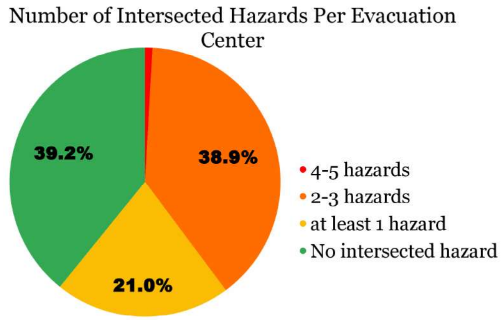

Figure 6. Geotagged Evacuation Centers exposed to Hazard

Based on these assessment results shown in Figure 6, 3,575 out of 17,042 ECs (21%) are exposed to at least 1 hazard, 6,637 ECs (38.9%) are exposed to 2-3 hazards, 151 ECs (1%) are exposed to 4-5 hazards, and 6,679 ECs (39.2%) are not intersected by any of the 8 hazards used in the analysis.

a. Hydro-meteorological

Flood

Flooding is one of the most frequent and damaging hazards in the world. The Philippines is a flood-prone country due to its geographic location, climate, and low elevations. The Mines and Geosciences Bureau has been conducting flood hazard assessment, which includes four categories: Low, Moderate, High, and Very High flood susceptibility. The description of each flood category is shown in Table 2.

Flood Susceptibility	Description
Low	Flood heights of 0.5 meter or less, with a flood duration of 1 to 3 days.
Moderate	Flood heights of greater than 0.5 meter up to 1 meter, with a flood duration of 1 to 3 days
High	Flood heights of greater than 1 up to 2 meters, with a flood duration of more than 3 days
Very High	Flood heights of greater than 2 meters, with a flood duration of more than 3 days

Table 2. Flood susceptibility categories

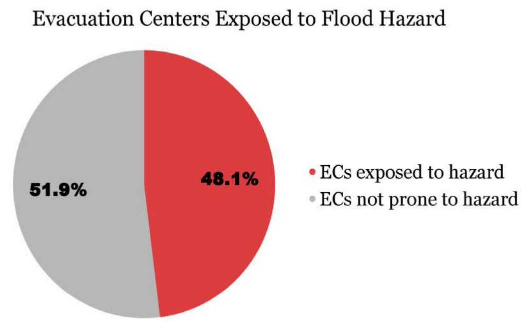

Figure 7. Geotagged Evacuation Centers exposed to Flood Hazard

Out of the 17,042 geotagged ECs, 8,185 (48.1%) are situated in flood-prone areas and 8,857 (52%) are not intersected by the flood hazard data (Figure 7). In terms of exposure per susceptibility level, Figure 8 shows that out of the 8,185 ECs prone to flood hazard, 603 (3.5%) are very highly susceptible, 2,065 (12.1%) are highly susceptible, 2,417 (14.2%) are moderately susceptible, and 3,100 (18.2%) are least susceptible.

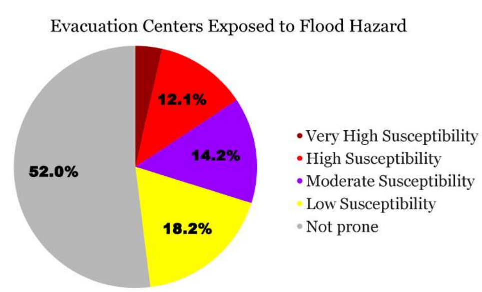

Figure 8. Geotagged Evacuation Centers exposed to Flood Hazard per susceptibility level

The implementation of appropriate mitigation measures as deemed necessary by project engineers and LGU building officials is recommended for areas that are susceptible to various flood depths. Site-specific studies including the assessment for other types of hazards should also be conducted to address potential foundation problems (MGB, 2018).

Rain-Induced Landslide

Rain-induced landslides (RIL) occur when the mass movement of rock, soil, and debris down a slope due to gravity is triggered by prolonged or heavy rainfall. Landslides may occur in offshore, coastal, or onshore environments. MGB's RIL information includes five categories: Depositional Zone, Low, Moderate, High, and Very High susceptibilities. The description of each category is shown in Table 3.

RIL Susceptibility	Description
Low	Gently sloping areas with no identified landslides
Moderate	Areas with moderately steep slopes where soil creep and other indications of possible landslide occurrence are present.
High	Areas with steep to very steep slopes that are underlain by weak materials, with the presence of numerous old/inactive landslides. These sites may be considered not suitable for permanent habitation but may be developed for alternative uses subject to the implementation of appropriate mitigation measures after performing site-specific geotechnical studies.
Very High	Areas with steep to very steep slopes that are underlain by weak materials, and have recent landslides, escarpments, and tension cracks present. These could be aggravated by human-initiated effects. These are considered as critical geohazard areas and are not suitable for development. Thus, it is recommended that these be declared as "No Habitation/No Build Zones" by the LGU, and that affected households/communities be relocated.
Depositional Zone	Areas along the debris flow path or accumulation zone could be affected by landslide debris materials. These are usually found at the base of slopes with manifestations of mass movement. These are considered as critical geohazard areas and may not be suitable for development. It is recommended that permanent habitation/development be avoided as remobilization of debris from previous landslide events may occur. In addition, relocation of settlements along debris flow paths is suggested.

Table 3. Rain-induced landslide susceptibility categories

Figure 9 shows the percentage of the ECs exposed to rain-induced landslide hazard. A total of 8,733 ECs (51.2%) are prone to the hazard, which includes 78 (0.5%) that are very highly susceptible, 1,026 (6%) highly susceptible, 2,047 (12%) moderately susceptible, 5,567 (33%) least susceptible, and 15 (0.1%) are in debris flow/possible accumulation zones (Figure 10). On the other hand, 8,309 ECs

(48.8%) are not prone to the hazard.

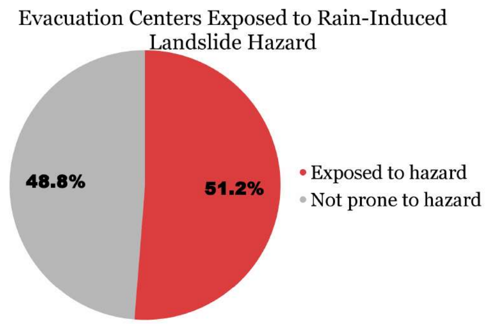

Figure 9. Geotagged Evacuation Centers exposed to Rain-Induced Landslide Hazard

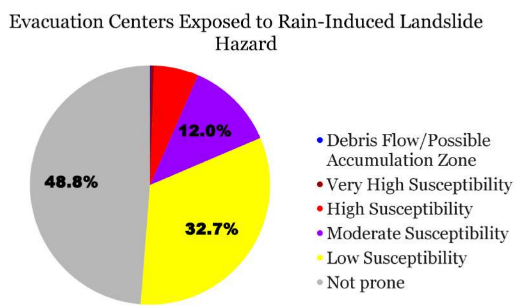

Figure 10. Geotagged Evacuation Centers exposed to Rain-Induced Landslide Hazard per susceptibility level

Implementation of appropriate mitigation measures as deemed necessary by project engineers and LGU building officials is recommended for landslide susceptible areas. This includes performing site-specific studies to address potential foundation or slope stability problems. Monitoring of signs or evidence of ground movement such as tension cracks, tilted trees and fences, and bulging road sections in areas that are moderately to critically susceptible to landslides should be done regularly and reported to local authorities (MGB, 2018).

b. Volcanic hazards

Lahar

Lahar is a volcanic hazard indirectly associated with eruption. It is sometimes called volcanic mudflows or debris flows. They are slurries of volcanic sediment, debris, and water that cascade down a volcano's slopes through rivers and channels. Lahars in tropical areas are mainly generated by torrential rainfall on unconsolidated deposits from a past eruption. These can also be triggered by the sudden draining of a crater lake or a collapsed natural or man-made dam or the movement of a Pyroclastic Density Currents (PDC) into a river or lake and eventual mixing with water (PHIVOLCS, 2018). Volcanoes with mapped lahar hazards used in the analysis include Banahaw, Bulusan, Cabalian, Kanlaon, Mayon, and Pinatubo.

As illustrated in Figure 11, 609 ECs (3.6%) ECs are susceptible to lahar hazard while the remaining 16,433 (96.4%) are safe from lahar.

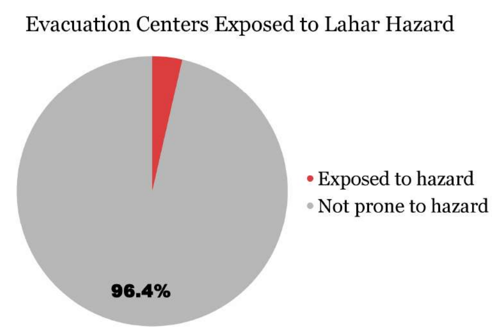

Figure 11. Geotagged Evacuation Centers exposed to Lahar Hazard

Lahar threat to people's lives can be addressed by 1) observing or implementing legal easement adjacent to river banks, as provided in existing laws, ordinances, and land-use plans, and 2) community preparedness and evacuation plan. At-risk communities must learn to evacuate themselves when lahar threats are imminent (PHIVOLCS, 2018).

Pyroclastic Density Currents

Pyroclastic Density Currents (PDCs) are mixtures of fragmented volcanic particles (pyroclastics), associated with an explosive volcanic eruption where it produces hot gasses and ash that run down the volcanic slopes or on the outer

regions from the source vent at high speeds. Base surges, a special class of PDC, are fast-moving and water-vapor-rich pyroclastic surges generated by explosive phreatomagmatic eruptions. PDCs are the most lethal of all volcanic hazards and can cause incineration, asphyxiation, abrasion, dynamic pressure impact, and burial in hot volcanic material (PHIVOLCS, 2018). Volcanoes with mapped PDC hazard include Banahaw, Bulusan, Cabalian, Kanlaon, Mahagnao, and Mayon.

Based on Figure 12, 368 ECs (2.2%) are prone to PDCs while the other 16,674 ECs (97.8%) are assessed as not prone from the hazard.

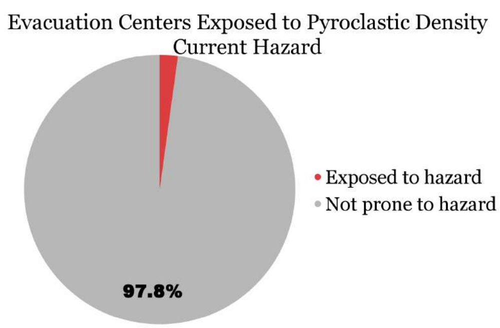

Figure 12. Geotagged Evacuation Centers exposed to Pyroclastic Density Current Hazard

Lava Flow

Lava flows are rivers of incandescent molten rock or lava moving downslope or away from an eruption vent. Steep slopes encourage faster and longer flows than areas with gentle slopes or terrain (PHIVOLCS, 2018). Volcanoes with lava flow hazard maps include Bulusan, Kanlaon, and Mayon.

In Figure 13, 33 ECs (0.2%) are prone to lava flow while the remaining 17,009 ECs (99.8%) are not prone to the hazard.

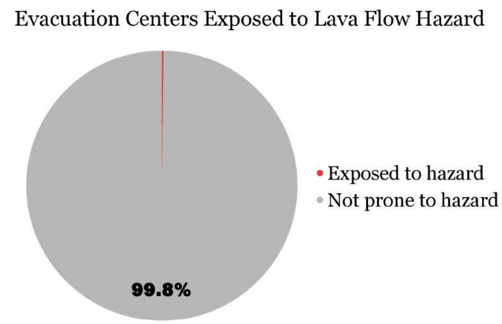

Figure 13. Geotagged Evacuation Centers exposed to Lava Flow Hazard

c. Seismic

Ground Rupture

During an earthquake, the occurrence of ruptures along the surface of an active fault can severely damage structures transected by and found within the proximity of the fissures (Selda et al., 2019). Ground rupture hazard refers to the deformation on the ground that marks the intersection of the fault with the earth's surface (PHIVOLCS, 2018). While the recommended buffer zone, or Zone of Avoidance, of PHIVOLCS against ground rupture is at least 5 meters on both sides of the active fault, for this study, given that the ECs data are point geometry, ECs within 300m of an active fault were assessed as prone to ground rupture.

Figure 14 shows that approximately 351 ECs (2.1%) are prone to ground rupture while 16,691 ECs (97.9%) are safe from the hazard.

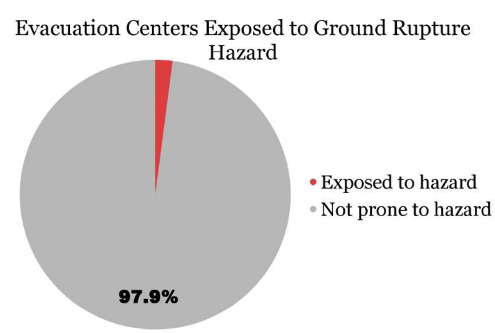

Figure 14. Geotagged Evacuation Centers exposed to Ground Rupture Hazard

Liquefaction

Liquefaction is a phenomenon wherein sediments, especially near bodies of water, behave like liquid similar to quicksand (PHIVOLCS, 2019). This may lead to sinking and/or tilting of structures above it, sandboil, or fissuring.

Out of the 17,042 ECs, 9,650 ECs (56.6%) are assessed as safe while 7,392 ECs (43.4%) are susceptible to liquefaction (Figure 15). Based on the analysis, 2,144 (12.6%) are highly susceptible, 1,038 (6.1%) are moderately susceptible, 1,078 (6.3%) are least susceptible, and 3,132 (18.4%) are generally susceptible to liquefaction hazard.

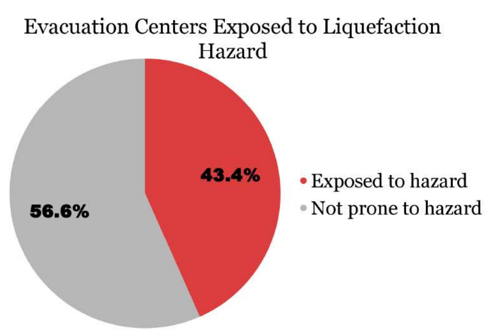

Figure 15. Geotagged Evacuation Centers exposed to Liquefaction Hazard

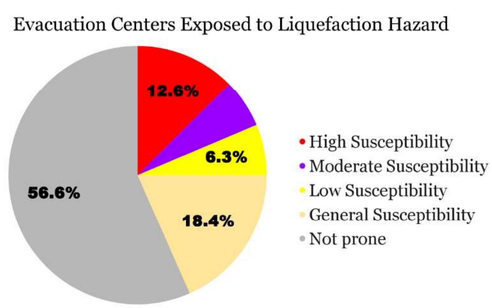

Figure 16. Geotagged Evacuation Centers exposed to Liquefaction Hazard per susceptibility level

The presence of liquefaction hazard does not restrict construction of any structure and development, for as long as proper engineering considerations are applied.

Liquefaction hazards can be mitigated by following the provisions of the National Building Code and the Structural Code of the Philippines (PHIVOLCS, 2020).

Tsunami

Tsunami refers to the series of waves caused commonly by an earthquake under the sea (PHIVOLCS, 2019). This may lead to flooding, coastal erosion; drowning of people, or damage to properties.

As shown in Figure 17, 2,350 ECs (13.8%) are exposed to tsunami hazard, 13,359 ECs (78.4%) are safe, and 1,333 (7.8%) belong to provinces whose tsunami hazard maps are still being updated.

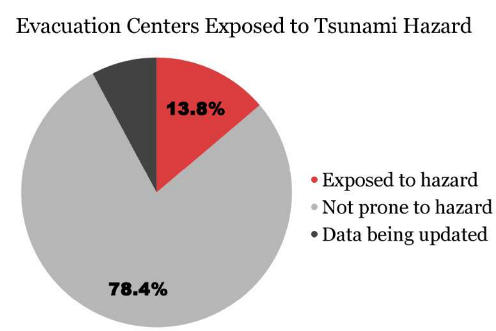

Figure 17. Geotagged Evacuation Centers exposed to Tsunami Hazard

The exposure of ECs to the hazard indicates that these ECs are located in cities or municipalities near or along the coast. Hence, the location of ECs in tsunami-prone areas must be re-evaluated. High-elevation sites and evacuation areas specific for tsunami hazard should be identified.

Tsunami threat to people's lives can be addressed by community preparedness and tsunami evacuation plan. Advice for tsunami evacuation comes from public agencies and local governments. But more importantly, coastal communities must learn to evacuate themselves when they recognize the three natural signs of tsunami, namely 1) strong ground shaking, 2) unusual rise or fall of sea level, and 3) strong or unusual sound coming from the sea (PHIVOLCS, 2020).

3.4 EC-to-Population Ratio

With the current number of geotagged ECs, the EC-to-population ratio was computed at the provincial and regional levels. Table 4 shows the results per region while Tables 5 and 6 show the provinces with the highest and lowest EC to population ratios computed.

Region	EC Count	EC to Population Ratio
NCR	1,115	1:12,094
CAR	855	1:2,103
1	1,768	1:2,998
2	600	1:6,143
3	1,364	1:9,107
4A	1,646	1:9,839
4B	816	1:3,957
5	1,356	1:4,485
6	1,610	1:4,941
7	1,659	1:4,872
8	1,613	1:2,819
9	456	1:8,499
10	762	1:6,592
11	380	1:13,799
12	304	1:16,123
13	738	1:3,801

Table 4. EC-to-Population ratio of each region in the Philippines

Province	EC Count	Population (PSA, 2020)	Ratio
NCR, City of Manila, First District	18	1,846,513	1:102,584
South Cotabato	40	1,672,791	1:41,820
Bulacan	137	3,708,890	1:27,072
NCR, Third District	171	3,861,951	1:22,585
Cavite	237	4,344,829	1:18,333

Table 5. Five provinces with the highest EC-to-Population ratio in the Philippines

The City of Manila ranks highest with a ratio of 1:102,584, followed by South Cotabato with 1:41,820, and Bulacan with 1:27,072. While the actual numbers vary, the ratio indicates that for every EC in Manila City, around 102,584 people should be accommodated.

Province	EC Count	Population (PSA, 2020)	Ratio
Mountain Province	210	158,200	1:753
Siquijor	91	103,395	1:1,136
Biliran	155	179,312	1:1,157
Abra	192	250,985	1:1,307
Dinagat Islands	94	128,117	1:1,363

Table 6. *Five provinces with the lowest EC-to-Population ratio in the Philippines*

Table 6 shows the five provinces with the lowest EC-to-Population ratios. Mountain Province ranks first in having the lowest EC-to-Population ratio with 1 EC for every 753 people, Siquijor with a ratio of 1:1,136, Biliran with a ratio of 1:1,157, Abra with a ratio of 1:1,307, and Dinagat Islands with a ratio of 1:1,363.

IV. Conclusion

The Philippines has been subjected to various natural hazards for the past decades. Major disasters can result in numerous loss of lives and destruction of livelihood and property. These disasters can also negatively impact assets, production factors, output, employment, or consumption (Hallegate and Przyluski, 2010). It is therefore crucial to establish and maintain an updated geospatial database of ECs at the national level to facilitate a systematic approach in evacuating vulnerable communities in times of disaster.

The result of the hazard assessment shows that 10,363 (60.8%) of the total 17,042 geotagged ECs are prone to at least one or more hazards. Though not included in this analysis, depending on the magnitude of an earthquake, all cities may experience ground shaking should movement occur along any earthquake sources (active faults and trenches) in the vicinity. Ashfall may also be experienced should eruptions take place in nearby active volcanoes. All sites are also prone to severe wind hazard.

As these ECs serve as temporary shelters for the population before, during, and after hazard events or disasters, and are established to protect people and minimize injuries and potential loss of lives, proper and adequate mitigation measures should be made based on the generated hazard assessment results such as the re-evaluation of the location and building conditions of existing ECs and the construction of dedicated ECs per city or municipality following the National Building Code of the Philippines. Majority of the identified ECs are schools, government buildings, or public spaces by design, hence may not be properly equipped to accommodate evacuees. Moreover, the high percentage of schools designated as evacuation centers can lead to interference of school activities.

Based on the spatial analysis of EC-to-Population ratio, the number of evacuees per EC is significantly high. Overcrowding in ECs can affect the evacuation process and relief operations and could raise various health and sanitation concerns like increased transmission of diseases (Ramos et al., 2015). Data on the floor area, capacity or number of persons and/or families the EC can support, the presence of available toilet facilities, building condition, and availability of non-potable water and food packs may be added as supplementary information for each identified EC for further analysis and studies

Once the ECs geodatabase is completed, analysis on the distribution of ECs per city or municipality and their accessibility and proximity to existing transportation and road networks is recommended.

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ANNEX

The detailed and summarized results of the hazard assessment of evacuation centers in the Philippines may be accessed or downloaded through this link:

https://docs.google.com/spreadsheets/d/1giwm421m5LdWINUu8gs5CBRgwgRhVzLJxOffdMcg8L8/edit?usp=sharing