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Exposure Analysis of Tacloban City's Humanitarian Supply Chain to Climate-Related Hazards: Towards a Risk-informed Site Selection Process

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Abstract

Public service continuity calls for facilities that can withstand the impacts of hazard events without significant damage or loss of functionality. Using geospatial analysis, the study evaluated the coastal City of Tacloban's critical point facilities (CPFs) and road network— those identified to provide essential support services in times of crisis - for exposure to sea-level rise (SLR) and the three other hazards of (1) flooding, (2) storm surge, and (3) rain-induced landslide. The study found that many of the City's CPFs and most road networks linking these facilities are at high risk of some, if not all, of these hazards. This finding substantiates the City's Super Typhoon (ST) Haiyan experiences, confirming weaknesses in the design of disaster supply chains that should be resolved to prevent further impacts on affected sectors. This study illustrates how the exposure analysis of humanitarian supply chain assets to various climate-related hazards can provide decision-makers with a firm understanding of the number and location of assets that may be compromised per hazard. Towards evidence-based decision-making, the paper elaborates on using Geographic Information Systems (GIS)-based conjunctive multi-criteria decision analysis (MCDA) for risk-informed site selection.

Keywords: hazard exposure analysis, climate-related hazards, humanitarian supply chain, public service continuity, Sustainable Development Goals 11

1. Introduction

Between 1998 and 2017, climate-related and geophysical disasters killed 1.3 million people and left a further 4.4 billion injured, homeless, displaced, or in need of emergency assistance globally. While most fatalities were due to earthquakes and tsunamis, 9 out of 10 disasters were attributed to extreme weather events (CRED and UNDRR, 2018). As a direct result of over 11,500 extreme weather events within the same decade, more than 526,000 people died worldwide, with losses estimated to be US $ 3.47 trillion, excluding costs of residual risks or unavoidable loss and damage (Eckstein et al., 2018). The Climate Change 2014 Synthesis Report warns that further global warming will amplify existing risks and create new risks for natural and human systems, including urban systems. The effects of heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea-level rise, and storm surges will be dire for those lacking essential infrastructure and services or living in exposed areas which may result in massive displacement (IPCC, 2015).

Recognizing that sustainable development and poverty eradication are significantly hampered by human and material losses due to disasters, rather than responding to disasters, the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030 shifted the focus towards addressing underlying factors that expose people, communities, and assets to risks and undermine their capacity to adapt to, respond, or bounce back from hazard events. Towards this end, the SFDRR seeks to "substantially reduce disaster damage to critical infrastructure and disruption of basic services by 2030" and "promote the mainstreaming of disaster risk assessments into land-use policy development and implementation, including urban planning" through multi-hazard approach and inclusive risk-informed decision-making (UNDRR, 2015). Among the sustainable development goal (SDG) targets is to "develop quality, reliable, sustainable, and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all" by 2030 (SDG 9.1).

Eckstein et al. (2020) analyzed the quantified impacts of extreme weather events on fatalities and economic losses from 1999-2018 in the Global Climate Risk Index (GCRI) 2020. The study noted the ten most affected countries in the last two decades, namely: 1) Puerto Rico, 2) Myanmar, 3) Haiti, 4) Philippines, 5) Pakistan, 6) Vietnam, 7) Bangladesh, 8) Thailand, 9) Nepal; and 10) Dominican Republic. The study also listed the ten most affected countries by extreme weather events in 2018, namely: 1) Japan, 2) Philippines, 3) Germany, 4) Madagascar, 5) India, 6) Sri Lanka, 7) Kenya, 8) Rwanda, 9) Canada; and 10) Fiji. In both indices, the Philippines is among the Top 5 countries threatened by extreme weather events and recurrent catastrophes from tropical cyclones.

The Philippines is uniquely exposed to a plethora of hazards, including recurrent typhoons, earthquakes, and active volcanoes. Between 1900 and 2014, the Disaster Risk Reduction in the Philippines Status Report indicates that typhoons exhibit extreme spatial variability, uneven distribution frequency, and extent of impact. The same report also notes that each year, about 20 tropical cyclones enter the Philippine territory on average, with approximately eight or nine making landfall, making them the most significant contributors to disaster damage in the country. Disaster records in the country show that cyclones resulting in landslides, storm surges, and floods have caused the most significant losses of life and property. Six super-scale events, including Super Typhoon Haiyan, caused 80 percent of these disasters (UNDRR, 2019). Along with a projected temperature increase of 1.8°–2.2°C and an increase in precipitation, with some days exceeding 300 mm of rain in 2050, sea levels are also expected to rise 48-65 cm by the year 2100 in the Philippines. This rate is faster than the global average of 30 cm (USAID, 2017). There is a strong impetus for mainstreaming disaster risk reduction and climate change adaptation (DRR-CCA) to improve resilience in the country.

Developing robust humanitarian supply chains (HSC) (e.g., Figure. 1) by strategically locating critical facilities in low-risk areas is crucial in building disaster resilience in the Philippines. Logistics serve two primary functions in the whole process of disaster risk reduction and management: 1) it is responsible for providing the needed resources and equipment for all operating units during disaster response, and 2) it guarantees the speedy recovery and rehabilitation of affected areas and population by ensuring the smooth flow of materials and other needs in the area of operation. Left exposed to natural hazards, damage to logistics facilities may have cascading effects within the HSC that may hamper the adequate flow of goods, services, and information from supply to where it is needed, exacerbating and potentially prolonging the suffering of affected populations (UP SURP, 2016). This paper examines the exposure of Tacloban's HSC to hydrometeorological hazards and sea-level rise towards improving service continuity through infrastructure resilience.

2. Study Area Situationer

Haiyan, which entered the Philippine Area of Responsibility (PAR) in November 2013, is considered the worst typhoon to ever hit the country in terms of damage to properties in the history of the Philippines. The National Disaster Risk Reduction and Management Council (NDRRMC) reported that, upon landfall, until it exited the PAR in less than a day, it caused PhP 93 billion in damages to nine regions, spread across 44 provinces, around 600 municipalities, and 57 cities. The report indicated that around 16 million individuals were affected, while over 5.1 million were displaced by its onslaught. Approximately 6,300 individuals were reported dead, 28,688 were injured, and 1,062 were reported as missing. An estimated 550,928 houses were destroyed, while 589,404 were partially damaged. The total cost of damage to infrastructure was estimated at around PhP 10 billion. In contrast, damage to the social sector is pegged at PhP 43 billion, the productive sector lost PhP 24 billion, and the cross-sectoral damage is estimated at PhP 3 billion. Affected provinces also suffered from power outages as 1,959 transmission facilities, including backbone transmission lines, steel poles, and converter stations, were damaged during Haiyan. Water supply was reported to be rationed in localities where supply is limited (NDRRMC-OCD, 2013).

As the Eastern Visayas region's central trade, industry, and education hub, Tacloban City is a highly urbanized city comprising 17 rural and 121 urban barangays (PhilAtlas.com). With 42 of the City's 138 barangays have coasts and lowlands that are occupied mainly by informal settler families (NDRRMC-OCD, 2013; p. 22), reports indicated 58,432 units as damaged housing, with urban poor dwellings accounting for nearly a third of these structures. Because thousands of families were left homeless and without food, water, clothes, and other necessities, and as roads were impassable for several days, delaying the arrival and distribution of relief goods, dire circumstances forced people to ransack and loot almost all stores and warehouses in the City (NEDA, 2014; p. 34).

Funded by the Department of Science and Technology (DOST), a team of researchers from the University of the Philippines School of Urban and Regional Planning (UP SURP) reviewed the performance of the HSC in Tacloban City in 2015, hoping to prevent the same experiences as that of Haiyan from re-occurring. The study found that many areas in the province of Leyte were unable to access aid or were underserved due to the following: 1) damaged transport networks and communications, which delayed relief operations for days; 2) inadequate supply levels; 3) poorly coordinated delivery of relief supplies, especially during the last mile distribution, and 4) supplies wastage due to inadequate warehousing facilities (UP SURP, 2016).

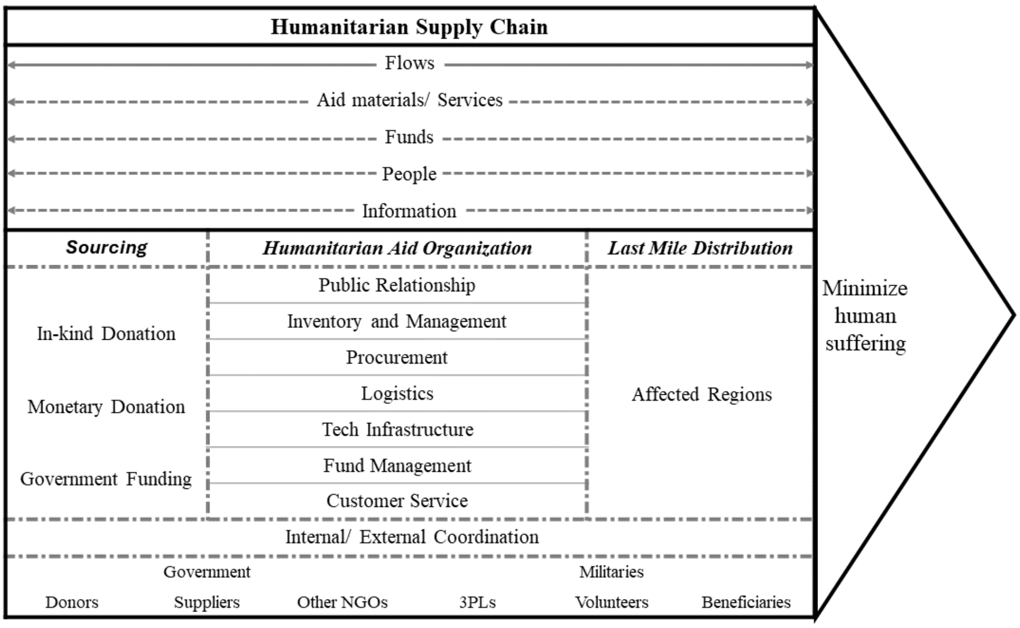

Figure 1. Framework for Humanitarian Supply Chain Management
Source: Yu et al., 2015

3. Methodology

Since local government units are mandated to serve as first disaster responders during disasters (RA 10121. Sec.15), they must be adequately equipped to carry out essential functions to meet the life preservation and basic subsistence needs of affected populations during disasters. On the other hand, the management of a HSC involves the integration and coordination of a large, dispersed group of experts to ensure the primary mission of humanitarian aid: "the delivery of products and services to the needy, whose immediate or long-term survival can depend on the efficient execution of operational activities of logistics and supply chain, including last mile distribution" (Argollo da Costa et al., 2012, p. 600). The effective and efficient performance of HSCs supports carrying out this essential function during disaster response as it enables the government, as the focal organization, to coordinate internally and with external actors and integrate various functions to respond to its constituent's needs. HSCs require the unhampered flow of goods and related information from the source to distribution until they reach their intended beneficiaries to alleviate suffering (Figure 1).

Public service continuity is defined as a public sector organization's capability to continue delivering services at acceptable predefined levels following a disruptive incident. This includes a wide range of emergencies, including localized acts of nature, accidents, and technological or attack-related emergencies. For government agencies to remain responsive and perform essential functions, there is a need to secure vital resources — all assets, people, skills, information, technology (including plant and equipment), premises, and supplies and information (whether electronic or not) that must be available to use when needed, to operate and meet its objective. There is also a need to establish, implement, and maintain appropriate procedures for managing the immediate consequences of disruptive incidents (PDRF and NDRRMC 2020). Towards this end, it is crucial to understand how critical point facilities (CPFs) that provide essential socio-economic support services, such as schools, hospitals/rural health units, local government buildings, roads, bridges, air/ seaports, communication towers, and power-related and water-related facilities (HLURB, 2015) can be impacted by various hazards. To inform disaster response planning, this study focuses on conducting a risk assessment on the physical assets comprising the HSC to understand the nature of risk and its characteristics as well as its potential consequences for service delivery (Figure 2).

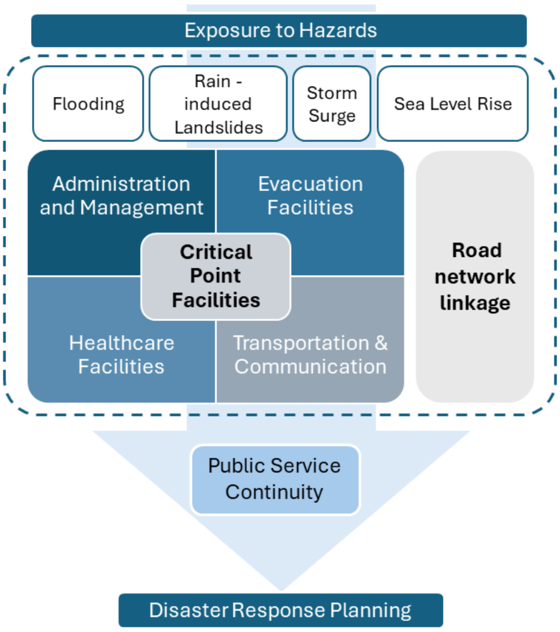

Figure 2. Conceptual Framework for the Study

The study examined the HSC infrastructure from the entry point (airports and seaports), circulation (roads and bridges), stockpiling (warehouses), and distribution (evacuation centers, barangay (village) halls, and hospitals) using a georeferenced inventory of facilities (Table 1). Based on this premise, the first part of this study investigated the exposure of critical point facilities and road networks to various hydro-meteorological risks and sea-level rise through geospatial analysis. The road network included routes to and from the entry point of goods to the warehouses where these are processed and stored (distribution hubs) for eventual distribution to barangay (village) halls, evacuation centers, and, in the case of medical supplies, to healthcare facilities (distribution outlets) where affected populations may access these. Hence, the road network considered all primary, secondary, and tertiary or residential roads in the study area.

Table 1. Inventory of Critical Point Facilities

Type	No.
Health Care Facilities	
Hospitals	1
District Health Centers	13
Barangay Health Stations	0
Total	14
Evacuation Facilities	
Evacuation Centers	0
Schools	113
Recreational Buildings	72
Churches	33
Day Care Centers	37
Total	254
Administration and Management	
Social Welfare Offices	9
Senior Citizen Center	1
Government Buildings	141
Protection Services Facilities	11
Storage (Warehouses)	*2*
Total	164
Transportation and Communications	
Transportation Terminals	5
Seaport	1
Airport	1
Fuel Station	21
Communication Facilities	9
Total	37
Total number of CPFs	**469**

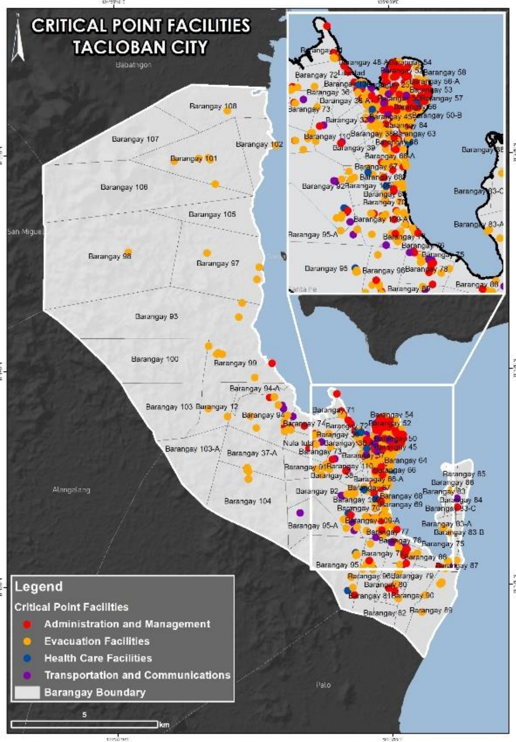

Figure 3. Critical Point Facilities Map

Tacloban City's CPFs (Table 1 and Figure. 3) and road network linkages (Figure 4) were examined for exposure to the following hazards: (a) sea-level rise (Figure 5), (b) flooding (Figure 6), (c) rain-induced landslide (Figure 7), and (d) storm surge (Figure 8) using geospatial and raster analysis to determine the extent of these hazards' effect on the system. The hazard data were based on the following assumptions: (a) 100-year-rain return for flood hazard, (b) 5.00m maximum tide of height for storm surge, and (c) 1.50m maximum height for sea-level rise. The study also investigated the effects of combined hazards on these physical assets (Figure 9). The hydro-meteorological hazard maps were from the Nationwide Operational Assessment of Hazards (NOAH) Center of the University of the Philippines (UP). The land use data was derived from existing land use maps in the City's draft Comprehensive Land Use Plan (CLUP) 2012, supplemented by secondary data sources like maps, documents, and reports from the local planning office. The road network data was derived from OpenStreetMap (OSM). The study used the process for exposure analysis contained in the Housing and Land Use Regulatory Board's (HLURB) Supplemental Guidelines on Mainstreaming Climate Change and Disaster Risks in the Comprehensive Land Use Plans (2015) to identify the potential impacts and the spatial manifestations of climate change concerning the HSC assets.

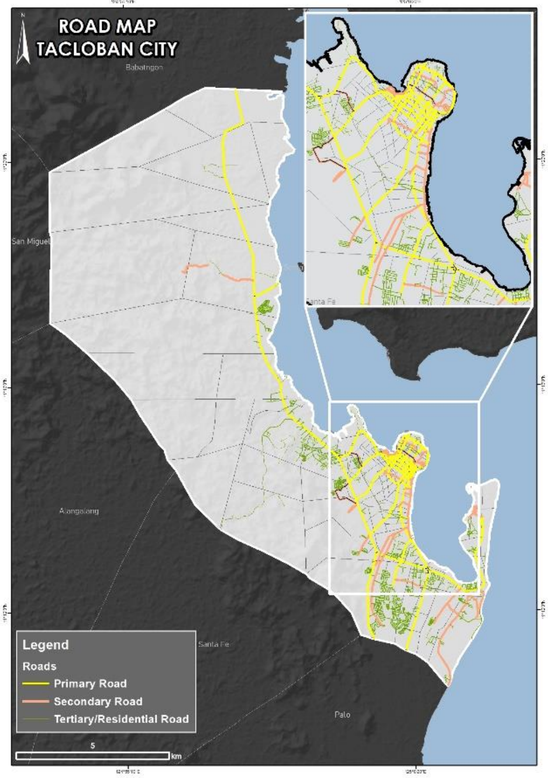

Figure 4. Road Network Map

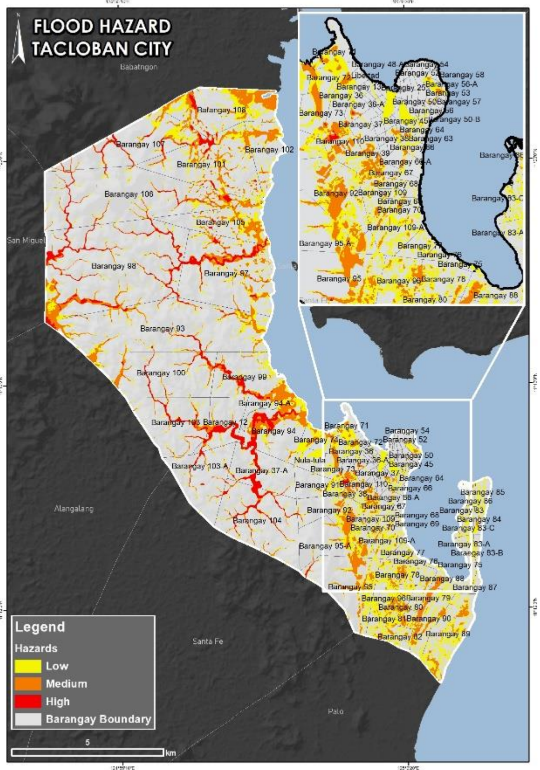

Figure 6. Flood Hazard Map

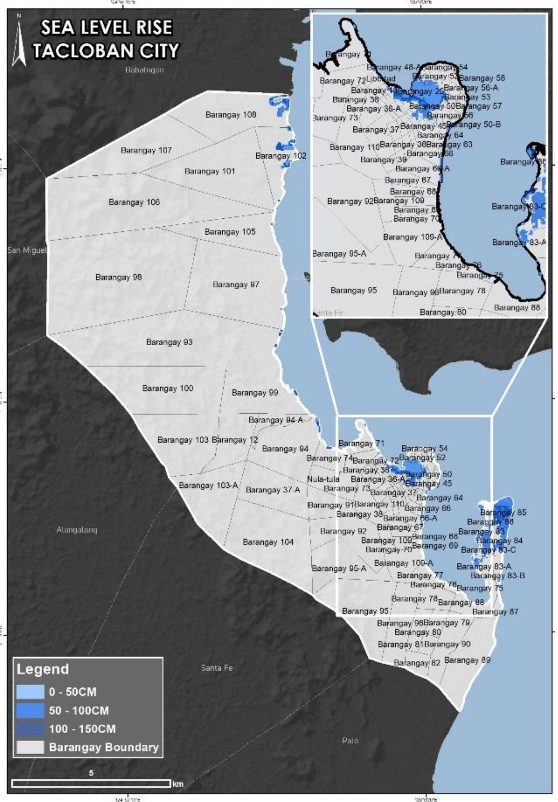

Figure 5. Sea Level Rise Map

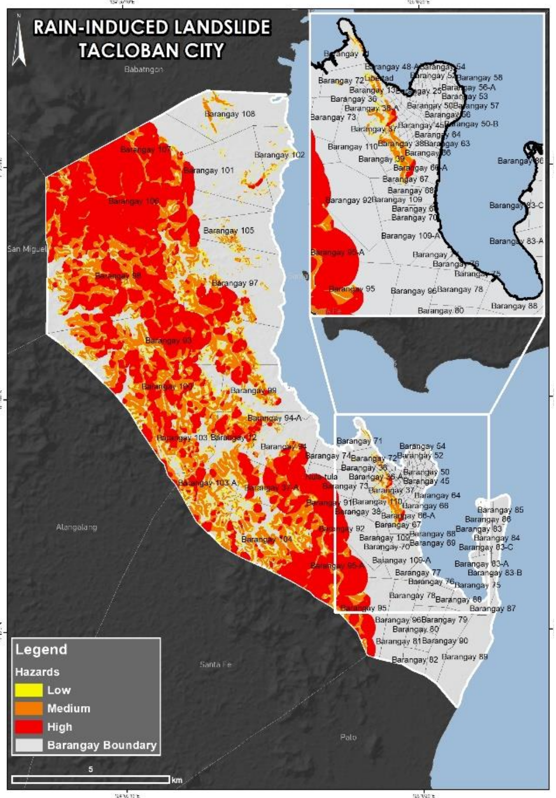

Figure 7. Rain-induced Landslide Hazard Map

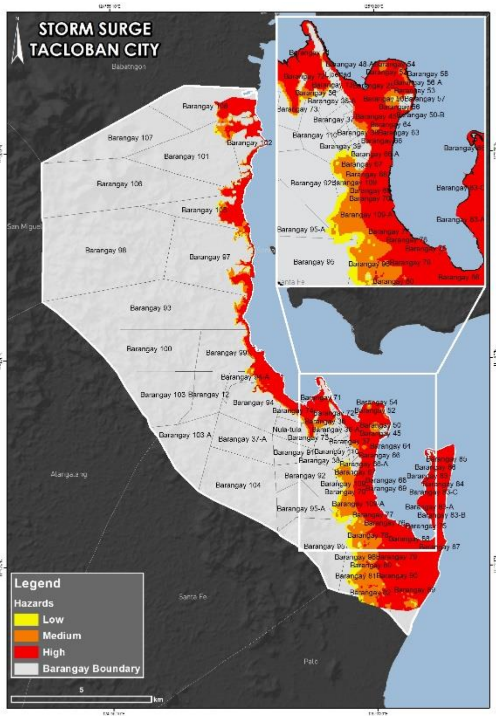

Figure 8. Storm Surge Hazard Map

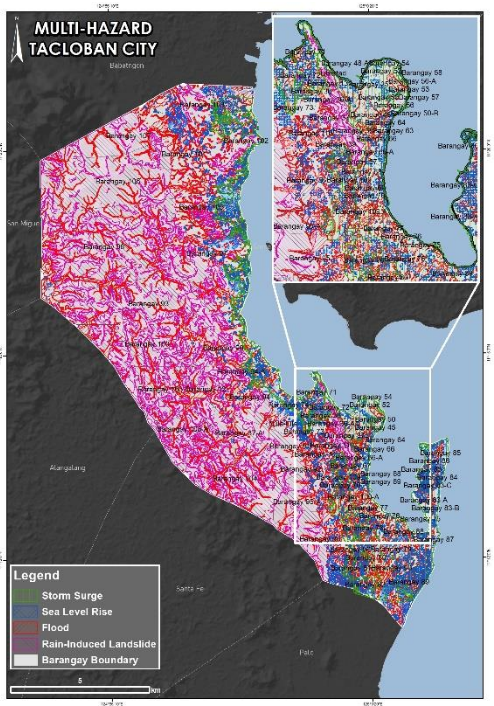

Figure 9. Multi-hazard Map

The second part of the study identified suitable areas for consideration in relocating critical point facilities using Geographic Information Systems (GIS) through a conjunctive multi-criteria decision analysis (MCDA) technique. This type of GIS overlay analysis is risk-averse and only accepts alternatives if they meet a cut-off value on every criterion (Greene et al., 2011). The overlay analysis was carried out on two levels to ensure that the lands identified are hazard-free and that no land-use conflicts exist among the potential sites.

The Potentially Suitable Areas were derived by subtracting hazard-prone areas from the territory (Figure 10). The Environmentally Suitable Areas were derived by further removing areas tagged as forest zones, protected areas, steeply sloping areas, environmentally sensitive areas, built-up areas, and Strategic Agricultural and Fisheries Zones (SAFDZ) (Figure 11).

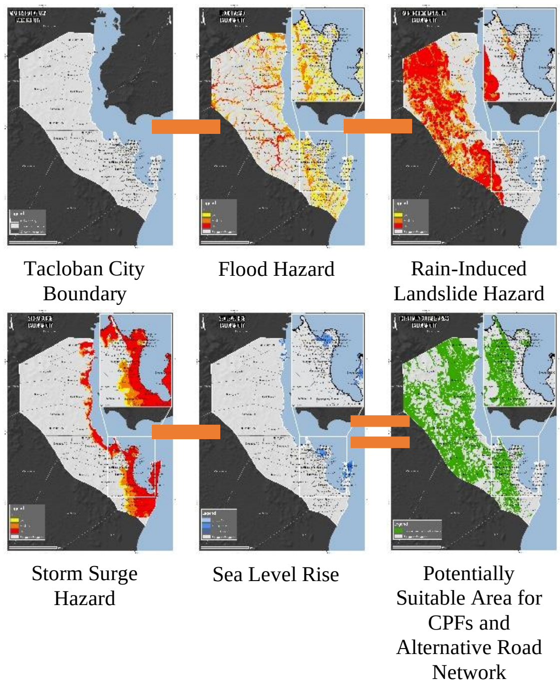

Figure 10. Illustration of the Process Used to Determine Potentially Suitable Land for Locating CPFs and Alternative Road Networks using GIS

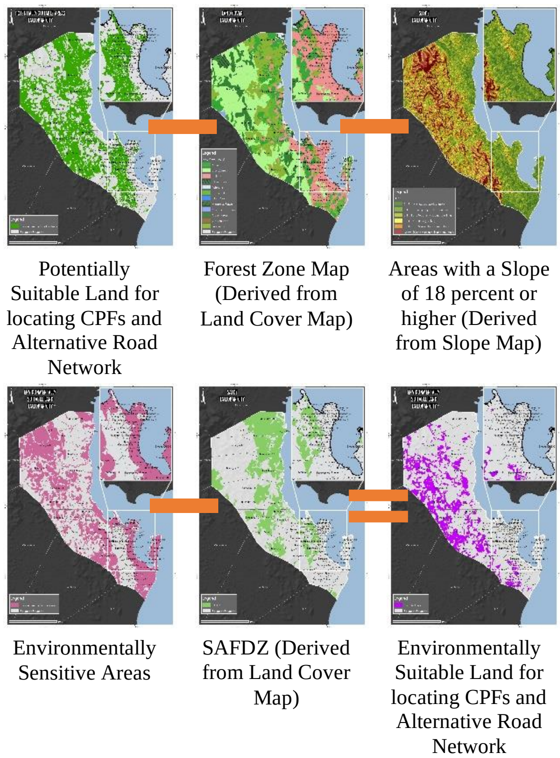

Figure 11. Illustration of the Process Used to Determine Environmentally Suitable Land for Locating CPFs and Alternative Road Networks using GIS

4. Results and Discussion

Tacloban City has a total land area of 20,172 hectares. Ranging from low to high exposure, it was found that flooding will likely affect 11.82 percent of its land area, while storm surges will affect 11.39 percent of its land area. On the other hand, rain-induced landslides will likely affect 25.01 percent of its land area. Sea level rise, indicated as a) 0-50 cm as low, b) 50-100 cm as moderate, and c) 1.00-1.5m as high risk, will affect none under the low scenario, less than one percent under the moderate scenario; and over 11 percent under the high scenario. Areas prone to multi-hazard account for 40.13 percent of Tacloban City's land area (Table 2).

Table 2. Land Area Affected per Hazard

Categories	Low *(has)*	Moderate *(has)*	High *(has)*
Flood	1,175.20 *(5.83%)*	908.00 *(4.50%)*	301.70 *(1.50%)*
Storm Surge	154.30 *(0.76%)*	488.00 *(2.42%)*	1655.00 *(8.20%)*
Rain induced Landslide	449.20 *(2.23%)*	1,760.10 *(8.73%)*	2,835.90 *(14.06%)*
Sea Level Rise	0.00 *(0 %)*	17.24 *(0.09%)*	2,246.48 *(11.14%)*
Multi-hazard	944.30 *(4.68%)*	2,617.90 *(12.98%)*	4,532.30 (22.47%)

4.1 Critical Point Facilities Exposure to Various Hazards

The review of HSC included 469 facilities, which were examined for their vulnerability to various hazards. These facilities included telecommunication facilities crucial to maintaining a constant flow of information, as well as transportation-related facilities like fuel stations, transport terminals, and ports. The study revealed that 64.11 percent of all these facilities are in areas highly susceptible to various hazards (Table 3).

4.1.1 Sea Level Rise (SLR)

According to the Department of Environment and Natural Resources-Land Management Bureau, the Philippines has a highly irregular coastline that spans 36,289 kilometers, making it one of the top eight countries likely to be affected by rising sea levels. A recent study suggests that the country may experience a five- to ten-fold increase in populations estimated to be below the projected high tide line. The study also indicates that the government will likely face more frequent coastal flooding due to rising sea levels (Kulp & Strauss, 2019). In 2015, the International Development Research Centre (IDRC) reported that, on average, sea levels around the world rise 3.10 cm every ten years, with SLR in the Philippines projected to increase between 7.6 and 10.2 cm each decade. The study assumes that sea-level rise hazards are classified into three categories: low risk (0-50 cm), moderate risk (50-100 cm), and high risk (100-150 cm). A significant portion of Tacloban City's highly developed urban area is located on the shore, making it vulnerable to coastal flooding due to sea-level rise.

A preliminary SLR assessment of Tacloban City using Climate Central's Coastal Risk Screening Tool — an interactive map showing areas threatened by sea level rise and coastal flooding using high-resolution airborne lidar data (Climate Central, 2020), suggests that despite the city's relatively high altitude, with most of its terrain exceeding 1.00 m in height, Tacloban may still face coastal inundation when the sea-level rise reaches 50 cm. While this initial review indicates that sea-level rise may impact less than 10 percent of the city's critical facilities, it can affect the Tacloban Airport— a vital entry point for aid workers and other forms of support into the city as well as the Tacloban City Astrodome (Table 3).

Table 3. Critical Point Facilities Exposure to Sea Level Rise

Categories	Number	SLR Low (0-50 cm)	SLR Moderate (50-100 cm)	SLR High (100-150 cm)
Administration & Management	164	6 *(3.66%)*	8 *(4.88%)*	18 *(10.98%)*
Evacuation Facilities	254	5 *(1.97%)*	12 *(4.72%)*	19 *(7.48%)*
Health Care Facilities	14	0 *(0 %)*	0 *(0 %)*	1 *(7.14%)*
Transportation & Communications Facilities	37	1 *(2.70%)*	3 *(8.11%)*	4 *(10.81%)*
Total	469	12 *(2.56%*	23 *(4.90%)*	42 *(8.96%)*

4.1.2 Flooding

The analysis found that 1) more than 25 percent of the 469 CPFs in the study area are low, 2) 5.35 percent are moderate, and 3) 1.50 percent have high exposure to flooding. By category, a) 28.05 percent of the facilities under the administration and management cluster; b) 35.03 percent of the evacuation facilities; c) 42.85 percent of healthcare facilities; and d) 32.44 percent of transportation and communications facilities are at varying levels of exposure to flooding (Table 4).

Table 4. Critical Point Facilities' Exposure to Flooding

Categories	Number	Low	Moderate	High
Administration & Management	164	38 *(23.17%)*	6 *(3.66%)*	2 *(1.22%)*
Evacuation Facilities	254	68 *(26.77%)*	17 *(6.69%)*	4 *(1.57%)*
Health Care Facilities	14	5 *(35.71%)*	0 *(0 %)*	1 *(7.14%)*
Transportation & Communications Facilities	37	10 *(27.03%)*	2 *(5.41%)*	0 *(0 %)*
Total	469	121 *(25.80%)*	25 *(5.35%)*	7 *(1.50%)*

4.1.3 Rain-Induced Landslides (RIL)

The study found that about 1) 25.59 percent of the CPFs are at low, 2) 5.33 percent are at moderate, and 3) 1.49 percent are at high exposure to rain-induced landslides. By category, a) 27.44 percent of the facilities of the administration and management cluster; b) 35.04 percent of the facilities of the evacuation facilities; c) 42.86 percent of healthcare facilities; and d) 32.43 percent of transportation and communications facilities are at varying levels of exposure to RIL (Table 5).

Table 5. Critical Point Facilities Exposure to Rain-Induced Landslides (RIL)

Categories	Number	Low	Moderate	High
Administration & Management	164	37 *(22.56%)*	6 *(3.66%)*	2 *(1.22%)*
Evacuation Facilities	254	68 *(26.77%)*	17 *(6.69%)*	4 *(1.57%)*
Health Care Facilities	14	5 *(35.71%)*	0 *(0 %)*	1 *(7.14%)*
Transportation & Communications Facilities	37	10 *(27.03%)*	2 *(5.41%)*	0 *(0 %)*
Total	469	120 *(25.70%)*	25 *(5.33%)*	7 *(1.49%)*

4.1.4 Storm Surge

Tacloban City's CPFs are threatened by storm surge exposure, with 1) 2.35 percent found at low, 2) 13.43 percent at moderate, and 3) 53.73 percent at high. Almost 70 percent of these HSC facilities are exposed in various levels: a) 60.9 percent of the administration and management cluster, b) 74.02 percent of the facilities of the evacuation facilities, c) 57.14 percent of healthcare facilities; and d) 81.08 percent of transportation and communications facilities are at varying levels of exposure to storm surge (Table 6).

Table 6. Critical Point Facilities' Exposure to Storm Surge

Categories	Number	Low	Moderate	High
Administration & Management	164	4 *(2.44%)*	19 *(11.59%)*	79 *(48.17%)*
Evacuation Facilities	254	7 *(2.76%)*	36 *(14.17%)*	145 *(57.09%)*
Health Care Facilities	14	0 *(0 %)*	2 *(14.29%)*	6 *(42.86%)*
Transportation & Communications Facilities	37	0 *(0 %)*	6 *(16.22%)*	24 *(64.86%)*
Total	469	11 *(2.35%)*	63 *(13.43%)*	254 (54.16%)

4.1.5 Exposure to Multi-Hazards

Over 76 percent of Tacloban City's critical point facilities are exposed to combined hydro-meteorological risks of flooding, rain-induced landslides, storm surge, and sea-level rise; 1) 5.97 percent at low, 2) 15.99 percent at moderate, and 3) 54.80 percent at high. By category, a) 59.76 percent of the administration and management cluster, b) 87.01 percent of the facilities of evacuation facilities, c) 71.43 percent of healthcare facilities, and d) 83.78 percent of transportation and communications facilities are at varying levels of multi-hazard exposure (Table 7).

Table 7. Critical Point Facilities Exposure to Multi-Hazards

Categories	Number	Low	Moderate	High
Administration & Management	164	7 *(4.27%)*	22 *(13.41%)*	71 *(42.77%)*
Evacuation Facilities	254	20 *(7.87%)*	44 *(17.32%)*	157 *(61.81%)*
Health Care Facilities	14	1 *(7.14%)*	2 *(14.29%)*	7 *(50.00%)*
Transportation & Communications Facilities	37	0 *(0.00%)*	7 *(18.92%)*	24 *(64.86%)*
Total	469	28 *(5.97%)*	75 *(15.99%)*	257 *(54.80%)*

4.2 Hazard Exposure of Road Networks Linking the HSC

Tacloban City Port (Main Hub) is Leyte's entry point for aid provisions. These goods are transferred to the following Distribution Hubs: a) Tacloban City Astrodome and b) Department of Social Welfare and Development (DSWD) Warehouse for further processing or repacking, as needed, before being sent to the various Distribution Outlets. The study traced the flow of goods through network analysis from the Main Hub to the Distribution Hubs and then to: a) 254 evacuation centers for food and non-food items, and b) 14 healthcare facilities in the case of medical supplies and equipment, where beneficiaries gain access to aid (see HSC routes in Table 8, Figures 10, 11, 12 and 13).

Table 8. Humanitarian Supply Chain (HSC) Routes

From	To	Number of Routes	Total Length
Tacloban City Port (Main Hub)	Tacloban City Astrodome (Distribution Hub 1)	1	3.17 km
	DSWD Warehouse (Distribution Hub 2)	1	2.43 km
Tacloban City Astrodome (Distribution Hub 1)	Evacuation Centers	113	483.07 km
	Barangay Halls	80	207.51 km
	Healthcare Facilities	14	37.59 km
DWSD Warehouse (Distribution Hub 2)	Evacuation Centers	111	459.43 km
	Barangay Halls	80	196.61 km
	Healthcare Facilities	13	37.69 km

A network analysis was likewise conducted to determine which parts of 469 HSC routes would be affected by various hazards. All paths linking these facilities together were included in the analysis. Out of the 2,445.80 km of roads in Tacloban City, 1,427.50 km of roads comprising the humanitarian supply chain network were overlaid onto the hazard maps to determine the extent of its exposure to various climate-related hazards (Figures. 12, 13, 14, and 15).

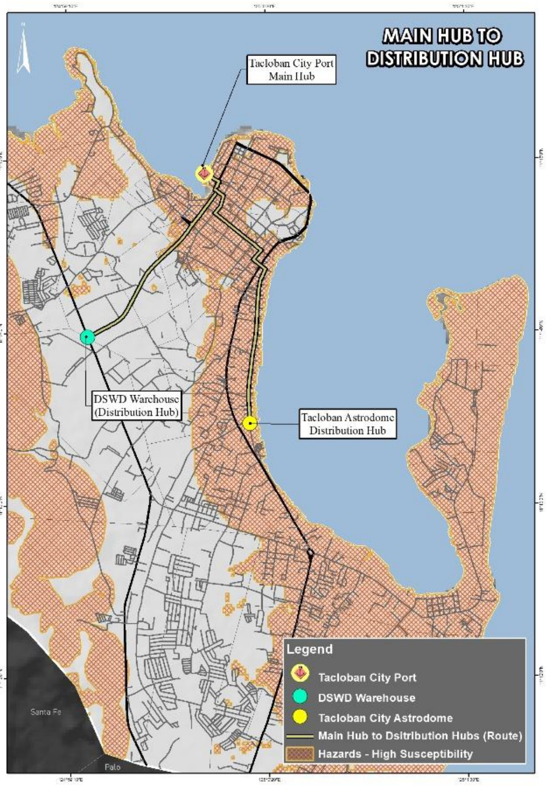

Figure 12. Multi-hazard Analysis of the Main Hub to Distribution Hub Route Map

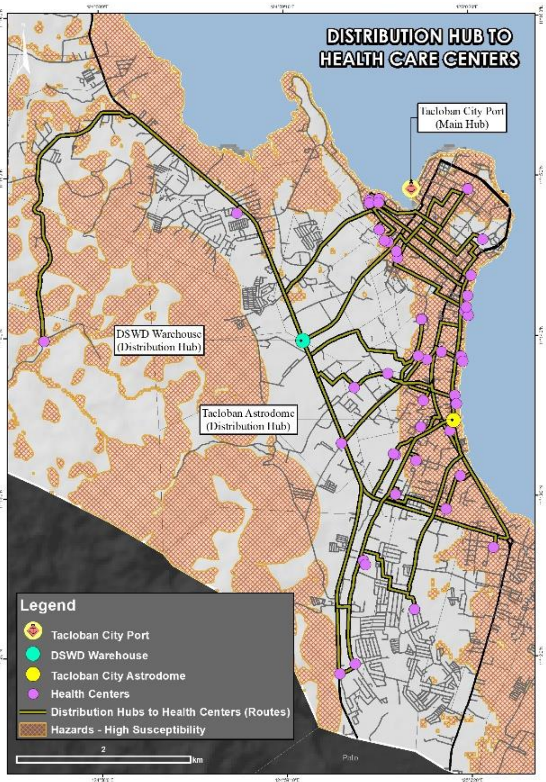

Figure 14. Multi-hazard Analysis of the Distribution Hub to Healthcare Centers Route Map

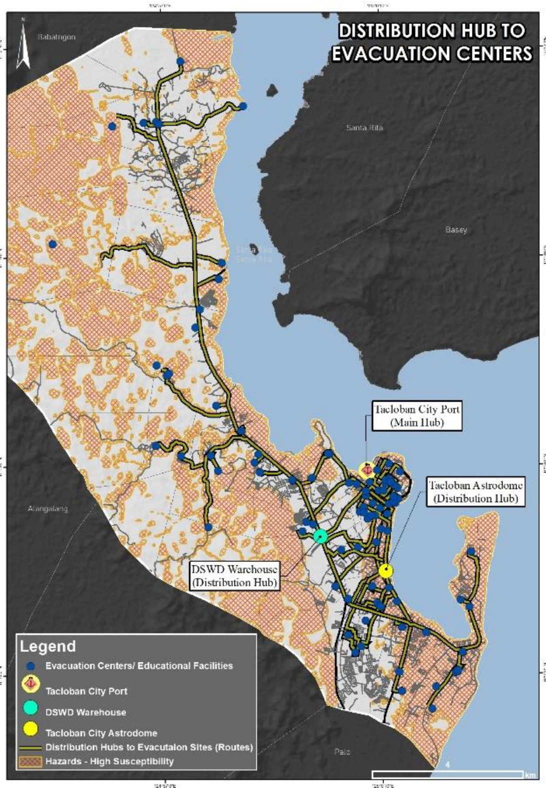

Figure 13. Multi-hazard Analysis of the Distribution Hub to Evacuation Centers

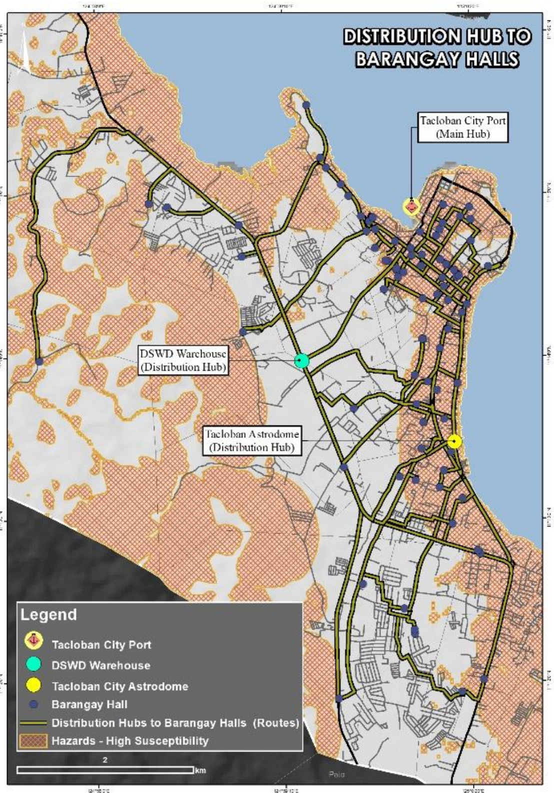

Figure 15. Multi-hazard Analysis of the Distribution Hub to Barangay Halls Route Map

The study found that a) 226.41 km is exposed to flooding, b) 352.87 km is exposed to storm surge, c) 27.79 km is exposed to rain-induced landslides, d) 27.79 km is exposed to sea-level rise, while e) 468.58 km is exposed to multi-hazards. When combined, 1114.94 km, about 78 percent of the routes identified in the study are exposed to various hazards (Table 9).

Table 9. HSC Routes Exposure to Various Hazards

Categories	Low (km)	Moderate (km)	High (km)	Total (km)
Flood	167.64	52.14	6.63	*226.41*
Storm Surge	33.62	98.24	221.01	*352.87*
Rain-induced Landslide	3.84	4.40	19.55	*27.79*
Sea Level Rise	7.45	11.57	20.27	*39.29*
Multi-hazards	93.80	124.2	250.49	*468.49*

4.3 Implications of Exposure Analysis to Humanitarian Supply Chain Facilities Planning

In line with the SFDRR 2015 – 2030 outcome on "preventing new and reducing existing disaster risks through the implementation of integrated and inclusive… measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience" prevention and mitigation is one of the pillars supporting the National Disaster Risk Reduction and Management Plan (NDRRMP) 2011-2028 vision for the country of "safer, adaptive and disaster resilient Filipino communities toward sustainable development." Avoiding hazards and mitigating their potential impacts requires a proactive understanding of hazards, risks, and vulnerabilities of population, assets, and the environment and factoring in climate and disaster risk assessment information into planning, investment, and development decisions (HLURB, 2015).

RA 10121, known as the Philippine Disaster Risk Reduction and Management Act of 2010, mandates government agencies to continue their operations and essential functions regardless of any disaster to provide "maximum care, assistance, and services to individuals and families affected by disaster, implement emergency rehabilitation projects to lessen the impact of a disaster and facilitate the resumption of normal social and economic activities" (Sec.2 (p)). The study provides an understanding of the hazard exposure of Tacloban City's HSCs. Per the review, more than 76 percent of the critical point facilities and more than 78 percent of the routes linking these are in areas highly exposed to multiple hazards (Figure 16). The Tacloban City Port, which serves as the entry point for aid provisions in Leyte, as well as the Tacloban City Astrodome, which serves as one of the two Distribution Hubs, are also situated along the coast that is at high-risk exposure to multiple hazards.

Tacloban Airport is exposed to the threats of SLR along with other facilities located on the coast. Substantial portions of the routes connecting the Distribution Hubs to the Evacuation Facilities, Health Care Facilities, and Barangay Halls are also exposed to various threats. The findings on the exposure of the physical assets comprising Tacloban's HSC validate the findings of previous studies and existing literature on damages incurred during Haiyan. The study puts forward the following recommendations to prevent future service delivery disruptions.

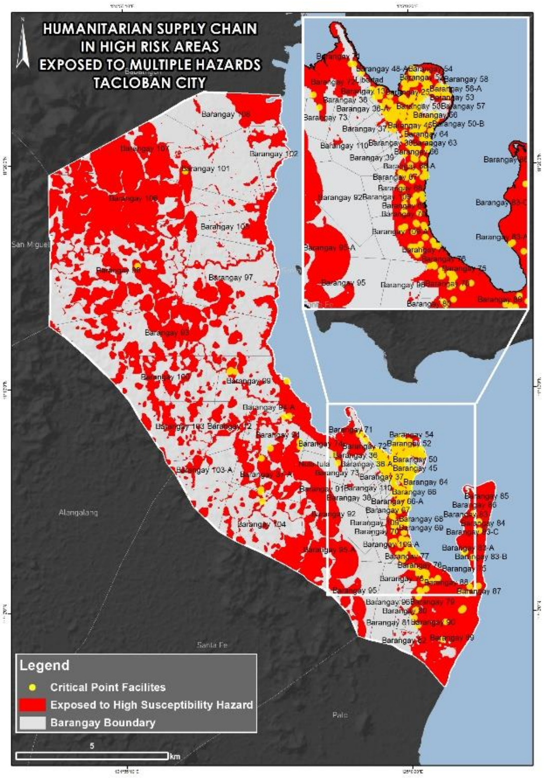

Figure 16. Elements of the Humanitarian Supply Chain in high-risk areas exposed to multiple hazards

4.3.1 Loss and Damage Prevention Through Decentralization

The study findings suggest the need for appropriate and safe sites for stockpiling and storing emergency supplies and essential goods to avoid resource waste. As much as possible, critical hubs should be placed in low-risk areas accessible to roads and thoroughfares that link them to various distribution outlets. Establishing distribution hubs outside the city's already densely built-up coastal area and having decentralized storage facilities may lessen the chance of considerable losses in a single event.

4.3.2 Facilities Strengthening

The exposure analysis results also suggest that in most cases, selecting a site that may be exposed to some degree to various hazards may be unavoidable. In such cases, planners must consider adopting parameters that increase these critical facilities' resilience during the conceptualization, design, planning, construction, and operation phases. Aside from complying with relevant codes, performance-based standards may provide an additional safety measure in these CPFs to improve their performance.

4.3.3 Redundancy

To achieve a resilient humanitarian supply chain, the findings in the study indicate the need to plan for redundancy in the development of critical infrastructure. Redundancies are alternative facilities that may be substituted in cases where one or more facilities are unusable. If a significant entry point, such as an airport, is destroyed, a different airport can readily take its place. Likewise, alternative routes to facilitate unimpeded movement between the distribution hubs, evacuation centers, and other critical point facilities will be vital in times of crisis.

The study emphasizes the need to keep emergency routes linking these facilities clear for unimpeded movement of goods between various facilities comprising the HSC. Since 78 percent of the routes identified in the study are exposed to various hazards, there may be a need to develop alternative routes and identify other possible means of transporting goods at the last mile. Since existing transportation facilities are highly exposed to various hazards, care must be taken to ensure that transportation facilities tagged for use during disaster response are relocated to hazard-free areas to ensure mobility.

4.4 Risk-informed Site Selection: a vital step toward making humanitarian supply chains resilient.

Judicious site selection plays a crucial role in ensuring the performance of the HSC. A conjunctive multi-criteria decision analysis using GIS was carried out in a two-step process to determine suitable locations for CPFs and possible alternative routes. A cursory approach removed all hazard-prone areas in the selection process, which yielded Potentially Suitable Areas for consideration (Figure 17). Spread out in 97 out of 138 barangays, these potentially suitable areas account for 5,738.09 hectares of the total area in Tacloban City. To ensure that the new areas where the HSC facilities may be constructed will not encroach on lands that are earmarked for protection or productive uses, the second GIS overlay excluded the following land uses and characteristics from the potentially suitable areas: (1) forest zones, (2) protected areas, (3) areas where the slope exceeds 18 degrees (steep slopes) (4) environmentally sensitive areas, (5) built-up areas, (6) Strategic Agricultural and Fisheries Zones, (SAFDZ) which yielded 2,541.92 hectares of Environmentally Suitable Areas (Figure 18) spread out in 36 barangays.

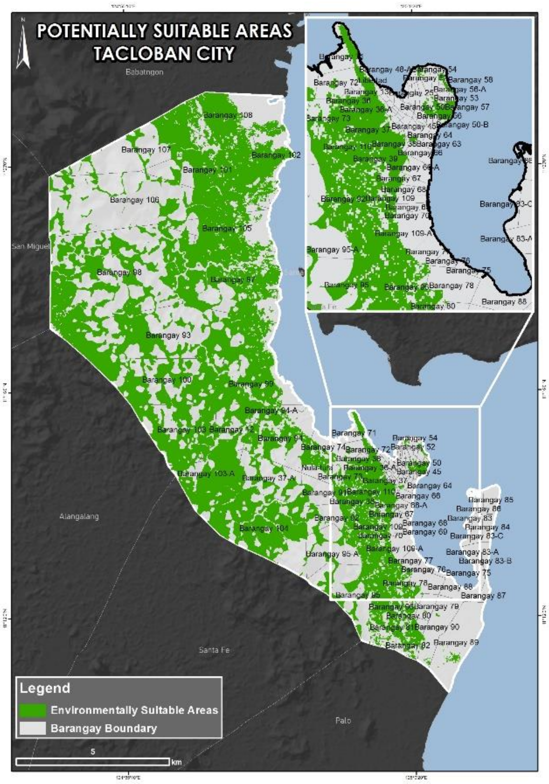

Figure 17. Potentially Suitable Areas for Locating CFPs and Alternative Road Network

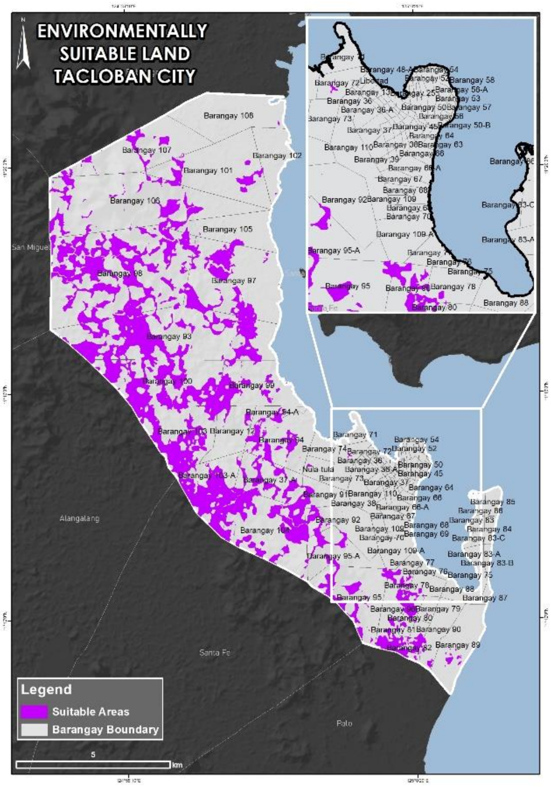

Figure 18. Environmentally Suitable Areas for Locating CPFs and Alternative Road Network

5. Conclusion

Amidst our fast-changing environment, the interdependency and complexity of risk drivers demand that we examine our urban centers as "systems of systems" in which a threat in one system will likely affect others. While UNDRR (2019) recognizes the inadequacy of current risk measurement and management approaches to meet the challenges of "multifaceted interconnectedness of hazard, as well as the barely understood breadth of exposure, and the profound detail of vulnerability" (p. iv), it also notes the urgency of reducing risks by avoiding decisions that create risk, by reducing existing risk, and by building resilience (p. xii) (UNDRR, 2019). This study illustrates how the conduct of exposure analysis of HSC assets to various climate-related hazards can provide decision-makers with a risk-informed decision-support tool that can support local governments' resilience to disaster risks in three ways: (1) understand risk reduction options, (2) facilitate wiser investment decisions, and (3) build more safely, with due recognition of the relevance of priority services and operations being carried out in these facilities before, during, and after a disaster (UNDRR, 2019). An evidence-based approach like the one used in this study can help ensure that taxpayer's money is invested in life-saving facilities that are not just efficient and cost-effective to construct, operate, and maintain but are also resilient to shocks and disruptions, starting from the very decision on where it is built.

6. Recommendations for Further Studies

Recent policy issuances by the Philippine National Government mandate local government units to utilize part of their Local Disaster Risk Reduction and Management Fund (LDRRMF) for disaster prevention and mitigation activities, including the conduct of risk assessment and vulnerability analysis for critical facilities and infrastructure (NDRRMC, 2013). Furthermore, guidelines on the development of resilient evacuation centers specifically require that the selection of construction sites for these facilities take into consideration the most recent risk assessments to ensure that these are not located in unsafe locations prone to natural and man-made hazards (Sec. 5.1.1.1), and to ensure year-round vehicular access to these facilities, especially before, during, and after a hazard event (Sec. 5.1.1.4) (DILG, 2018). To facilitate a robust process of selecting suitable sites for public facilities, the process described herein can be combined with cadastral information to determine viable sites for possible acquisition.

The study is limited to understanding the hazards facing various elements comprising Tacloban City's HSCs. Researchers are encouraged to evaluate the vulnerability of these facilities to various hazards by incorporating information on the condition of facilities, type of construction, and year of construction, among others, to determine other mitigation measures. To deepen the site selection process, parcel-level information on land classification, zoning assessment, tenure, and ownership, among others, that can support investment decisions may be included in the MCDA.

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References

Centre for Research on the Epidemiology of Disasters (CRED) and UN Office for Disaster Risk Reduction (2018) Economic Losses, Poverty and Disasters 1998- 2017 [Author(s) Wallemacq, Pascaline; House, Rowena] 31pp; Available online: https://www.preventionweb.net/files/61119_credeconomiclosses.pdf (accessed on 17 September 2019)

Eckstein, D., Künzel, V., Schäfer, L., & Winges, M. (2020). Global Climate Risk Index 2020: Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2018 and 1999 to 2018 Germanwatch Nord-Süd Initiative eV. Available online: https://www.germanwatch.org/en/17307 (accessed on 27 December 2019)

Eckstein, D., Hutfils, M. L., & Winges, M. (2019). Global Climate Risk Index 2019: Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2017 and 1998 to 2017. Germanwatch Nord-Süd Initiative eV. Available online: https://www.germanwatch.org/sites/default/files/Global%20Climate%20Risk%20Index%202019_2.pdf (accessed on 27 December 2019)

Greene, R., Devillers, R., Luther, J.E., & Eddy, B. G. (2011). GIS-Based Multiple-Criteria Decision Analysis. Geography Compass 5(6):412 – 432. DOI: 10.1111/j.1749-8198.2011.00431.x

Intergovernmental Panel on Climate Change, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 2015; 151 pp. ISBN 978-92-9169-143-2

United Nations Office for Disaster Risk Reduction, The Sendai Framework for Disaster Risk Reduction 2015-2030, 2015; 32 pp. Available online: https://www.preventionweb.net/go/43291 (accessed on 17 September 2019)

United Nations Office for Disaster Risk Reduction, Disaster Risk Reduction in the Philippines: Status Report 2019. Bangkok, Thailand, United Nations Office for Disaster Risk Reduction (UNDRR), Regional Office for Asia and the Pacific, 2019; 32 pp. Available online https://reliefweb.int/report/philippines/disaster-risk-reduction-philippines-status-report-july-2019 (Accessed on 12 September 2020)

United States Agency for International Development, Climate Change Risk in the Philippines: Country Fact Sheet, 2017; 5 pp.; Available online: https://www.climatelinks.org/sites/default/files/asset/document/2017_Climatepercent20Changepercent20Riskpercent20Profile_Philippines.pdf (Accessed on 17 February 2020)

National Disaster Risk Reduction and Management Council-Office of Civil Defense (NDRRMC-OCD). Final Report Effects of Typhoon Yolanda (Haiyan); n.d.; 148pp. Available online: http://www.ndrrmc.gov.ph/attachments/article/1329/FINAL_REPORT_re_Effects_of_Typhoon_YOLANDA_HAIYAN_06-09NOV2013.pdf (Accessed on 17 September 2019)

University of the Philippines School of Urban and Regional Planning (UP SURP), Planning Guidance for Disaster Response and Rehabilitation via Humanitarian Logistics Management: UP-DOST Build Back Better Program, 2016; 203pp. (unpublished)

Tacloban City Profile. Available online: https://www.tacloban.gov.ph/city-profile/ (Accessed on 17 September 2019)

PhilAtlas.com. Tacloban City Profile. Available online: Available online: https://www.philatlas.com/visayas/r08/tacloban.html (Accessed on 16 February 2020)

National Economic Development Authority (NEDA), Sulhog: Eastern Visayas Haiyan Reconstruction Plan, 2014; 70 pp. Available online: http://nro8.neda.gov.ph/development-plans (Accessed on 17 February 2020)

Housing and Land Use Regulatory Board (HLURB). Supplemental Guidelines on Mainstreaming Climate Change and Disaster Risks in the Comprehensive Land Use Plan, 2015; 318 pp. Available online: https://hlurb.gov.ph/services/local-government-unit/clup-guidebook/ (16 September 2021).

Yu, D., Yalcin, M. G., Özpolat, K., & Hales, D. N. Research in Humanitarian Supply Chain Management and A New Framework. Eurasian Journal of Business and Economics 2015, 8(15), 39–60. Available at: http://www.dx.doi.org/10.17015/ejbe.2015.015.03

Argollo da Costa, Sergio Ricardo & Campos, Vania & Bandeira, Renata. (2012). Supply Chains in Humanitarian Operations: Cases and Analysis. Procedia - Social and Behavioral Sciences. 54. 598–607. 10.1016/j.sbspro.2012.09.777. https://doi.org/10.1016/j.sbspro.2012.09.777.

Philippine Disaster Resilience Foundation, Office of Civil Defense, and National Disaster Risk Reduction and Management Council. Public Service Continuity Planning (PSCP) Guidebook, 2020. 110 pp

Department of Natural Resources- Land Management Bureau. Infographic Available online: https://lmb.gov.ph/index.php/87-programs-and-projects/ii-land-disposition/53-ld-lease (N.D.) (accessed on 16 September 2021)

Kulp, S.A., Strauss, B.H. New elevation data triple estimates global vulnerability to sea-level rise and coastal flooding. Nat Commun 10, 4844; 2019 Available online: https://doi.org/10.1038/s41467-019-12808-z (accessed on 10 September 2020)

International Development Research Centre (IDRC). Parts of the Philippines may submerge due to global warming. ScienceDaily. 2015; Available online: www.sciencedaily.com/releases/2015/10/151021104913.htm (accessed 17 September 2019)

Coastal Risk Screening Tool. Climate Central. https://coastal.climatecentral.org/map (accessed 22 September 2020)

Fourteenth Congress of the Philippines. Republic Act No. 10121, "Philippine Disaster Risk Reduction and Management Act of 2010". 2010. https://www.officialgazette.gov.ph/2010/05/27/republic-act-no-10121/

National Disaster Risk Reduction and Management Council (NDRRMC), the Department of Budget and Management (DBM), and the Department of Interior and Local Government (DILG). Joint Memorandum Circular No. 2013-1 Allocation of the Local Disaster Risk Reduction and Management Fund (LDRRMF). 2013. Available online: https://www.ndrrmc.gov.ph/attachments/article/1320/JMC_No_2013-1_re_Allocation_and_Utilization_of_LDRRMF.pdf (accessed 17 September 2019)

Department of Interior and Local Government (DILG). Memorandum Circular No. 2018-122. Guidelines for Local Government Units on Strengthening Evacuation Systems Using the Local Disaster Risk Reduction and Management Fund (LDRRMF). 2018 Available online: https://dilg.gov.ph/PDF_File/issuances/memo_circulars/dilg-memocircular-201888_6862a1ddb0.pdf (accessed 24 September 2019)

United Nations Office for Disaster Risk Reduction. Global Assessment Report on Disaster Risk Reduction 2019, United Nations, New York, https://doi.org/10.18356/f4ae4888-en. (Accessed 13 September 2019)

United Nations Office for Disaster Risk Reduction. DRR at the local level Making Cities Resilient Campaign & the Ten Essentials. Presented at the UNDRR-UNOSSC-PAHO joint online training program on "Making Cities Resilient: Developing and Implementing Local Disaster Risk Reduction Strategy to Respond to COVID-19 and to Better Prepare for the Future". Incheon, Korea, September 2020