Supplementary File

Towards Prospective Disaster Risk Management: Mapping Multi-hazard Urban Risk Dynamics Driven by Evolving Exposure and Vulnerability via Earth Observation

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Abstract

As local governments increasingly adopt geospatial Climate and Disaster Risk Assessment (CDRA) to inform prospective public policy, the reliability of existing static risk intelligence is challenged by the continuous evolution of building exposure, population distribution, and physical vulnerability. Recent multi-temporal datasets of the built environment, derived from Earth Observation, have enabled comprehensive regional exposure-hazard analyses, yet their intersection with physical vulnerability remains underexplored. This study evaluates multi-hazard urban risk dynamics under the compounding effects of earthquake and flood in Quezon City, Philippines, using high-resolution multi-temporal building height data and Sentinel-2 imagery for projecting exposure and vulnerability through probabilistic graph deep learning. To extend the current CDRA and static Barangay Vulnerability Index (BVI), we present annual development profiles in terms of compound annual growth rate (CAGR) of its existing risk metrics spanning 2016–2030, covering building exposure, physical vulnerability, and earthquake-flood risk indicators. Against a baseline of 41,935 injuries for hospitalization and 12,494 fatalities, our projections indicate annual increases of up to +298 injuries and +85 fatalities, with 24 barangays identified with high earthquake- and high flood-induced displacement growth. Variability in growth trajectories across 142 barangays reflects the documented northward expansion of urban development, contrasting with redevelopment-driven patterns in the highly urbanized southern districts. Overall, our findings highlight spatially uneven trajectories of multi-hazard risk, underscoring the need for participatory validation with planners and policymakers to translate these spatiotemporal risk profiles into representations that are accessible, actionable, and impactful for prospective disaster risk management in cities undergoing rapid urbanization.

References

EMI (2022) Climate and Disaster Risk Assessment Report for Quezon City: Climate Change, Earthquake, Flood, and Landslide Hazards, including Identification of Hotspot Barangays. Tech. rep., Quezon City Government and Earthquakes and Megacities Initiative

Table 1: Building material typology in District 1 (EMI 2022), where the row and column of **N** refer to the number of building typologies present per barangay and per typology (across the city), respectively.

				Alicia	**Bagong Pag-asa**	**Bahay Toro**	**Balingasa**	**Bungad**	**Damar**	**Damayan**	**Del Monte**	**Katipunan**	**Lourdes**	**Maharlika**	**Manresa**	**Mariblo**	**Masambong**	**N. S. Amoranto (Gintong Silahis)**	**Nayong Kanluran**	**Paang Bundok**	**Pag-ibig sa Nayon**	**Paltok**	**Paraiso**	**Phil-Am**	**Project 6**	**Ramon Magsaysay**	**Salvacion**	**San Antonio**	**San Isidro Labrador**	**San Jose**	**Sienna**	**St. Peter**	**Sta. Cruz**	**Sta. Teresita**	**Sto. Cristo**	**Sto. Domingo (Matalahib)**	**Talayan**	**Vasra**	**Veterans Village**	**West Triangle**
				District 1 (37 barangays)																																				
Material	**Symbol**	**Description**	**N**	13	15	15	15	15	13	14	14	14	14	14	14	13	13	13	14	14	14	15	14	14	14	15	14	15	14	14	13	14	15	15	15	13	13	15	15	15
Wood	**W1W3**	Wooden light-frame (small)	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	W2	Wooden light-frame (large)	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	N	Makeshift or informal	141	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Masonry	**CHBMWS**	Concrete hollow block	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	URA	Unreinforced adobe walls	138	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●		●	●	●	●
	URM	Unreinforced masonry walls	140	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	RM2	Reinforced masonry walls with diaphragms	80		●	●	●	●												●		●				●		●			●		●	●	●	●		●	●	●
Concrete	**CWS**	Concrete with steel	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C1	Reinforced concrete moment frame	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C2	Reinforced concrete shear wall	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C4	Concrete shear walls and frames	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	PC2	Precast concrete frames with shear walls	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Steel	**S1**	Steel moment frames	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	S2	Steel braced frames	114		●	●	●	●		●	●	●	●	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	S3	Steel light frames	125	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●	●	●	●	●		●	●	●	●			●	●	●

Table 2: Building material typology in Districts 2, 5, and 6 (EMI 2022), where the row and column of **N** refer to the number of building typologies present per barangay and per typology (across the city), respectively.

				Bagong Silangan	**Batasan Hills**	**Commonwealth**	**Holy Spirit**	**Payatas**	**Bagbag**	**Capri**	**Fairview**	**Greater Lagro**	**Gulod**	**Kaligayahan**	**Nagkaisang Nayon**	**North Fairview**	**Novaliches Proper**	**Pasong Putik Proper**	**San Agustin**	**San Bartolome**	**Sta. Lucia**	**Sta. Monica**	**Apolonio Samson**	**Baesa**	**Balong-bato**	**Culiat**	**New Era**	**Pasong Tamo**	**Sangandaan**	**Sauyo**	**Talipapa**	**Tandang Sora**	**Unang Sigaw**
				District 2 (5)					District 5 (14 barangays)														District 6 (11)										
Material	**Symbol**	**Description**	**N**	14	15	15	15	15	15	14	15	15	15	15	15	15	15	15	15	15	14	15	15	15	13	15	15	15	15	14	15	15	13
Wood	**W1W3**	Wooden light-frame (small)	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	W2	Wooden light-frame (large)	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	N	Makeshift or informal	141	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Masonry	**CHBMWS**	Concrete hollow block	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	URA	Unreinforced adobe walls	138	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	URM	Unreinforced masonry walls	140	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	RM2	Reinforced masonry walls with diaphragms	80	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●		●	●	
Concrete	**CWS**	Concrete with steel	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C1	Reinforced concrete moment frame	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C2	Reinforced concrete shear wall	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C4	Concrete shear walls and frames	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	PC2	Precast concrete frames with shear walls	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Steel	**S1**	Steel moment frames	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	S2	Steel braced frames	114		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●		●	●	●	●	●	●	●	
	S3	Steel light frames	125	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 3: Building material typology in District 3 (EMI 2022), where the row and column of **N** refer to the number of building typologies present per barangay and per typology (across the city), respectively.

				Amihan	**Bagumbayan**	**Bagumbuhay**	**Bayanihan**	**Blue Ridge A**	**Blue Ridge B**	**Camp Aguinaldo**	**Claro (Quirino 3-B)**	**Dioquino Zobel**	**Duyan-duyan**	**E. Rodriguez**	**East Kamias**	**Escopa 1**	**Escopa 2**	**Escopa 3**	**Escopa 4**	**Libis**	**Loyola Heights**	**Mangga**	**Marilag**	**Masagana**	**Matandang Balara**	**Milagrosa**	**Pansol**	**Quirino 2-A**	**Quirino 2-B**	**Quirino 2-C**	**Quirino 3-A**	**San Roque**	**Silangan**	**Socorro**	**St. Ignatius**	**Tagumpay**	**Ugong Norte**	**Villa Maria Clara**	**West Kamias**	**White Plains**
				District 3 (37 barangays)																																				
Material	**Symbol**	**Description**	**N**	13	14	14	13	12	12	15	13	13	13	14	15	12	12	13	13	13	15	15	13	13	15	15	14	15	14	14	13	15	15	15	13	14	14	14	14	14
Wood	**W1W3**	Wooden light-frame (small)	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	W2	Wooden light-frame (large)	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	N	Makeshift or informal	141	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Masonry	**CHBMWS**	Concrete hollow block	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	URA	Unreinforced adobe walls	138	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●
	URM	Unreinforced masonry walls	140	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	RM2	Reinforced masonry walls with diaphragms	80							●					●						●	●			●	●		●	●	●	●	●	●	●			●	●		
Concrete	**CWS**	Concrete with steel	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C1	Reinforced concrete moment frame	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C2	Reinforced concrete shear wall	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C4	Concrete shear walls and frames	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	PC2	Precast concrete frames with shear walls	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Steel	**S1**	Steel moment frames	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	S2	Steel braced frames	114		●	●		●		●			●	●	●						●	●			●	●	●	●			●	●	●	●		●	●		●	●
	S3	Steel light frames	125	●	●	●	●			●	●	●		●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●		●	●	●

Table 4: Building material typology in District 4 (EMI 2022), where the row and column of **N** refer to the number of building typologies present per barangay and per typology (across the city), respectively.

				Bagong Lipunan ng Crame	**Botocan**	**Central**	**Damayang Lagi**	**Don Manuel**	**Doña Aurora**	**Doña Imelda**	**Doña Josefa**	**Horseshoe**	**Immaculate Concepcion**	**Kalusugan**	**Kamuning**	**Kaunlaran**	**Kristong Hari**	**Krus na Ligas**	**Laging Handa**	**Malaya**	**Mariana**	**Obrero**	**Old Capitol Site**	**Paligsahan**	**Pinagkaisahan**	**Pinyahan**	**Roxas**	**Sacred Heart**	**San Isidro**	**San Martin de Porres**	**San Vicente**	**Santol**	**Sikatuna Village**	**South Triangle**	**Sto. Niño**	**Tatalon**	**Teachers Village East**	**Teachers Village West**	**U. P. Campus**	**U. P. Village**	**Valencia**
				District 4 (38 barangays)																																					
Material	**Symbol**	**Description**	**N**	15	14	14	14	13	14	15	13	15	14	13	15	15	14	13	14	14	15	14	12	15	14	15	14	15	14	15	14	14	14	15	14	15	15	15	15	15	15
Wood	**W1W3**	Wooden light-frame (small)	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	W2	Wooden light-frame (large)	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	N	Makeshift or informal	141	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Masonry	**CHBMWS**	Concrete hollow block	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	URA	Unreinforced adobe walls	138	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	URM	Unreinforced masonry walls	140	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	RM2	Reinforced masonry walls with diaphragms	80	●					●	●		●		●	●	●					●			●	●	●	●	●		●	●	●		●		●	●	●	●	●	●
Concrete	**CWS**	Concrete with steel	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C1	Reinforced concrete moment frame	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C2	Reinforced concrete shear wall	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	C4	Concrete shear walls and frames	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	PC2	Precast concrete frames with shear walls	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Steel	**S1**	Steel moment frames	142	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	S2	Steel braced frames	114	●	●	●	●	●		●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●		●	●	●		●	●	●	●	●	●	●	●	●	●
	S3	Steel light frames	125	●	●	●	●		●	●		●	●		●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●		●	●	●	●	●	●	●	●	●