INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 14, No. 6, p. 329-349, 2019
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Typhoon vulnerability and risk assessment of mission critical infrastructures of state universities and colleges in the Philippines: The case of Cagayan State University

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Article published on June 30, 2019

Key words: Typhoon, Disaster resiliency, Vulnerability assessment, Exposure, Sensitivity, Adaptive capacity, Risk assessment, Mission-critical infrastructures.

Abstract

Disaster risk reduction concerns many nations along the most disaster-prone areas. Academic sector is inevitable to the threats and impacts of hazards and as such, typhoon is ubiquitous hazard in the tropical areas where Philippines is one. Vulnerability and risk assessment is carried out as an evaluation of mission-critical infrastructures (MCIs) for disaster resiliency. MCIs are said to be the backbone of universities where the functions may serve as administrative, instructional, research and extension purposes, and auxiliary services (e.g. sports) and these operations are essential for any academic institutions. The concept of vulnerability and risk assessment is carried out using the concept from Intergovernmental Panel on Climate to assess the vulnerability and risk of MCI to typhoon hazard. Vulnerability has three determinants namely, Exposure, Sensitivity, and Adaptive Capacity. The three determinants are evaluated by formulating multi-parametric indicators to assess the infrastructures and using indices and scoring. GIS software is incorporated in this study in reflecting the level of vulnerability of the infrastructures where mitigation and policy formulation and strengthening can be adapted. The results in this study reveals that 7 MCIs have a high risk to typhoon hazard and highly vulnerable.

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Introduction

Typhoons or tropical cyclones are geophysical disturbances resulting from over-heating of large bodies of water (tropical oceans) and deployed by atmospheric heat transfer (Emanuel, 2003). Tropical cyclones are general term but misinterpreted by different region. Maximum wind speed categorizes cyclones for providing alerts and warnings. Tropical cyclones with less than a maximum wind speed near of $17ms^{-1}$ near the center is considered a tropical depression while higher maximum wind speed but not exceeding $32ms^{-1}$ are tropical storms and beyond the $32ms^{-1}$ maximum wind speed, it is categorized as hurricane (for Northern America) or typhoon (in the Asia-Pacific Region) (Emanuel, 2003).

Asia-Pacific region is prone to typhoon hazard and Philippines is one of the most affected. Philippines is vulnerable to climate change (Peñalba, Elezague, Pulhin, & Cruz, 2012) and in addition, the country experience typhoons yearly at an average number of 20 per year and half of these number made landfall or cross the landmass of the country (PAGASA, n.d.). According to a report eight cities out of 10 most disaster risk cities are in the Philippines and typhoon is one of the hazard to imposed threat (Schuengel, 2015). From year 2012 to 2018, there were at least 14 category 4 and 5 typhoons crossed the country (see Fig. 1). Two of these typhoons landed the same province with short interval. Typhoon Haima landed in Peñablanca, Cagayan in the year 2016 and recently in the year 2018 Typhoon Mangkhut made a landfall in Baggao, Cagayan.

Typhoon is a major cause of devastation in tropical countries and affect all economic sector (Nguyen, Liou, & Terry, 2019) . Heavy rains and strong winds brought by typhoon are destructive and the analysis in field of engineering and meteorology are of great significance (Binglan, Fei, & Xueling, 2011).

Physical damages of typhoon to building, featuring its strong winds, include the uplifting of roofs and some its entirety, shattering of doors and windows, and damages caused by flying debris (Jin, Yang, & Li, 2008) (Yau, Lin, & Vanmarcke, 2011). While it structurally damages the building, it also incurs damage and interrupts electrical supply, water system, and communications. These damages may lead to disruption of services in any sector lasting for a week or longer if not properly mitigated. Schools are no exemption from these impacts as it not only affects them during typhoon but the impending discontinuity of operation and recovery (Tong, Shaw, & Tekeuchi, 2012). Also, infrastructure are lifeline system in which it ensures social and economic activities and conclusively regarded as backbone of operations specially in academic institutions (Wei, Wang, Wang, & Tatano, 2014).

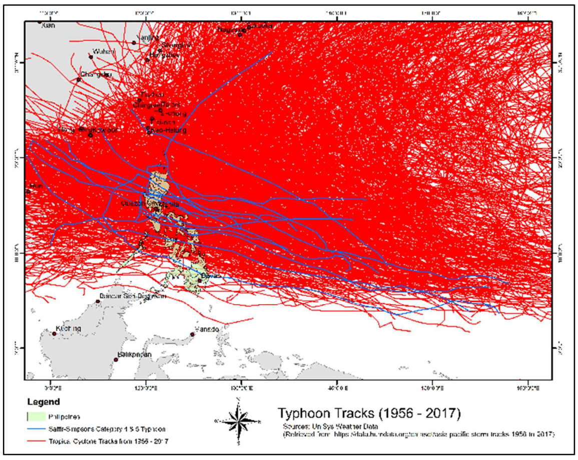

Fig. 1. Typhoon tracks showing the Philippines as a typhoon-prone country.

The race for development of models and assessment on this concern seemed to arise globally. These developments and approaches can save people, property and the environment and reduce economic losses (Hoque, Phinn, Roelfsema, & Childs, 2017). In addition to the threats of typhoon, climate change is known to increase the frequency of future tropical cyclones as it may triple in number and also intensify the magnitudes with an increase (Economic and Social Comission for Asia and the Pacific, 2017) of the mean maximum wind speed of +2 to 11% globally (Knutson, *et al.,* 2010). Economic and Social Commission for Asia and the Pacific also strongly argued that the hazard analysis and assessment should base from the rising threats from CC projections to ensure fitting to current needs (Pinelli, *et al.,* 2004) in comprehensive decisions in adaptation and growing human society (Nishijima, Maruyama, & Graf, 2012) . Some of the researches involving typhoon are in the form of experimental like behavioral analysis of buildings to wind, numerical and probabilistic models using multi-parameter and historical data, damage analysis and assessment which involves pre-disaster and post-disaster surveys, vulnerability and risk assessments using scoring system and indices. Often, assessment using index and component indicators is helpful tool in hazard management and planning (Parsons, *et al.,* 2016). Vulnerability assessment is also an integral part of disaster mitigation as it will provide information of potential threats in any area and allows planners to identify and prioritize mitigation opportunities (Odeh, 2002).

This study is a campus-wide assessment of multi-parameter vulnerability indicators which aims to assess the vulnerability of existing mission-critical infrastructures, portray the findings in maps using Geographic Information System (GIS) software, and formulate new policies in disaster risk reduction and adaptation.

Materials and methods

Study area

Tuguegarao City is a center of commerce and government transactions in the Cagayan Valley region in the Philippines. Topographically, the city is found in the valley of the region at the western part of the Sierra Madre mountain ranges bounding the Luzon Island landmass and the west part of the Pacific Ocean. The province of Cagayan where the city is found is prone to typhoon. Yearly, the province is expected to experience 4 to 5 typhoons crossing the province and leaving devastation to any sector.

The impacts of typhoon to universities includes physical damages of building, disabled water and electrical supply, cut-off communications, and interruption of services which were experienced by the university. In this end, the assessment is helpful in disaster risk mitigation.

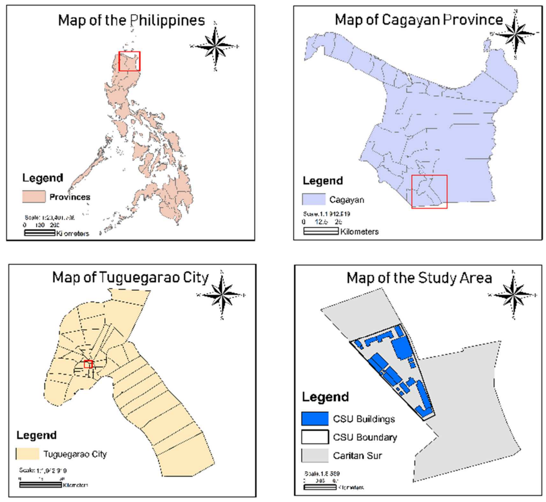

Fig. 2. Study area

Conceptual framework

The research project covers the instruction, research and extension, administration and other support services of the involved project sites. The type of hazards experienced by these SUCs/HEIs are determined, and the resiliency of these buildings are evaluated based from assessing their vulnerability. The fig. below illustrates the conceptual framework of the study.

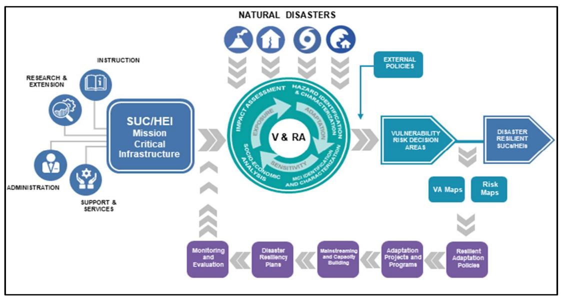

Fig. 3. Conceptual framework of the study.

Exposure Units and Database

Mission-critical infrastructures (MCIs) are said to be the backbone of state universities and colleges' existence and operation. In this study, MCI are categorized according to their function as administrative, instructional, research and extension, and auxiliary functions.

The MCIs present in the university were digitized using Google Earth software with the use and addition of ESRI base map from ArcMap software. The validation of the MCI was carried out using the development plan of the campus and field validation.

To carried out the assessment, exposure database was first developed. The database comprises of the data from structural component, electrical components, water supply system, communication (e.g. landline and internet connection), and other materials and utilities. The structural components include the foundation, frames (columns and beams), walls, wall openings (windows and doors), and roofing. The electrical components include the main switches (panel boards), lightings, switches, and convenience outlets. The water supply system includes the water outlets, water tanks and water pumps. Communication includes the telephone and antenna, while the other utilities and materials include the computers, documents, and chemicals.

The database also had a data about the building typology like number of floors, building construction type (wooden, masonry, or combination), and shape. It also includes the age of the building and the occupants from day basis to night basis.

Vulnerability assessment

Vulnerability assessment is basically a function of the three determinants of exposure, sensitivity, and adaptive capacity. Though, vulnerability definition is dynamic and should be defined on a case-to-case basis (Deutsche Gesellschaft für Internationale Zusammenarbeit, 2014). Adapting the concept from IPCC and making it suitable for infrastructures of universities, the determinants of vulnerability were break down by many more different parameters and indicators. These factors were identified first before the vulnerability assessment. Every factor is composed of more indicators which were scored from 1 to 5 corresponding to a rating of “very low”, “low”, “moderate”, “high”, and “very high”, respectively

Table 1. Five-point scale scoring for level of exposure, sensitivity, and adaptive capacity.

Vulnerability index	Vulnerability category	RGB	Color
0-1.00	Very low	5, 125, 20	
1.001-2.00	Low	181, 235, 26	
2.001-3.00	Moderate	250, 255, 135	
3.001-4.00	High	255, 156, 20	
4.001-5.00	Very high	255, 44, 41	

The exposure, sensitivity, and adaptive capacity scoring indicators is shown in tables 2, 3 and 4. The assessment is a multi-parameter scoring which every all the three determinant has many more component and the scoring and rating was averaged.

Exposure indicators were considered according to the area being exposed to hazard. Also, exposure indicator is quantified in percentage according to what were present and how much of these within the building would be exposed. Table 2 shows the formulated exposure scoring matrix for scoring the exposure level of the buildings.

Table 2. Exposure indicator rating matrix.

Exposure Indicators	Very low	Low	Moderate	High	Very high
	1	2	3	4	5
Percentage of floor area exposed to hazard	≤ 10% of exposed	11-20% of exposed	21-30% of exposed	31-50% of exposed	> 50% of exposed
Percentage of foundations exposed to hazard	≤ 10% of exposed	11-20% of exposed	21-30% of exposed	31-50% of exposed	> 50% of exposed
Percentage of wall area exposed to hazard	≤ 10% of exposed	11-20% of exposed	21-30% of exposed	31-50% of exposed	> 50% of exposed
Percentage of wall opening (doors and windows) exposed to hazard	≤ 10% of exposed	11-20% of exposed	21-30% of exposed	31-50% of exposed	> 50% of exposed
Percentage of roofing exposed to hazard	≤ 10% of exposed	11-20% of exposed	21-30% of exposed	31-50% of exposed	> 50% of exposed
Percentage of people exposed to hazard	≤ 10% of exposed	11-20% of exposed	21-30% of exposed	31-50% of exposed	> 50% of exposed
Percentage of computer exposed to hazard	≤ 10% of exposed	11-20% of exposed	21-30% of exposed	31-50% of exposed	> 50% of exposed
Percentage of documents, books, etc. exposed to hazard	≤ 10% of exposed	11-20% of exposed	21-30% of exposed	31-50% of exposed	> 50% of exposed
Percentage of convenience outlet, lightings, ACU, etc exposed to hazard	≤ 10% of exposed	11-20% of exposed	21-30% of exposed	31-50% of exposed	> 50% of exposed
Percentage of water system exposed to hazard	≤ 10% of exposed	11-20% of exposed	21-30% of exposed	31-50% of exposed	> 50% of exposed

The matrix presents scoring of the exposed people, utilities, and structural components of the building within the MCI which can be adversely affected. The structure component to be scored includes the floor area, foundations, wall doors and windows, and roofing. In structural engineering, roofing take most of damage because wind may came from any direction during the disaster (Yau, Lin, & Vanmarcke, 2011).

For the occupancy, protection of building occupants against injuries is important and top priority (Lee, Ham, & Kim, 2013). Therefore, the percentage of students, teaching personnel, and other staff were included. The utilities also included for assessment were computers, documents, books, electrical components and loads (switches, lights, outlets etc.) and water supply system which includes faucet (water outlet), water tanks and pumps.

Table 3. Sensitivity indicator rating matrix.

Sensitivity Indicators	Very low 1	Low 2	Moderate 3	High 4	Very high 5
WINDOWS					
Material Used	Wooden Window (WW)	Metal Sheet (MS)	Jalousie	Glass Metal Framed (GMF)	Glass Aluminum (GA)
WALLS					
Material Used	Reinforced Concrete	Concrete Hollow Blocks (CHB)	Wood	Brick	Glass
DOORS					
Door Material	Wooden Door (WD)	Metal Sheet (MSM)	Glass Metal Framed (GMF)	Glass Door (GD)	None
CEILING					
Ceiling Material Used	Concrete	Wood	Cement Fiber	Gypsum Board	None
ROOF					
Roof Coverings	Clay Tile	Concrete Tile/Concrete Slab	Stainless Steel Roof	Metal Roofing Sheet/Corrugated GI Sheet	Asbestos
Roof Frame Material	Wood (Hardwood)	Wood (Softwood)	Steel (Bolted Connection)	Steel (Bolted and Welded Connection)	Steel (Welded Connection)
Roofing Type	Dome/Arch	Flat	Hip	Shed	Gable
FLOOR					
Floor Material	Polished Concrete	Concrete+Granite Tile	Concrete+Ceramic Tile	Wood	Vinyl
FRAMES (Columns and Beams)					
Materials of columns used	Reinforced Concrete	Reinforced Concrete+Steel	Reinforced Concrete+Timber	Steel	Timber
Materials of beams used	Reinforced Concrete	Reinforced Concrete+Steel	Reinforced Concrete+Timber	Steel	Timber
FOUNDATION					
Foundation type	Pad	Strip	Pile	Raft	None
Soil type	Type A	Type B	Type C	Type D	Type E
Category of foundation		Deep		Shallow	
OCCUPANCY					
(Day Basis)					
Percentage of Students	less than or equal to 10	11 to 20	21 to 30	31 to 50	greater than 50
Percentage of Teaching Personnel	less than or equal to 10	11 to 20	21 to 30	31 to 50	greater than 50
Percentage of Non-Teaching Personnel	less than or equal to 10	11 to 20	21 to 30	31 to 50	greater than 50
(Night Basis)					
Percentage of Students	less than or equal to 10	11 to 20	21 to 30	31 to 50	greater than 50
Percentage of Teaching Personnel	less than or equal to 10	11 to 20	21 to 30	31 to 50	greater than 50
Percentage of Non-Teaching Personnel	less than or equal to 10	11 to 20	21 to 30	31 to 50	greater than 50
BUILDING SENSITIVITY INFORMATION					
Building Age	less than or equal to 30	31 to 50	50 to 65	65 to 75	greater than 75
Building Functions	Auxiliary (Sports, Hostel, etc.)	Research	Instruction	Laboratory (IT, Biotech, etc.)	Administrative
Building Height T (m)	greater than 5	4.5 to 5	4 to 4.5	3 to 4	less than or equal to 3
Wind Speed (kph)	less than or equal to 60	61 to 120	121 to 200	201 to 250	greater than 250
Building Type		Concrete	Masonry	Steel	Wood

Sensitivity scoring matrix are conceptualized by the definition of IPCC that these (factors) may affect it adversely or benefit the buildings. In this case, the indicators were aligned to the exposure indicators but the basis were the strength of material used in the construction of the building and physical features of both building and surrounding in which Tamura & Cao (2019) emphasized that damage depends not only to the wind speed but also on the strength or quality of structures (Tamura & Cao, 2019).

Structurally, roof is a critical structural component wherein the prevailing wind increases in magnitude as height does and hence, roof is positioned on the topmost of structures. Roof take damage severely as observed which relates to the performance in counteracting wind load from strong wind (Stewart, 2003; Jin, Yang, & Li, 2008; Sparks, Schiff, & A., 1994; Manning, 1994).

Table 4. Adaptive capacity scoring matrix.

Adaptive capacity	Very low 1	Low 2	Moderate 3	High 4	Very high 5
Information	No IECs and are not yet aware of the hazards and their impacts to the SUC	Not updated IECs; Limited awareness of the hazards and their impacts to the SUC	Partially updated IECs; Partial access to hazard forecasting information and early warning system	Fully updated IECs; Full Access to hazard forecasting information and early warning system, and AGROMET station; Communication procedures are not fully in place to respond	Fully updated IECs; Full Access to flood forecasting information and early warning system, AWLS and AGROMET station; Communication facilities and procedures are in place to respond to the occurrence of the hazards.
Technology	No early warning systems and no disaster resilient plans and designs	Has early warning systems but not working; has building plans and designs but not within the standards	Has early warning systems but not updated; Disaster resilient buildings has yet to be designed	Has available early warning systems, updated but not fully implemented; has existing disaster resilient building plans and designs	Full implementation of the early warning systems; Construction of disaster resilient buildings based on the national building codes and standards.
Infrastructure	No necessary infrastructure are constructed	Existing infrastructure are not within the standard to withstand the impacts of hazards	Necessary infrastructure & facilities has to be retrofitted to ensure the strength and safety during the occurrence of the hazards	Existing infrastructure are within the standard but not enough to accommodate the projected impacts of the hazards	These infrastructures and facilities are strong and adequate enough to withstand the projected hazards and their impacts.
Institutional	No available institutional policies, DRR development plans, and building codes and standards	Limited awareness of the building codes and standards; institutional policies and DRR development plans and procedures are yet to be formed	Full access to building codes and standards; Relevant institutional policies, DRR development procedures, and legislation are passed but implementing guidelines are still need to be formulated	Full access to building codes and standards; Relevant institutional policies, DRR development procedures, and legislation are passed; Implementing guidelines are formulated but not fully implemented nor tested	Full access to building codes and standards; There are existing relevant institutional policies, DRR development procedures and implementing guidelines; legislation is in place to respond quickly to hazards and to control the situation.

Adaptive capacity	Very low 1	Low 2	Moderate 3	High 4	Very high 5
Financial	No available financial resources for renovation & maintenance; have no financial assistance to affected critical infrastructures	Has very limited financial resources for R&M, upgrading and rehabilitation; Limited financial assistance to about 15% of affected critical infrastructures	Has limited financial resources for R&M, upgrading and rehabilitation; Limited financial assistance to at least 30% of affected critical infrastructures	Has available resources but not adequate for R&M, upgrading & rehabilitation and construction of new buildings; Has available financial assistance to at least 50% of affected critical infrastructures	Funds and finances are enough or adequate for R&H, upgrading, rehabilitation and construction of new buildings; Available financial assistance to all affected critical infrastructures.
Human Capital	No available experts to design, build and maintain the critical infrastructure in the SUC	Personnel and staff are available but not skilled to design, build and maintain the critical infrastructure in the SUC	Has limited experts and technical support with limited knowledge to carry out the necessary technical functions	Has available experts and technical support, knowledgeable but inexperienced to carry out the relevant technical functions	Human resources are enough and adequate, knowledgeable and experienced enough to carry out all the relevant and necessary technical functions and responsibilities.

The adaptive capacity scoring matrix relies on the 6 dimensions of the Local Climate Change Action Plan of Department of Interior and Local Government (Department of Interior and Local Government, 2014). The six dimensions consist of the information of the hazard that is present, technology to forecast the hazard, infrastructure to lessen the impacts, institutional that updates the buildings in accordance with existing standards, financial to cope up for rehabilitation of might incurred damages, and human capital for the expertise in the field of engineering, planning and decision making for resilience. In addition, the six dimensions of adaptive capacity as Chen & Lee (2010) find out from their study is somehow synonymous that disaster education, coordination of the school to the community, evaluation of structures, educational materials and design activities for safety should be stressed out and should be prioritized and impart to both students and teachers (Chen & Lee, 2010).

Vulnerability Index

The building components listed in the exposure database are evaluated according to their sensitivity and exposure to hazards. The hazard maps of the region are intersected with the shape files of the SUCs for the researchers to have an idea in filling out some details in the exposure component. The adaptive capacity is also evaluated according to the technologies present in the university that can be used to mitigate the effects of these hazards. The vulnerability index (*VI*) of every building is generated based from the formula:

$$VI = \frac{Exposure\ x\ Sensitivity}{Adaptive\ Capacity} \qquad (1)$$

Where:

VI: the vulnerability index of the MCIs

Exposure: computed average scores of exposure indicators

Sensitivity: computed average scores of the sensitivity indicators

Adaptive Capacity: computed average scores of the AC indicators

Equation 1 was adapted from the vulnerability formula developed by the IPCC in 2014. A five-point rating scale is also generated to assess the level of vulnerability of the buildings and for easier visualization of the vulnerability levels of each infrastructure. This five-point scale is presented below

Score and level of exposure, sensitivity, and adaptive capacity has a five-point rating scale with a range of 1 to 5, each range corresponds the level and color of exposure, sensitivity and adaptive capacity. The five-point rating scale also is used for the vulnerability rating.

Table 5. Five-point rating scale for vulnerability index rating.

Vulnerability index	Vulnerability category	RGB	Color
0.00-0.99	Very low	5, 125, 20	
1.00-2.00	Low	181, 235, 26	
2.01-4.00	Moderate	250, 255, 135	
4.01-10.00	High	255, 156, 20	
10.01-25.00	Very high	255, 44, 41	

Risk assessment

The disaster risk assessment (DRA) is conducted after the vulnerability of the mission-critical infrastructures and investments have been determined. In DRA, two factors are considered: the likelihood of occurrence of the hazard and its severity of consequence. The likelihood of occurrence (LOO), more popularly known as probability of occurrence, is defined as the chance that a hazard will occur in any given year. This is determined through years of historical data. The table for the values of likelihood of occurrence for this study is based from the Draft Reference Manual on Mainstreaming Disaster Risk Reduction and Climate Change Adaptation in the Comprehensive Land Use Plans, NEDA-UNDP, HLURB (2012) adapted by the Department of Interior and Local Government and is presented at the table.

Table 6. Risk scoring table.

Measure of the likelihood of occurrence of the hazard	Return period in years	Likelihood of occurrence score
Very likely	Every 1-3 years	6
Likely	Every 3-10 years	5
Slight chance	Every 10-30 years	4
Unlikely	Every 30-100 years	3
Highly likely	Every 100-200 years	2
Very rare event	Every 200-300+ years	1

The severity of consequence (SOC) is defined as the impact of an identified risk to safety, resources, work performance, property, and/or reputation. This assesses the impacts to personnel safety, resources, work performance, property damage, and institutional reputation associated with each rating. The rating scale for the severity of consequence is shown below.

After the ratings for the likelihood of occurrence and severity of consequence has been generated, the risk index is then computed using the formula below.

$$RI = LOO \times SOC \quad (2)$$

Where

RI: the risk index

LOO: the likelihood of occurrence score, and:

SOC: the severity of consequence score reflected as the vulnerability index of the MCIs

Fig. 4. Campus map of CSU-Andrews.

To better visualize the level of risk that a State University is exposed to, a color-coding scale is developed, according to the risk indices generated. This color-coded risk scale is presented at the table below.

Table 7. Color-coded scale for risk assessment.

Risk index	Risk category	RGB	Color
1-4	Low	255, 252, 3	
5-11	Moderate	245, 25, 212	
12-24	High	219, 13, 7	

Results and discussion

Cagayan State University

The Cagayan State University Andrews (CSU-Andrews) campus is located the urban area of Tuguegarao City (121°43'28.783"E 17°37'14.271"N). The university serves as a higher education institution (HEI) in the region as it caters different degree programs in fields of medicine, business and accountancy, hospitality management, education, and law studies where enrollees are from different parts of the region.

The university comprises of 21 buildings in CSU-Andrews being assessed which include, the Administration Building, CTED Building, E-Library, Multimedia Center and Printing Office, IAS and College Student Government, Student Center, Multipurpose Gymnasium, Old CBEA Building, CHIM and CBEA Building, Generator and Powerhouse, Carpentry and Warehouse, Amphitheater, CHIM and Office Laboratory, General Services and ROTC Office, Research, Extension and Development Building, CAHS and Law Building, Security Guard House and Restrooms. Also the building in which the OSSW, Campus Clinic, Guidance Office, Sports, Cultural, and CSU Communicator are situated, is considered in the evaluation to natural disasters. Fig. 4 shows the campus map of the university being assessed in this study.

The buildings were of different typology, different shape and number of floors but most of them are masonry made with roofings of typical metal sheet and glass window pane. The building occupancy category of the university are fall under the Occupancy Category III or Special Occupancy Structures of (ASEP, 2016a) the minimum design load for these kind of building should be designed with a minimum wind load of 300 KPH according to (ASEP, 2016b). These characteristics of buildings is used in the latter scoring.

Exposure rating

Table 8. Summary of findings for CSU-Andrews exposure level.

Building ID	Building Name	Exposure		Summary of Findings
		Average Score	Exposure Level	
1	Administration Building	3.4	High	31-50 percent of the present elements are exposed to strong winds
2	Athena Building (Classrooms and Laboratory Rooms)	4.2	Very High	Greater than 50 percent of the present elements are exposed to strong winds such as the floors walls, and windows including other electric component that were installed outside.
3	Library	2.4	Moderate	21 – 30 percent of the present elements are exposed to strong winds
4	Auxiliary Services; Media Center & Printing Office; GAD	2.7	Moderate	21 – 30 percent of the present elements are exposed to strong winds
5	Internal Audit Office; Classrooms; Student Government Center	2.9	Moderate	21 – 30 percent of the present elements are exposed to strong winds
6	OSSW; Guidance & Counselling; Student Government Center	3.2	High	31-50 percent of the present elements are exposed to strong winds
7	Student Center	2.9	Moderate	21 – 30 percent of the present elements are exposed to strong winds
8	Gymnasium and other Administration Offices	3.2	High	31-50 percent of the present elements are exposed to strong winds
9	CBEA Classrooms & Infrastructure Office	3.5	High	31-50 percent of the present elements are exposed to strong winds
10	College of Entrepreneurship & Accountancy Classrooms and Laboratory; Quality and Control Office	4.3	Very High	Greater than 50 percent of the present elements are exposed to strong winds such as the floors walls, and windows including other electric component that were installed outside.

Building ID	Building Name	Exposure		Summary of Findings
		Average Score	Exposure Level	
11	CHIM New Hostel (under construction)	4.2	Very High	Greater than 50 percent of the present elements are exposed to strong winds such as the floors, walls, and windows including other electric component that were installed outside
12	Campus Hostel; UNI-COOP	3.1	High	31-50 percent of the present elements are exposed to strong winds
13	Generator/ Powerhouse	1.8	Low	11-20 percent of the present elements are exposed to strong winds
14	Carpentry and Warehouse	2.4	Moderate	21 – 30 percent of the present elements are exposed to strong winds
15	Auditorium (amphitheater)	3.2	High	31 – 50 percent of the present elements are exposed to strong winds
16	College of Hospitality and Industry Management Classrooms and Laboratory	3.1	High	31 – 50 percent of the present elements are exposed to strong winds
17	General Services Office; ROTC Office	2.2	Moderate	21 – 30 percent of the present elements are exposed to strong winds
18	Research, Extension and Development Office	2.2	Moderate	21 – 30 percent of the present elements are exposed to strong winds
19	College of Allied Health Sciences; College of Law	3.2	High	31 – 50 percent of the present elements are exposed to strong winds
20	Security Guardhouse	3.1	High	31 – 50 percent of the present elements are exposed to strong winds
21	Restrooms	2.2	Moderate	21-30 percent of the present elements are exposed to strong winds

Generally, the exposure of the infrastructures of CSU-Andrews have a moderate to high exposure rating with at most 31 to 50% of the elements were exposed to typhoon hazard.

Most of the buildings with very high exposure to typhoon hazards were high-rise like the case of the Athena building, College of Business, Entrepreneurship and Accountancy Building and CHIM New hostel. These buildings have a high outer wall percentage exposed and in addition to that the windows are made from glass window pane and metal frame. There are also lighting components that are highly exposed which account to a high exposure rating of these buildings.

Sensitivity rating

Table 9. Summary of findings for sensitivity level of CSU-Andrews.

Building ID	Building Name	Sensitivity		Summary of Findings
		Score	Sensitivity Level	
1	Administration Building	3.01	High	The building is equipped with low strength materials such as window pane and frames are made from glass and steel, respectively; high percentage of occupant present during the hazard, and other physical aspects of the building cannot guarantee to withstand the hazard.
2	Athena Building (Classrooms and Laboratory Rooms)	2.73	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete, thick wooden doors and finished wooden-made ceilings. No occupant is present during the hazard.
3	Library	3.17	High	The building is equipped with low strength materials such as window pane and frames are made from glass and steel, respectively; other physical aspects of the building cannot guarantee to withstand the hazard.
4	Auxiliary Services; Media Center & Printing Office; GAD	2.51	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete. No occupant can be seen during the hazard.

Building ID	Building Name	Sensitivity		Summary of Findings
		Score	Sensitivity Level	
5	Internal Audit Office; Classrooms; Student Government Center	2.47	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete. No occupant can be seen during the hazard.
6	OSSW; Guidance & Counselling; Student Government Center	3.1	High	The building is equipped with low strength materials such as window pane and frames are made from glass and steel, respectively; high percentage of occupant present during the hazard, and other physical aspects of the building cannot guarantee to withstand the hazard.
7	Student Center	2.48	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete. No occupant can be seen during the hazard.
8	Gymnasium and other Administration Offices	2.72	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete. No occupant can be seen during the hazard.
9	CBEA Classrooms & Infrastructure Office	3.06	High	The building is equipped with low strength materials such as window pane and frames are made from glass and steel, respectively; high percentage of occupant present during the hazard, and other physical aspects of the building cannot guarantee to withstand the hazard.
10	College of Entrepreneurship & Accountancy Classrooms and Laboratory; Quality and Control Office	2.45	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete, thick wooden doors and finished wooden-made ceilings. No occupant is present during the hazard.
11	CHIM New Hostel (under construction)	3.04	High	The building is equipped with low strength materials such as window pane and frames are made from glass and steel, respectively; other physical aspects of the building cannot guarantee to withstand the hazard.
12	Campus Hostel; UNI-COOP	2.35	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete. No occupant can be seen during the hazard.
13	Generator/ Powerhouse	2.26	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete, thick wooden doors and finished wooden-made ceilings. No occupant is present during the hazard.
14	Carpentry and Warehouse	3.07	High	The building is equipped with low strength materials such as window pane and frames are made from glass and steel, respectively; other physical aspects of the building cannot guarantee to withstand the hazard.
15	Auditorium (Amphitheater)	3.3	High	The building is equipped with low strength materials such as window pane and frames are made from glass and steel, respectively; other physical aspects of the building cannot guarantee to withstand the hazard.
16	College of Hospitality and Industry Management Classrooms and Laboratory	2.77	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete. No occupant can be seen during the hazard.
17	General Services Office; ROTC Office	2.35	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete. No occupant can be seen during the hazard.
18	Research, Extension and Development Office	3.44	High	The building is equipped with low strength materials such as window pane and frames are made from glass and steel, respectively; high percentage of occupant present during the hazard, and other physical aspects of the building cannot guarantee to withstand the hazard.
19	College of Allied Health Sciences; College of Law	2.45	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete. No occupant can be seen during the hazard. cannot guarantee to withstand the hazard.

Building ID	Building Name	Sensitivity		Summary of Findings
		Score	Sensitivity Level	
20	Security Guardhouse	2.4	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete. No occupant can be seen during the hazard.
21	Restrooms	2.36	Moderate	The building is constructed from medium-to-high strength materials such as reinforced concrete. No occupant can be seen during the hazard.

Sensitivity level of the buildings depend on the material used in their construction and other physical features of the building. Most of the buildings have moderate to high sensitivity rating and as observed the materials used for walls, windows, and doors were concrete hollow blocks (CHB), glass-metal frame combination, and wooden doors. Dominate roof design was hip and gable and the material is of galvanized ir. In prior to typhoon hazard, the previous considered element under sensitivity are critical as the hazard is attributed to strong wind. In addition, a higher building will be more sensitive comparative to a low-rise building. Occupants during typhoon were considered a zero percentage because of early memorandum to suspend classes and no security guard will stay during the disaster. The university also is not used as evacuation center to shelter those greatly affected during the onslaught of typhoon.

Adaptive capacity rating

Table 10. Summary of findings for the level of adaptive capacity of CSU-Andrews.

Building ID	Building Name	Adaptive Capacity		Summary of Findings
		Average Score	AC Level	
1	Administration Building	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
2	Athena Building (Classrooms and Laboratory Rooms)	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
3	Library	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
4	Auxiliary Services; Media Center & Printing Office; GAD	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
5	Internal Audit Office; Classrooms; Student Government Center	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
6	OSSW; Guidance & Counselling; Student Government Center	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
7	Student Center	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
8	Gymnasium and other Administration Offices	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions

Building ID	Building Name	Adaptive Capacity		Summary of Findings
		Average Score	AC Level	
9	CBEA Classrooms & Infrastructure Office	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
10	College of Entrepreneurship & Accountancy Classrooms and Laboratory; Quality and Control Office	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
11	CHIM New Hostel (under construction)	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
12	Campus Hostel; UNI-COOP	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
13	Generator/ Powerhouse	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
14	Carpentry and Warehouse	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
15	Auditorium (Amphitheater)	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
16	College of Hospitality and Industry Management Classrooms and Laboratory	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
17	General Services Office; ROTC Office	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
18	Researh, Extension and Development Office	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
19	College of Allied Health Sciences; College of Law	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
20	Security Guardhouse	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions
21	Restrooms	2.33	Moderate	Unavailable technology and infrastructures, partial access to information and financial assistance, and inexperienced experts to carry out relevant technical functions

The adaptive capacity of CSU-Andrews was the same for all buildings and it was rated moderate for all of the buildings. The level of dissemination of information about the hazards are very high aside from Information, Education and Communications (IECs), infrastructure to reduce wind are also present since the location is in the urban area of the city and some trees are also grown inside and outside of the university premises which can be a preventive measure for the strong winds. In addition, the technology dimensions were updated and all personnel and students have their mobile devices that can access weather forecast. The infrastructure and technology dimension of AC is also set as mitigation and preparedness for disaster (Asian Disaster Reduction Center, 2005).

In terms of institutional, the rating was set to moderate level due to the not much DRR plans and other buildings are not in compliance to the latest revised structural standards. The human capital involved the expertise of engineering and DRR officials which is not present in the university. In terms of wealth, the university has a limited fund for rehabilitation and reconstructing buildings that can be damage. Another issue for that is the minimum amount also can be obtained or requested from the government after the devastation of typhoon if ever.

The next figs (Figs 5, 6 and 7) are the maps showing the exposure level, sensitivity level and adaptive capacity level of the buildings in the university. The scores were incorporated in the attribute table of the building shapefiles and had been colored using the five-point scale presented in Table 1.

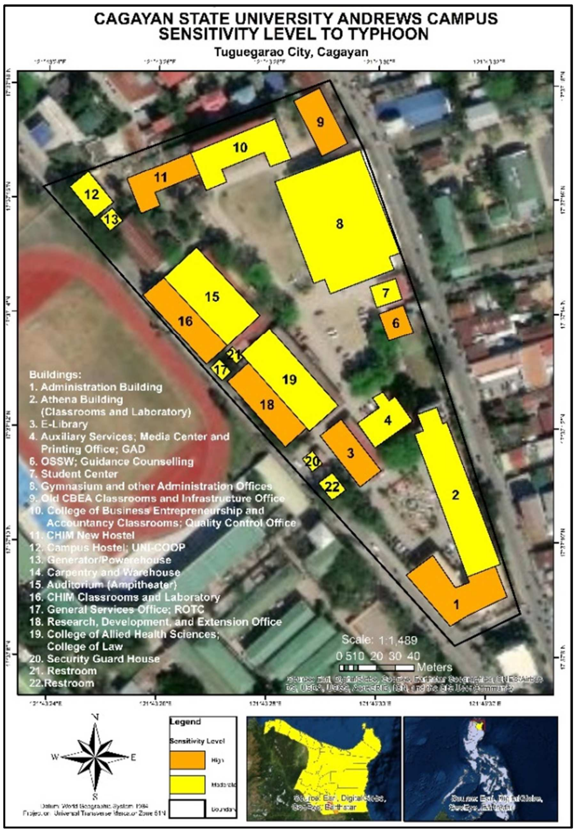

Fig. 6. Sensitivity level to typhoon map of CSU-Andrews.

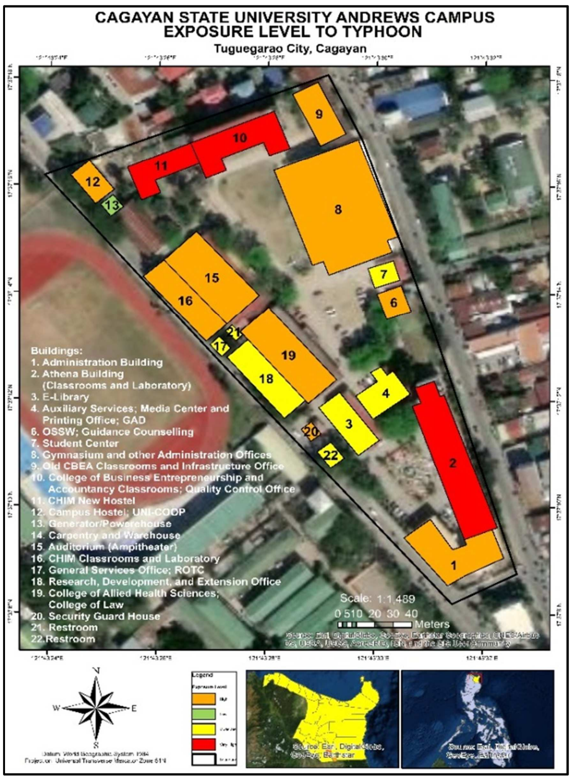

Fig. 5. Exposure level to typhoon map of CSU-Andrews.

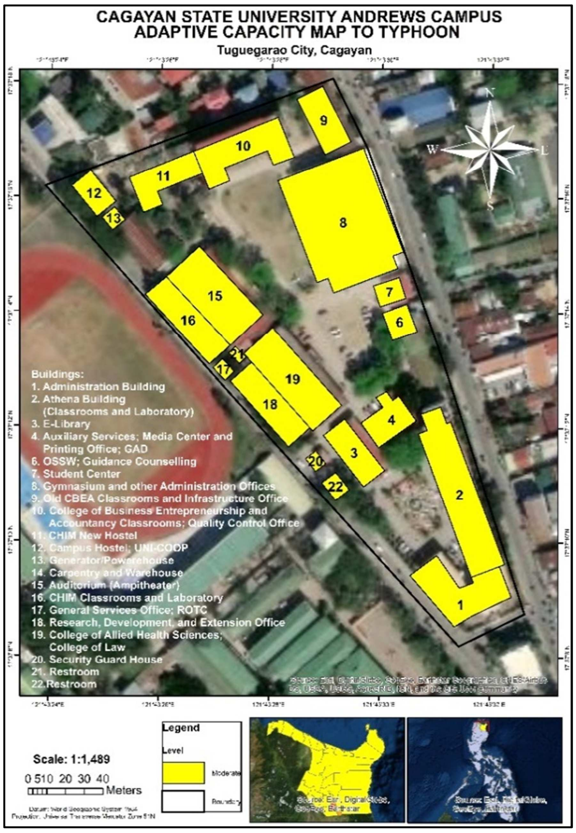

Fig. 7. Adaptive capacity level map of CSU-Andrews.

Over-all vulnerability level of the MCIs in the university

Table 11. Summary of findings for vulnerability level of MCIs.

Building ID	Building Name	Vulnerability Index		Summary of Findings
		Average Score	Threat Level	
1	Administration Building	4.39	High	Majority of the buildings are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
2	Athena Building (Classrooms and Laboratory Rooms)	4.92	High	Majority of the buildings are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
3	Library	3.27	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
4	Auxiliary Services; Media Center & Printing Office; GAD	2.91	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
5	Internal Audit Office; Classrooms; Student Government Center	3.07	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
6	OSSW; Guidance & Counselling; Student Government Center`	4.26	High	Majority of the building components are exposed to strong winds. Most of the structural components are constructed from low strength materials.
7	Student Center	3.09	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
8	Gymnasium and other Administration Offices	3.74	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
9	CBEA Classrooms & Infrastructure Office	4.59	High	Majority of the building components are exposed to strong winds. Most of the structural components are constructed from low strength materials.
10	College of Entrepreneurship & Accountancy Classrooms and Laboratory; Quality and Control Office	4.52	High	Majority of the building components are exposed to strong winds. Most of the structural components are constructed from low strength materials.
11	CHIM New Hostel (under construction)	5.48	High	Majority of the building components are exposed to strong winds. Most of the structural components are constructed from low strength materials.
12	Campus Hostel; UNI-COOP	3.13	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
13	Generator/ Powerhouse	1.75	Low	The building has low exposure to strong winds. Most of the structural components are constructed from low strength materials.
14	Carpentry and Warehouse	3.16	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
15	Auditorium (Amphitheater)	4.53	High	Majority of the building components are exposed to strong winds. Most of the structural components are constructed from low strength materials.

Building ID	Building Name	Vulnerability Index		Summary of Findings
		Average Score	Threat Level	
16	College of Hospitality and Industry Management Classrooms and Laboratory	3.68	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
17	General Services Office; ROTC Office	2.21	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
18	Research, Extension and Development Office	3.25	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
19	College of Allied Health Sciences; College of Law	3.36	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
20	Security Guardhouse	3.09	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.
21	Restrooms	2.23	Moderate	Some of the building components are exposed to strong winds. Most of the structural components are constructed from medium to high strength materials.

The assessment reflected that the level of vulnerability of buildings was at moderate to high vulnerability from typhoon hazards. The highly vulnerable buildings were obviously the high-rise buildings with greater than 2 floors and those old buildings (greater than 30 years).

Disaster risk assessment

Table 12. Summary of findings for the risk level of MCIs in the university.

Building Name	Risk Assessment			Risk index		Summary of Findings
	LOO	SOC	SOC Rating	Score	Threat Level	
Administration Building	5	3	High	15	High	The building has high vulnerability and in terms of the return period, typhoon is likely to occur. The risk is still high as it affects the administration and other services of the campus.
Athena Building (Classrooms and Laboratory Rooms)	5	3	High	15	High	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effect to instructional services of the campus.
Library	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effect to learning resources of the campus.
Auxiliary Services; Media Center & Printing Office; GAD	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effect to other services of the campus.
Internal Audit Office; Classrooms; Student Government Center	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effects to other services of the campus.
OSSW; Guidance & Counselling; Student Government Center	5	3	High	15	High	The building has high vulnerability and in terms of the return period, typhoon is likely to occur. The risk is still high as it affects the non-instructional services of the campus.

Building Name	Risk Assessment			Risk index		Summary of Findings
	LOO	SOC	SOC Rating	Score	Threat Level	
Student Center	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effects to instructional services of the campus.
Gymnasium and other Administration Offices	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effect to non-instructional and administration services of the campus.
CBEA Classrooms & Infrastructure Office	5	3	High	15	High	The building has high vulnerability and in terms of the return period, typhoon is likely to occur. The risk is still high as it affects the instructional services of the campus.
College of Entrepreneurship & Accountancy Classrooms and Laboratory; Quality and Control Office	5	3	High	15	High	The building has high vulnerability and in terms of the return period, typhoon is likely to occur. The risk is still high as it affects the instructional services of the campus.
CHIM New Hostel (under construction)	5	3	High	15	High	The building has high vulnerability and in terms of the return period, typhoon is likely to occur. The risk is still high as it affects the other services of the campus.
Campus Hostel; UNI-COOP	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effect to non-instructional and administration services of the campus.
Generator/ Powerhouse	5	1	Low	5	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effects to power supply of the campus.
Carpentry and Warehouse	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effects to other services of the campus
Auditorium (Amphitheater)	5	3	High	15	High	The building has high vulnerability and in terms of the return period, typhoon is likely to occur. The risk is still high as it affects the other services of the campus.
College of Hospitality and Industry Management Classrooms and Laboratory	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effects to instructional services of the campus.
General Services Office; ROTC Office	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effects to other services of the campus.
Research, Extension and Development Office	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effects to RDE services of the university.
College of Allied Health Sciences; College of Law	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effects to instructional services of the campus.
Security Guardhouse	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effects to other services of the campus.
Restrooms	5	2	Moderate	10	Moderate	The building has moderate vulnerability and in terms of the return period, typhoon is likely to occur. The risk has a moderate effects to other services of the campus.

The number of buildings with high risk were found out to be at least 7 (33.33%). This buildings are dangerous during typhoon.

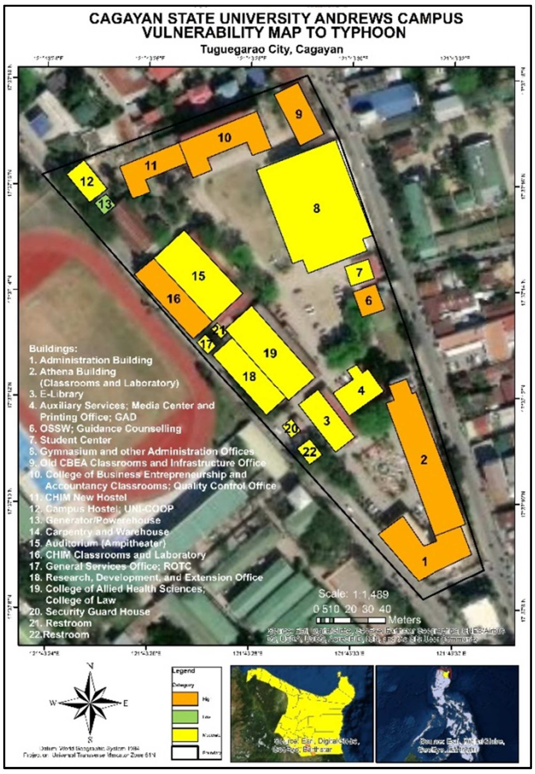

Fig. 8. Vulnerability map of CSU-Andrews.

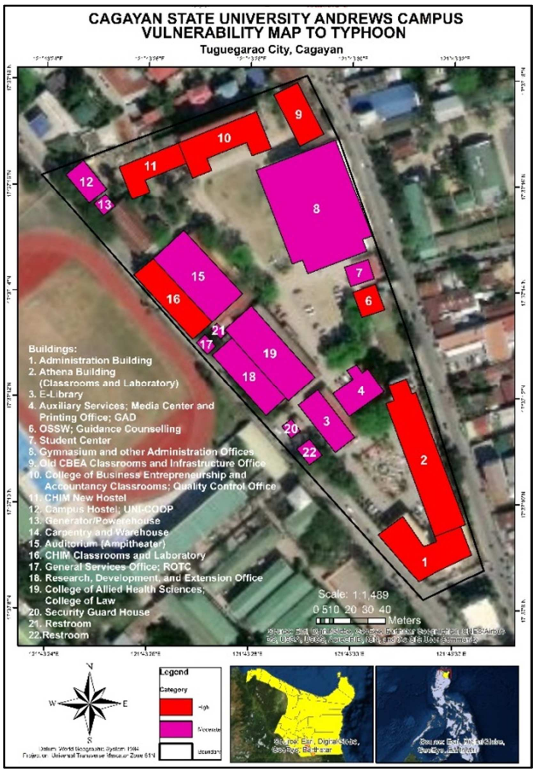

Fig. 9. Typhoon risk map of CSU-Andrews.

The CSU-Andrews have at least 7 identified building with high vulnerability rating. Spatially, these buildings are scattered within the area of the university. These buildings are attributed with either high exposure or high sensitivity rating.

Risk is identified as a shareable area of exposure, hazard and vulnerability. The risk map defines the most susceptible in terms of the frequency of typhoon. The basis for the severity of consequence was the output of the vulnerability index assessment in this sense the definition of risk from IPCC can also be adapted and integrated in this study and out of 19 MCIs, 7 buildings were assessed at high risk to typhoon hazard.

Typhoon Mangkhut (Ompong) onslaught in the university

Typhoon Mangkhut locally known in the Philippines as "Ompong" made a landfall in Baggao, Cagayan approximately forty kilometers Northeast of Tuguegarao City. CSU-Andrews were still affected and some of the trails of devastation are still present. The succeeding figs are images taken after the disaster.

Fig. 10. Peeled-off roof and blewn off debris after the disaster Typhoon Ompong.

Fig. 11. Collapse ceiling revealing roof truss and roofing sheet after the typhoon.

Fig. 12. Toppled one side wall of an old building in the university.

Fig. 13. Blown off glass walls (left) and outside debris of Research Development and Extension Building and left part of the Gymnasium used as canteen.

Fig. 14. Damaged trees inside the university.

These images were shot after the onslaught of the typhoon and can be a justification of the indicators involved in this study to assess the vulnerability of MCIs. The images revealed that other buildings also need rehabilitation to made them less vulnerable. In this end, the policy interventions on disaster mitigation should be strengthen and need for comprehensive adaptation.

Conclusion

The vulnerability assessment made in this study reflects that the buildings in the Cagayan State University – Andrews campus have a high level of vulnerability and risk of mission-critical infrastructures to typhoon hazard. Using the concept of vulnerability from IPCC, the results are quite relative to the indicated level of vulnerability as shown in the aftermath of the recent typhoon.

The procedure of the assessment is tedious in manner that it takes many parameters to be involved and yet this is reasonable since the hazard is destructive and will not just destroy a part of a building but can also destroy the whole structure. The parameters used gives a low value as it incorporates other parameters that can be omitted but on the other hand, the parameters may also be used in other hazards in assessing vulnerability as it can be adjusted to give more reliable and justified result of the level of vulnerability and how risky the infrastructures to hazards are.

The matrices formulated for scoring were also helpful not just identifying the level of vulnerability and risk but in determining better structural designs, proper electric supply and water system lay-outing, reinforcing of attach utilities for communication, and as well as disaster reduction, preparedness and mitigation formulations.

Acknowledgement

This study is funded by the Commission on Higher Education (CHED) in the Philippines under the DARE-TO research grant that made this study a success in delivering disaster resiliency to universities in the Philippines.

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