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Flood Risk of Metro Manila Barangays: A GIS Based Risk Assessment Using Multi-Criteria Techniques

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ABSTRACT

This study examined the flood prone areas within Metro Manila to find out their degrees of disaster risk. More specifically, the study considered the population densities of Metro Manila barangays, the smallest political units of the country, the gender and age population, the structural materials and the recorded depths of flooding. Geographic Information System (GIS) using multi-criteria techniques was the tool of analysis of the study. Projecting the population density of each barangay, the children, elderly and women populations to 2020 and 2030 and simultaneously examining the recorded depths of its flood waters and existing structural materials, the study identified the barangays that will be at high risk by 2020 and 2030. Although the study is limited to population data and physical characteristics of barangays, the findings may be useful to urban and regional planners and government agencies involved in disaster risk reduction and mitigation management. The study can be integrated in future development plans of specific areas and be used to guide future flood control measures. Finally, the study may be considered by other countries in their analysis of similar flooding experiences.

Keywords: *Barangay, Flood Risk, Assessment, Geographic Information System, Scenario*

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INTRODUCTION

Floods as natural hazards affecting Metro Manila are probably the most damaging and devastating because of their long-term and repetitive effects. According to Rabonza (2009), the occurrence of floods in Metro Manila has resulted in losses of many lives and extreme damage to properties. In the 2000 study of Fano, flooding in Metro Manila was found to have been documented as early as 1898 (Gilbuena et. al., 2013). To reduce losses due to flooding, there is a need to know how far areas are affected by floods and how vulnerable the people of these areas have become, thus spatial assessment of risk and identification of areas affected by floods would be effective. Proper spatial flood risk assessment is challenging because it concerns many facets of the society, e.g., population density, gender, age, structural materials. In 1985, according to the 1990 Japan International Cooperation Agency (JICA) study (Zoleta-

Nantes, 2000a), 7% of Metro Manila was estimated to be prone to flooding. Considering that disaster due to floods is attributed to both natural (geographical and physical characteristics) and man-made factors (World Meteorological Organization, 2008), the growing vulnerability of Metro Manila to flooding could not be solely attributed to climate. It could also be due to growth of population, rapid urbanization and urban sprawl. Furthermore, although highly populated cities carry high economic values, disaster due to flooding results in a setback in development for several years (Tingsanchali, 2012).

Flood damages depend on the flood type i.e., depth of flood, its flow velocity and duration of flood occurrence. Increasing population density coupled with assets exposed to floods in cities increase the probability of urban flood damages. For instance, the unplanned migration from the rural areas has led to an uncontrolled urban sprawl. This has increased human settlements and urbanization and in turn, has reduced the flood drainage capacity of a city (Tingsanchali, 2012). Considering that a major aim of flood risk management is to minimize human loss and economic damage, flood occurrences need to be mitigated in order to reduce disaster risks and in turn, the evaluation of implemented measures is possible. Different future scenarios could be plotted and modeled in order to factor in the probable vulnerability of populations in the cities. These models could provide advance knowledge on the depth, the duration and the flow velocities of flood, thus giving ground for pre-flood activities to reduce damages and losses.

Vulnerability, in general, is the exposure of people and assets to floods (Karmakar et. al. 2010); it is the characteristics of individual persons or groups and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (Blaikie et al. 2003). According to Fuchs, Holub et. al. (Mazzorana 2012), vulnerability in a built environment is related to the susceptibility of physical structures, i. e., it is the expected degree of loss resulting from the impact of a certain event on the elements at risk. Its assessment requires the evaluation of different parameters and factors, e. g., type of element at risk, resistance, and implemented protective measures, i. e., local structural protection. In line with social vulnerability, according to Susman and study team (Cardona 2003), this is the degree to which different social classes are differentially at risk. With respect to urban vulnerability, this is the affected total population in a high density city. In other words, cities with a high concentration of people and goods are vulnerable to floods (Kubai et. al. 2009). The study defines vulnerability with respect to the flooding susceptibility of barangays, where their populations and physical structures could be greatly at risk.

Risk is the likelihood of incurring harm, or the probability that some type of injury or loss would result from the hazard event (Cutter, et. al. 2009). It has been defined in the context of flood management, i. e., the recurring probability of a damaging event in a given area combined with negative economic, social, environmental consequences, say, damage to assets, loss of lives, and others (Meyer, et. al. 2009; Kubai, et. al., 2009). It has also been defined as the concrete occurrence and magnitude of several damages that depend on the economic and urban conditions of the flood prone area (Barredo and Engelen, 2010; Cancado, et. al. 2008). In Karmakar et. al. (2010), risk is a product of hazard and vulnerability of a region while flood risk is a combination of potential damage and probability of flooding (Kamakar et. al. 2010; IATF Working Group 2005). According to Barredo and Engelen (2010), flood risk is evaluated on the basis of 3 factors: hazards, exposure and vulnerability. If one of these factors increases, so does risk. This study defines risk/flood risk as the negative consequences experienced by barangays and their populations due to flooding.

This paper aims to do a flood risk assessment of Metro Manila at the barangay level, the smallest political unit in the Philippines (RA 7160). Previous risk maps detail flood risks on a city scale, but not on a barangay level. It is important to consider the barangays in various activities of cities, and to involve them in the disaster management plans and policies of the government because they are the front liners in defense. As cities tap the barangays for disaster risk reduction management (Andrade, 2013), barangays would be the best source of improvements in disaster reduction or mitigation programs (Zoleta-Nantes, 2000b) of the Philippine government. This study intends to answer the following questions: Which areas in Metro Manila would be prone to flooding? How many people would be affected? What barangays would be at high risk when flooding occurs? Would there be an increase in number of barangays that would be at high risk in the future? Or, would there be less? What would be the bad and worst flood risk scenarios of Metro Manila barangays? Although this study would be limited to the population densities, gender and age of populations and structural materials, flood risk maps showing the flooding scenarios of these barangays could be significant in future development plans of Metro Manila. More specifically, knowing what barangays need to be prepared for prior to flooding, this study could be significant in the land use planning of the cities and municipalities in Metro Manila. Their land use plans could be crafted to include flood risk reduction and mitigation measures and policies for the barangays.

FRAMEWORK

As flood risk assessment involves various aspects, the multi-criteria technique (Musungu et. al., 2012; Saini and Kaushik, 2012) could be considered. A structured approach could be used to analyze a series of alternatives (qualitative indicators of a criterion) with the view of ranking them from most preferable to least preferable. In the investigation of a methodology that the Cape Town City Council of South Africa used to improve its flood risk assessment, the criteria used were: exposure to hazards, methods of mitigation, sanitation and disease, and income. The alternatives under the “exposure to hazards” criterion included *no exposure to hazards, exposure to fire only, exposure to both flooding and fire, and flooding due to a number of factors, i. e., a leaking roof, rising water and flush floods* (Musungu et. al., 2012). Weights were given through the Pairwise Comparison Method of household preferences, the classic method for an Analytic Hierarchy Process (AHP) to determine the rank of an alternative (Saaty, 1980). The weights were linked to the settlement areas of Graveyard Pond of Cape Town as the attribute data in the GIS. That is, after each household had been allocated a weight, these were mapped in the GIS environment to identify disparities in vulnerability. Then, a vulnerability map was created for each criterion in the entire settlement (Musungu et. al., 2012). In the risk and vulnerability assessment of flood hazard in India, hydrological data alone was found to be insufficient because flood hazard is a multi-dimensional problem and socioeconomic data were necessary to create a flood hazard database. The study showed how flood hazard related information was extracted from satellite imageries and synthesized with census data at the village level to identify the land use exposed to different degrees of flood risk (Saini and

Kaushik, 2012). Along the Niger-Benue Basin in Nigeria, a geospatial methodology for detecting and extracting flood risk areas and vulnerable populations was developed for assessment. Satellite images, population census, and maps were obtained and entered into different software to extract and map the flood-prone areas and the population spatial spread. The study generated thematic maps, i.e., flood hazard layers overlaid on a base map (Nkeki et. al., 2013). The flood risk assessment model of the Dongting Lake (most important storage lake of the Yangtze River) in Hunan, China, used a 5-risk evaluation index. These indices were: density of population, density of industrial and agricultural products, density of one line embankment, average difference between control points, i.e., embankment top elevation and yearly highest water level, and proportion of danger embankment length to total embankment length (Chen et. al. 2012). In China, the study of the Jingiang flood diversion used the management of risk analysis data, the risk assessment models for flood risk analysis and the flood risk maps. More specifically, it used various kinds of data classified into 3 sets of indices. The first set was a 4-hazard index based on hydrodynamic models, e.g., average maximum flow velocity, flood depth, flood submerging range, and flood arriving time. The second set was composed of 3 additional hazard assessment indices based on weather, terrain, and river distribution. These were: annual average precipitation, average ground elevation, and land use rate. The final set on flood vulnerability was composed of 6 indices which were: population density, industrial output density, agricultural production density, breeding area percentage, animal density and road network density. The flood hazard and vulnerability indices were divided into 5 grades: very low, low, medium, high and very high (Liu et. al., 2013). Similarly, Dewan et. al. (2005) used 5 risk grades in their flood hazard assessment in Dhaka, Bangladesh as follows: least, less, moderate, high and very high risk grades.

According to Zoleta-Nantes (2000a), Metro Manila flood hazard studies had no available flood maps that could indicate which areas were at risk, nor what flood depths could be expected on certain flood magnitudes, except for the 1996 flood map of Solidum. The author stated that location data of flood-prone lands, which could be used by most government agencies in future flood occurrences, are still wanting. The study pointed out that there was a need for a listing of barangays, which were perennially inundated. This list, along with all available information about flood risks, could be incorporated into a database that could be used for flood prevention and disaster risk mitigation purposes, using the GIS. As Mao posited in 2009, if the vulnerability of an area is strong, then the flood disaster risk level of that area is high (Chen et. al., 2012). Zoleta-Nantes recommended that risk assessment be one of the yearly planning activities of Metro Manila local governments and their constituents. Furthermore, risk assessment could be undertaken within the context of urban development (Lindfield, 1990).

The study of Nguyen and James (2013) recognized children as the most vulnerable group especially during large flood events. Deaths of children were mostly reported in the highest and moderate flood prone regions, and very few cases in the low flood prone region. The deaths of children, however, were not directly caused by flood-related disease, but related to drowning due to lack of supervision from caregivers. Children and elderly represent age classes which are dependent for support in the event of flood (Meyer et. al., 2009a in Kubal et. al., 2010). The elderly are at risk due to their lower constitutional mobility (Cutter et al., 2003), where they are more likely to lack the physical and economic resources to respond effectively to a disaster; and are more likely to suffer health problems and experience slower recovery (Ngo 2001 in Cutter et. al., 2009). In line with gender, women are considered to be more vulnerable to disaster than men because of their roles as mothers and caregivers. That is, when disaster is about to strike, their ability to seek safety become restricted by their responsibilities to the very young and the very old, both of whom require help and supervision (Cutter et. al., 2009; Bianchi and Spain 1996 in Cutter et. al., 2009). On population density (Chen et. al. 2012), the more densely populated an area, the more people are in danger during high flood waters. Places with social health care and related infrastructure facilities play an important role in quality of life of the urban population. Thus, damages caused by flood events lead to substantial losses of such infrastructure (Kubai, et. al., 2009). Flood damage to nursing homes, kindergartens and schools poses unexpected financial discomforts for parents, relatives and the staff (Cutter et. al., 2003). In line with the structural materials of physical and social infrastructure, the stronger types of materials are more expensive than the weaker types of materials. Thus, type of structural material is assumed to be dependent on the income or financial affordability of the barangays and their residents.

This study on the flood risk grades of Metro Manila barangays used a multi-criteria technique to determine their environmental and social risks. Population density, gender, age, community structural materials and flood levels were the 5 indices. The gender and age indices were with respect to 3 population groups, namely: women, children and elderly, as these are particularly vulnerable to floods. The study anticipated that the higher the population density, the more the women, elderly and children, the weaker the structural materials, and the higher the flood levels recorded, the higher the risk grade of a barangay to flooding. The hypothesis of the study could be summarized as follows:

$$RG = f(PD, Pw, Pe, Pc, SM, FD), \text{ where: } SM = f(BY)$$

RG = risk grade or degree of flood risk of barangay,

PD = total population density of barangay

Pw = women population (females 15 to 64 years old)

Pe = elderly population (65 years old and above)

Pc = children population (0-12 years old)

FD = recorded flood depth

SM = structural materials within barangay

BY = income of barangay and its residents

PROFILE OF THE STUDY AREA

Figure 1 *Map of Metro Manila: Cities and Municipality*
Source: MMDA

The study area is the Metropolitan Manila area or simply known as Metro Manila (Figure 1). It is regionally designated as the National Capital Region. It is the smallest region in the country yet it is the political, economic, social and cultural center of the Philippines, aside from being the only region in the country that is totally urban. It is also considered as one of the modern metropolises in Southeast Asia (Set-up Projects Online Luzon, Regional Profile, para. 1). Metro Manila has a total land area of 638.55 km^2, approximately 0.21% of the country's entire land area (Kyoto University and Metroplanado, 2010). Manila Bay is along the western part of Metro Manila. The shallow waters of Laguna Lake bounds the region in the south and southeast. The Pasig River bisects Metro Manila from Laguna Lake to Manila Bay, covering a distance of about 24 kilometers. The entire region is a mix of physical features and natural constraints. These are the coastal plain of Manila Bay, a companion plain around Laguna Bay, the inland Marikina and the Guadalupe Plateau (Zoleta-Nantes, 2000a). It is bordered by the province of Bulacan in the north, Rizal in the east and northeast, Cavite in the southwest, and Laguna in the south. The western part of Metro Manila gives the flat fluvial and deltaic lands of the region while the eastern part is composed of the rugged lands of Marikina Valley and Sierra Madre Mountain Ranges. Metro Manila is located at 14º40'N and 121º3'E. It lies on a swampy peninsula with an average elevation of 10 meters. According to the Köppen climate classification system, Metro Manila has a tropical monsoon climate with no distinctive seasons. As it lies within the tropics, its temperature ranges from slightly lower than 20ºC to slightly higher than 38ºC. Furthermore, it has high levels of humidity (Asian Human Network Databank, n.d.). Rainy season in Metro Manila is from May to November. When the southwest monsoon is very active, its average rainfall is 200mm or more within a two-day period. The cities of Valenzuela, Malabon, Caloocan, Navotas, Manila, Pasay, Parañaque and Las Piñas are considered to be the most flood prone areas in Metro Manila. The floods in these cities are associated with the tidal movements in Manila Bay, especially in inundating lands that are up to 0.3 meters above mean sea level. In addition to this, land subsidence has been measured up to 0.33 meters in central Manila. Laguna Bay's shores are fringed with deep soils that have water tables. Areas along the Marikina Valley, i.e., the cities of Marikina, Pasig, Taguig and the municipality of Pateros, are the flood-prone areas of inland Metro Manila. These areas also have poor soil drainage, a shallow water table, and low soil stability which make the areas susceptible to earthquake and flood hazards. As for the areas lying in and along Guadalupe Plateau, flood risks are lower. These areas, with resistant volcanic rocks rise up to 40 meters to 70 meters above sea level. More specifically, these are Quezon City, San Juan City, Makati City, Mandaluyong City and Muntinglupa City, and portions of Pasig City, Parañaque City and Las Piñas City (Zoleta-Nantes, 2000b).

Metro Manila is the Philippines' seat of government where the City of Manila is its capital. The region is subdivided into 17 local government units (LGUs) comprising of 16 highly urbanized cities and one first class municipality (Figure 1) with a total of 1,705 barangays (Department of Interior and Local Government-National Capital Region, Profile section 12). Based on the 2010 NSO census on population, Metro Manila's 11,855,975 individuals comprise 13% of the country's total population.

METHODOLOGY

In the flood risk assessment of Metro Manila barangays, the following major steps for data collection and analysis were considered: First, data gathering of the relevant GIS layers were taken from different government agencies like the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) and the Mines and Geosciences Bureau (MGB) for the flood hazards of Metro Manila; the Metropolitan Manila Development Authority (MMDA) and the National Mapping Resource and Information Agency (NAMRIA) for the boundary maps of cities and municipality in Metro Manila; and the Open Street Maps (OSM) for other map requirements. Population data were gathered from the National Statistics Office (NSO). Barangay structural materials were taken from the 2003 Metro Manila Earthquake and Impact Reduction Study (MMEIRS).

Second, the establishment of the base map and Geographic Information System (GIS)[1] database of the study used the Digital Elevation Model (DEM) of Metro Manila with its surrounding provinces. Then, other layers, i. e., the updated city/municipality boundaries, and the GIS vector layers: waterways, roads and buildings, were overlaid for reference purposes.

[1]GIS mapping is a reliable tool for geo-environmental catastrophe evaluation because it provides a cost-effective way of facilitating flood susceptibility mapping, flood risk assessment and flood management (Lawal, et. al., 2011). It is capable of processing spatial data and attribute data and represent real spatial entities and provide spatial analysis (Siddik and Rahman, 2013; Liu et.al., 2013; Pornasdoro, et.al., 2012).

The Philippine Reference System (PRS92) was used as the Coordinate Reference System for all the layers. In determining the spatial characteristics that existed between datasets of barangays, the collected data were considered in the base map as different variables, but interacting with each other. The flood layers adopted the number of divisions by the Mines and Geosciences Bureau (MGB) (2013), which were VERY HIGH, HIGH, MODERATE, LOW and VERY LOW frequencies.

Third, the study utilized a multi-criteria technique, where the environmental and social risks of barangays were examined. Based on the Framework, 5 indices were considered, namely: population density, gender, age, structural materials and flood depths; where, the gender and age indices were with respect to 3 population groups, i. e., women, children and elderly, the most vulnerable groups to floods. The women population data was females from 15 to 64 years old; the children population data was from 0 to 14 years old and the elderly population data was from 65 years old and above. It is noted that NSO data for these specific groups were available only for city/municipality level and none for barangay level.

Fourth, using the equation in the Framework of the study, the Flood Risk Grade per barangay polygon was computed through Geoprocessing. To have a more realistic picture of risk grades of barangays, the paper considered the bad and worst scenarios. The study assumed that the population growth of Metro Manila was due not only to its natural birth increase but, also due to in-migration from the rural areas. Based on the 2007 and 2010 NSO population data, the population of barangays was initially projected for 2020. However, as this was only a few years away, a longer term projection was considered necessary. Thus, population projection for a relatively more distant future (2030) was also done. The study considered three population projection equations, namely: linear[2], geometric[3], and exponential[4] and using the land areas of barangays, the population densities were computed accordingly. The arithmetic/linear population projections gave the lowest increase in population density while the exponential population projections gave the highest increase in population density. Thus, the linear projections were used to represent the bad risk scenario and the exponential projections were used to represent the worst risk scenario. Based on the Framework above, the population densities were divided into 5 levels using percentile classification (Walton et. al., 2008). More specifically, the population densities of barangays had the following classification: VERY LOW for up to the 20th percentile or 20,000 and less people per square kilometer, LOW for up to the 40th percentile or 20,001 to 40,000 per square kilometer, MEDIUM/MODERATE for up to the 60th percentile or 40,001 to 75,000 people per square kilometer, HIGH for up to the 80th percentile or 75,001 to 120,000 people per square kilometer, and VERY HIGH for up to the 100th percentile or Above 120,000 people per square kilometer.

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[2]Linear Formula: $P_t = P_0 + bt$, *where* P_0 *= initial population;* P_t *= population t years later; and b = annual amount of population change, i. e., [b =* $(P_0 - P_{first\ \mathrm{year}})$ / (Last year-First Year)].
[3]Geometric Formula: $P_t = P_0\,(1+r)^t$, *where* P_0 *= initial population and* P_t *= population t years later and r = growth rate. According to NSO, r = 1.78 from 2000 to 2010.*
[4]Exponential Formula: $P_t = P_0\,(e^{rt})$, *where* P_0 *= initial population,* P_t *= population t years later, r = annual rate of growth, e = base of the natural logarithm.*

Fifth, the analysis was an area-based or polygon-based approach in which the base GIS datasets were represented by polygons (NEDA-ADB, 2007). Finally, the vector layers of the Metro Manila barangays were processed for years 2020 and 2030. Figure 2 gives the summary of the methodology of the study.

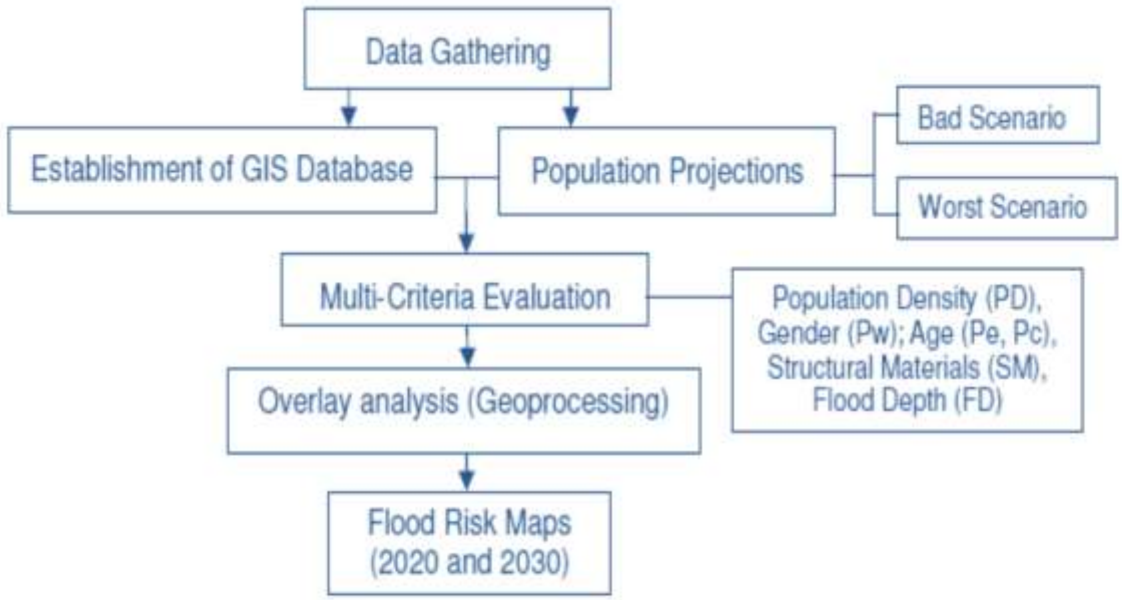

Figure 2 *Summary of Methodology of Study*

FINDINGS

Figure 3 shows the base map of the study while Figure 4 shows the flood vulnerability of areas in Metro Manila with respect to the frequency of occurrence. As mentioned in the Methodology, these were classified into VERY HIGH, HIGH, MEDIUM/MODERATE, LOW and VERY LOW flood vulnerability layers, in case of a 1/100 Annual Exceedance Probability (AEP) flood. These were integrated in GIS with flood depth records, the Barangay population densities (Figure 5 and Table 1), the women population trends (Figure 6), the children and elderly population trends (Figure 7) and the 2000 Metro Manila structural materials map (Figure 8). The study assumed that structural materials in Metro Manila have not changed significantly over the years. As anticipated in the Framework, the larger the footprint area of a barangay with weak structural materials, the higher the flood depth occurrence, the higher the population density of the barangay, and the higher the children, elderly and women population of the city/municipality where the barangay is located, the worse the risk scenario.

Figure 3 Base Map of Metro Manila Using the Digital Elevation Model (DEM)

Figure 4 Flood Vulnerability Map of Metro Manila

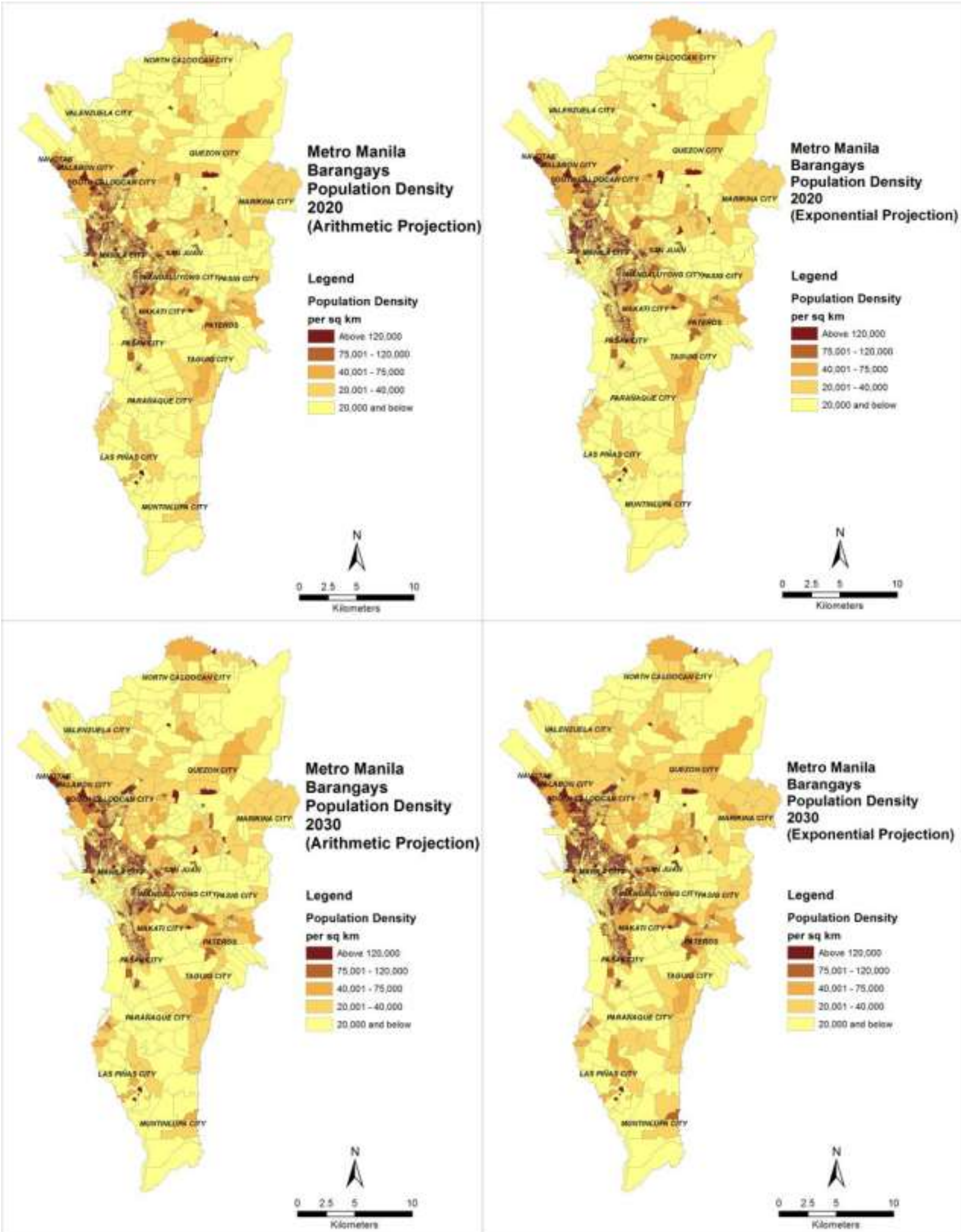

***Figure 5** Population Density Maps of Metro Manila Barangays*
Source: MMDA, NSO and authors Arithmetic and Exponential Projections

Table 1 *Metro Manila Population Densities by Cities and Municipality: 2010, 2020, 2030*

Name of City or Municipality	No. of Bgys	Land Area Sq. Km.	Population Densities				
			2010	2020		2030	
				Arithmetic	Exponential	Arithmetic	Exponential
City of Manila	897	33	73,820,398	68,319,424	88,202,673	62,818,450	105,386,787
Caloocan City	188	54	10,332,128	10,984,756	12,345,088	11,638,013	14,750,223
Las Piñas City	20	33	475,181	516,189	567,758	557,197	678,372
Mandaluyong City	27	11	1,101,271	1,354,285	1,315,826	1,607,299	1,572,182
Makati City	33	23	1,137,648	889,646	1,359,290	641,644	1,624,115
Malabon City	21	15	674,267	641,199	805,632	608,130	962,589
Marikina City	16	24	219,104	217,867	261,791	216,630	312,795
Muntinlupa City	9	38	152,670	143,444	182,414	134,218	217,953
Navotas City	14	11	721,889	698,619	862,531	675,350	1,030,574
Parañaque City	16	45	310,761	351,086	371,305	391,410	443,645
Pasay City	201	18	12,645,823	11,881,827	15,109,550	11,117,830	18,053,272
Pasig City	30	32	985,152	1,124,659	1,177,084	1,264,167	1,406,410
Pateros Municipality	10	2	357,753	390,730	427,452	423,707	510,731
Quezon City	142	134	4,372,676	4,579,665	5,224,584	4,786,655	6,242,465
San Juan City	21	6	772,831	796,035	923,398	819,239	1,103,300
Taguig City	27	29	286,865	153,346	342,754	19,826	409,531
Valenzuela City	33	45	441,696	484,204	527,750	526,711	630,569
Total	1,705						

Source: 2007 and 2010 NSO-NCR, NCR in Figures and authors' 2020 and 2030 projections

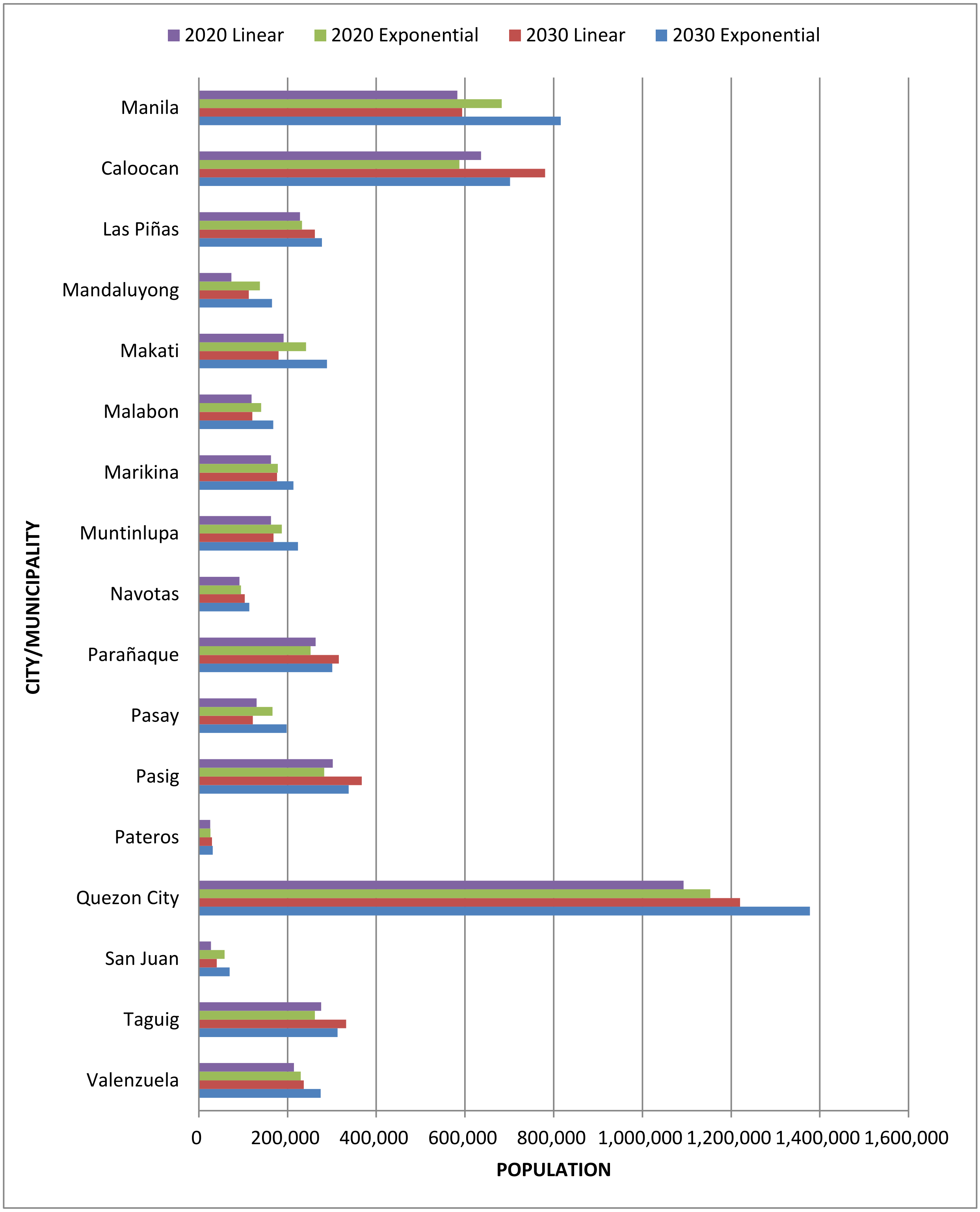

Figure 6 *Women Population Trends for 2020 and 2030 by City and Municipality*
Source: NSO-NCR 2007 Census of Population, Report #2-66M, Vol. 1: Demographic and Housing Characteristics and Authors' Arithmetic/Linear and Exponential Projections for 2020 and 2030

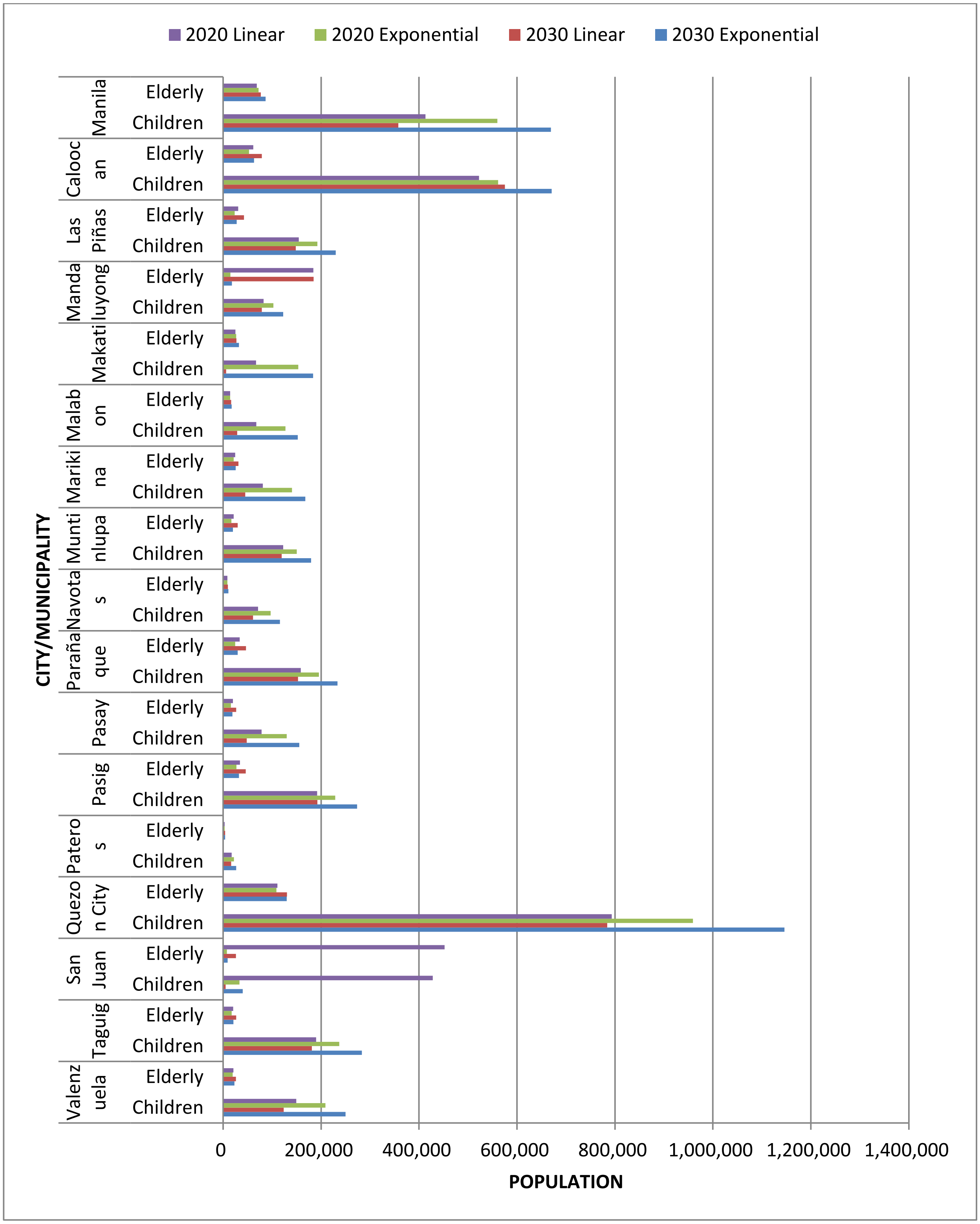

***Figure 7** Children and Elderly Population Trends for 2020 and 2030 by City and Municipality*
Source: NSO-NCR 2007 Census of Population, Report #2-66M, Vol. 1: Demographic and Housing Characteristics; Authors' Arithmetic/Linear and Exponential Projections for 2020 and 2030

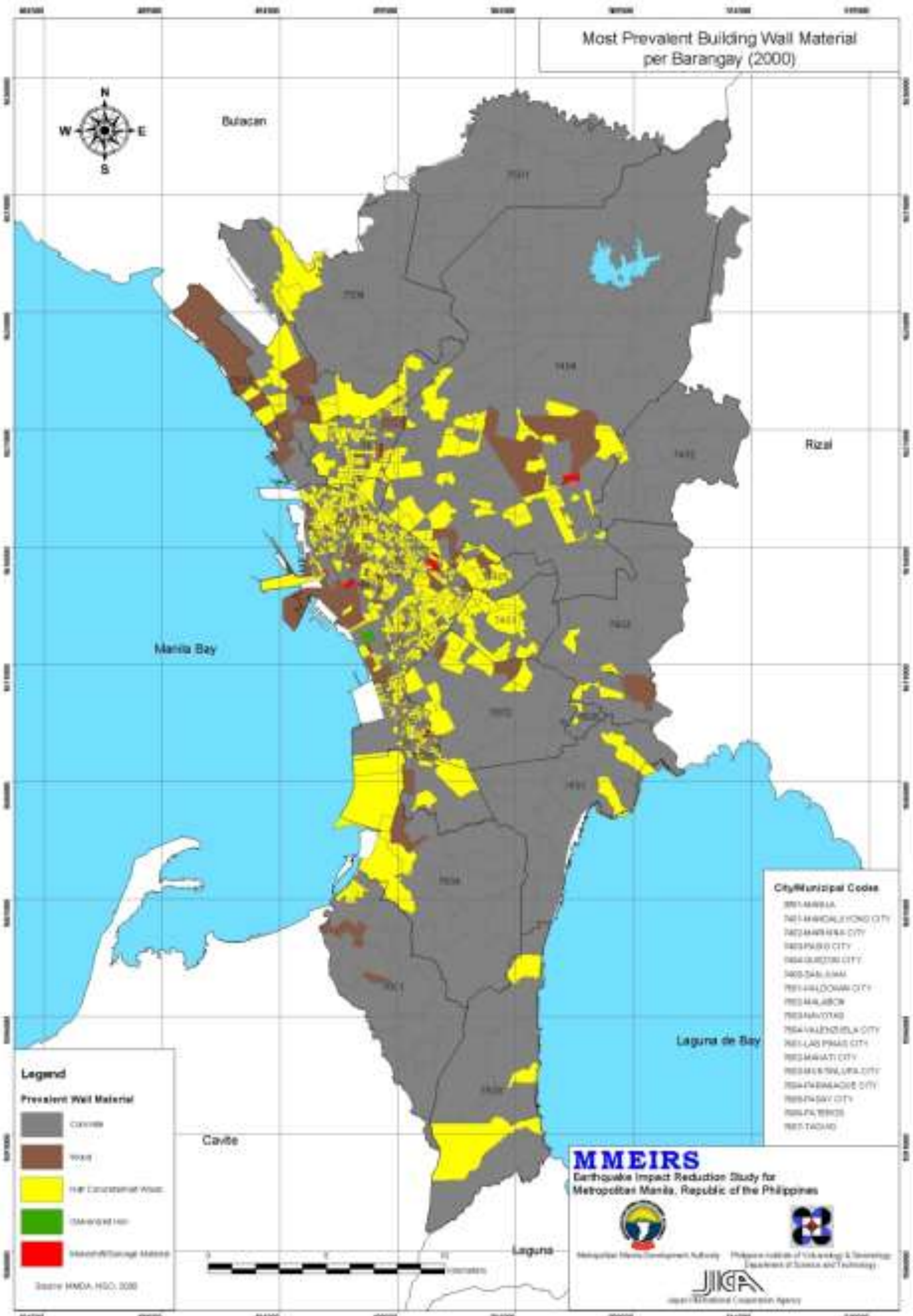

Figure 8 *Most Prevalent Building wall material per barangay*

Source: MMDA, PHIVOLCS, JICA

Table 2 shows the distribution of Metro Manila barangays with respect to Bad and Worst scenario risk grades for 2010, 2020 and 2030. More specifically, the Bad scenario shows that 391 barangays had VERY LOW to LOW risks in 2010 while 369 barangays have VERY LOW to LOW risks in 2020 and 331 barangays in 2030. The decrease in the number of barangays with VERY LOW and LOW risk grades shows an increase in number of barangays (366) in the MODERATE risk grade. In the worst scenario, Table 2 shows that in year 2010, 746 barangays in Metro Manila had a grade of HIGH risk and 214 barangays a grade of VERY HIGH risk. By 2020, these figures increase to 757 and 256 barangays for HIGH and VERY HIGH risks, respectively, and by 2030, to 729 HIGH risk and 301 VERY HIGH risk barangays. This finding is in contrast with the LOW and MODERATE risk grade barangays, which decrease significantly in 2010 and 2020 due to the shift of some of the barangays to higher risk grades. According to G. Smith of the University of North Carolina (2010), when flood recurs in the same area, the level of flooding can be expected to be higher than the previous level. This explains the findings of the study on the shift of some barangays from LOW and MEDIUM risk grades to HIGH risk grade from 2010 to 2030. The increase in the number of higher risk grade barangays can mean that recurring floods in Metro Manila are at higher levels for these areas.

Table 2 *Number of Barangays According to Bad and Worst Scenario Flood Risk Grades (2010, 2020, 2030)*

Year	Bad Scenario Risk Grades					Worst Scenario Risk Grades					Total Brgys
	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High	
2010	132	259	354	746	214	132	259	354	746	214	1705
2020	127	242	351	739	246	120	235	337	757	256	
2030	113	218	366	715	263	109	212	354	729	301	

Table 3 shows the percentage of the total barangays per city/municipality affected by each risk grade in the Worst Scenario by year 2020 and 2030. About 50-57% of the barangays of Manila, Malabon and Navotas cities can be expected to be at HIGH risk grades in 2020 and 2030; about 40% of Marikina barangays can also be at HIGH risk grade in both years; and 28% of Valenzuela barangays can be expected to be in the same situation in 2020 and 2030. Some areas in the cities of Manila, Malabon and Navotas are below sea level that in the event of high tide alone, some areas already get flooded. Looking at the other indices of Flood Risk Grade in the Framework, the City of Manila has the highest population density in Metro Manila; it is 2nd highest in children and elderly population, 3rd highest in women population; and a large portion of its wall structures are of wood, half concrete/half wood and makeshift/salvage materials. Thus, the 57.5% of its barangays at HIGH risk by 2030. With respect to Malabon and Navotas cities, although their population densities have moderate rankings: 10 and 9, respectively, and their vulnerable populations (women, children and elderly) rank 13 and 15, respectively, these cities have more than 50% of their barangays at HIGH risk by 2030. The generally wood and half concrete/half wood types of structural materials in these cities can be an explanation. On the other hand, Valenzuela City, ranks 7th highest in its vulnerable population and nearly the same rank in population density as Malabon and Navotas cities, but the wall materials within the city are mostly concrete, which is a relatively stronger material than wood or half concrete/half wood and thus, the 28% of Valenzuela barangays at HIGH risk by 2030. In the light of VERY HIGH risk grade category, barangays of 5 cities can be expected to be at this grade level in 2030, where between 11-35% of the barangays of these cities can be at VERY HIGH risk grades. These cities are: Caloocan, Manila, Marikina, Taguig and Valenzuela.

Table 3. *Percent of Metro Manila Barangays by Cities and Municipality According to Worst Scenario Flood Risk Grades for 2020 and 2030*

City / Municipality	Total Brgys	Percentage Barangays and Risk Grades (Worst Scenario)									
		VERY LOW		LOW		MODERATE		HIGH		VERY HIGH	
		2020	2030	2020	2030	2020	2030	2020	2030	2020	2030
Manila	897	8.5	4.3	12.3	8.9	14.1	14.1	51.3	57.5	13.8	15.2
Caloocan	188	14.2	13.7	14.6	15.8	38.1	25.1	23.3	33.3	9.8	12.1
Las Pinas	21	0.0	0.0	90.4	66.7	9.6	14.3	0.0	19.04	0.0	0.0
Mandaluyong	27	11.2	11.2	18.5	18.5	37.0	33.3	33.3	37.0	0.0	0.0
Makati	33	27.2	9.1	66.7	66.7	6.1	18.1	0.0	6.1	0.0	0.0
Malabon	21	0.0	0.0	28.7	24.0	19.0	19.0	52.3	52.3	0.0	4.7
Marikina	17	5.8	5.8	11.8	5.8	11.8	12.1	41.1	41.1	29.5	35.2
Muntinlupa	9	33.3	33.3	33.3	33.3	22.2	22.2	11.1	11.1	0.0	0.0
Navotas	14	0.0	0.0	21.5	7.3	28.5	28.5	50.0	57.1	0.0	7.1
Paranaque	14	7.2	7.2	28.6	21.5	57.1	57.1	7.1	14.2	0.0	0.0
Pasay	201	8.9	6.0	9.1	9.1	66.7	68.1	10.4	11.4	4.9	5.4
Pasig	31	19.4	16.2	25.8	25.8	54.8	54.8	0.0	3.2	0.0	0.0
Pateros	10	0.0	0.0	80.0	70.0	10.0	20.0	10.0	10.0	0.0	0.0
Quezon City	142	56.1	50.7	15.4	16.9	14.4	16.9	11.3	12.7	2.8	2.8
San Juan	21	23.9	19.2	23.8	23.8	28.5	28.5	19.1	23.8	4.7	4.7
Taguig	27	7.5	3.8	18.5	11.1	44.4	44.4	22.2	29.6	7.4	11.1
Valenzuela	32	0.0	0.0	15.8	6.3	34.3	40.6	28.1	28.1	21.8	25.0

Tables 4 and 5 show the specific barangays expected to be at HIGH and VERY HIGH worst scenario risks by 2020 and 2030. It is noted that most of these are located along creeks, riverbanks or coastal areas. For instance, the Caloocan City barangays that would be at Very High Risk grades by 2020 and 2030 are near the Sapang Alat River, a river bordering Caloocan City and Bulacan Province; in Quezon City, Barangay Commonwealth is near the Tullahan River and in San Juan City, Barangay Rivera is along San Juan River. Figure 9 illustrates the worst flood risk scenario of barangays for 2020 and 2030.

Table 4. *Barangays at HIGH Flood Risks by 2020 and 2030 (Worst Scenario)*

City/Municipality	HIGH RISK	
	2020	**2030**
City of Manila	620 barangays in Tondo, Sta Cruz, Malate, Sampaloc, Paco, Quiapo, Binondo, Pandacan, Intramuros, Ermita, Port Area near Pasig River and Tributaries	556 barangays in Tondo, Sta Cruz, Malate, Sampaloc, Paco, Quiapo, Binondo, Pandacan, Intramuros, Ermita, Port Area near Pasig River and Tributaries
Caloocan City	24 barangays in North Caloocan; 20 barangays in South Caloocan	27 barangays in North Caloocan; 36 barangays in South Caloocan
Las Piñas City		Talon Singko, Almanza Uno, Talon Uno, Talon Kuatro
Mandaluyong City	Namayan, Hulo, Plainview, Mabini – J Rizal, Daang Bakal, Bagong Silang, Addition Hills, Pleasant Hills	Namayan, Hulo, Plainview, Mabini – J Rizal, Daang Bakal, Bagong Silang, Addition Hills, Pleasant Hills, Maluway
Makati City		Pembo, Rizal
Malabon City	Dampalit, Catmon, Muzon, Concepcion, San Agustin, Nugan, Ilongos, Potrero	Dampalit, Catmon, Muzon, Concepcion, San Agustin, Nugan, Ilongos, Potrero
Marikina City	Jesus Dela Pena, Kalumpang, San Roque, Sto Nino, Tanong, Industrial Valley	Jesus Dela Pena, Kalumpang, San Roque, Sto Nino, Tanong, Industrial Valley
Muntinlupa City	Putatan	Putatan
Navotas City	Tangos, Daang-hari, San Jose, North Bay Blvd (North and South), Navotas East and West	Tangos, Daang-hari, San Jose, North Bay Blvd (North and South), Navotas East and West, Bangculasi
Parañaque City	BF Homes	BF Homes, San Antonio
Pasay City	21 barangays along coastal area	23 barangays along coastal area
Pasig City	Rosario, Sta Lucia, Maybunga, Kalawaan, Manggahan	Rosario, Sta Lucia, Maybunga, Kalawaan, Manggahan
Pateros Municipality	Sta Ana	Sta Ana
Quezon City	San Bartolome, Nagkakaisang Nayon, Sta Lucia, Bagong Pagasa, Tatalon, Dona Imelda, Matandang Balara, Culiat, Apolonio Samson, Ramon Magsaysay, Alicia	San Bartolome, Nagkakaisang Nayon, Sta Lucia, Bagong Pagasa, Tatalon, Dona Imelda, Matandang Balara, Culiat, Apolonio Samson, Ramon Magsaysay, Alicia, Baling asa, Paltok
San Juan City	Salapan, Progreso , San Perfecto	Salapan, Progreso , San Perfecto, Pasadena
Taguig City	Western Bicutan, Lower, Bicutan, Wawa, Sta Ana, Bagumbayan, Bagong Tanyag	Western Bicutan, Lower, Bicutan, Wawa, Sta Ana, Bagumbayan, Bagong Tanyag, Ibayo
Valenzuela City	Marulas, Malinta, General T de Leon, Caruhatan, MapulangLupa, Dalandanan, Isla, Pariancillo Villa	Marulas, Malinta, General T de Leon, Caruhatan, MapulangLupa, Dalandanan, Isla, Pariancillo Villa

***Table 5** Barangays at VERY HIGH Flood Risks by 2020 and 2030 (Worst Scenario)*

City/Municipality	VERY HIGH Risk	
City of Manila	209 barangays in Tondo, Sta Cruz, Sampaloc, Paco, Quiapo, Binondo, Pandacan, Intramuros, Ermita, Port Area near the Pasig River and Tributaries	243 barangays in Tondo, Sta Cruz, Sampaloc, Paco, Quiapo, Binondo, Pandacan, Intramuros, Ermita, Port Area near the Pasig River and Tributaries
Caloocan City	Barangays 8, 12, 14, 35, 36, 168, 171, 173, 174, 175, 176, 177,178, 180, 181,182,183, 185, 186, 187	Barangays 8, 12, 14, 35, 36, 168, 171, 173, 174, 175, 176, 177,178, 180, 181,182,183, 185, 186, 187
Malabon City		Tonsuya
Marikina City	Concepcion 1, Nangka, Parang, Malanday	Concepcion 1, Nangka, Parang, Malanday
Navotas City		Tanza
Pasay City	10 barangays along coastal area	11 barangays along coastal area
Pasig City	Pinagbuhatan	Pinagbuhatan
Quezon City	Commonwealth, Payatas, Holy Spirit, Batasan	Commonwealth, Payatas, Holy Spirit, Batasan
San Juan City	Rivera	Rivera
Taguig City	Hagonoy, Signal Village	Hagonoy, Signal Village
Valenzuela City	Wawang Pulo, Tagalag, Coloong, Balangkas, Bisig, Malanday	Wawang Pulo, Tagalag, Coloong, Balangkas, Bisig, Malanday

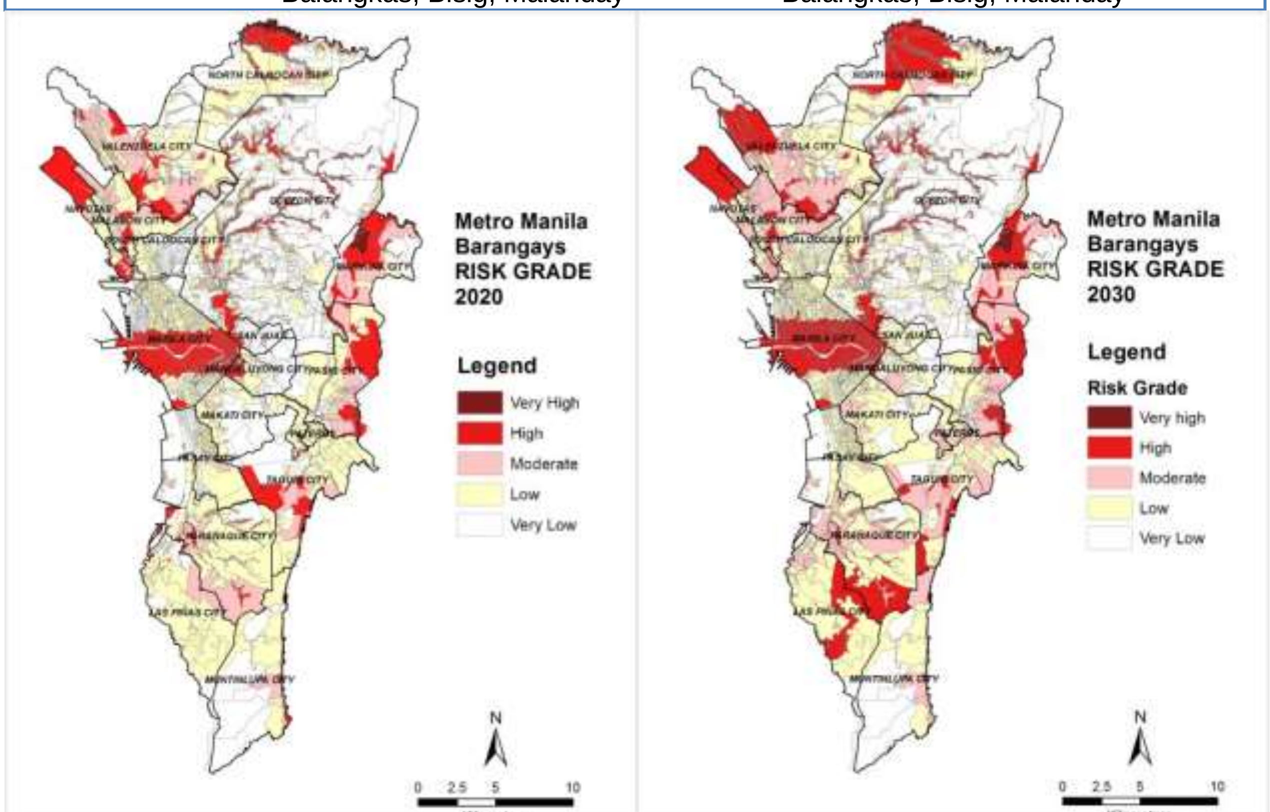

***Figure 9** Worst Scenario Flood Risk Maps of Metro Manila Barangays for 2020 and 2030*

CONCLUSIONS AND RECOMMENDATIONS

The study cannot be said to be without limitations. Nevertheless, a GIS-based risk assessment of multiple criteria can improve the accuracy of flood risk assessment for Metro Manila with the consideration of the smallest political unit of Philippine society, the barangay. Firstly, the study shows barangays that can be at high and very high flood risks in the near future and in a relatively more distant future, and has implications to the disaster risk mitigation/reduction policies of LGUs. For instance, with the Marikina River rising as high as 21 meters during heavy downpours, the Marikina City government implemented structural mitigation programs through a number of flood-control projects and raised public awareness and emergency preparedness through a Disaster Management Office, i. e., Rescue 161 (Ordinance 264 of 1998) and a Disaster Preparedness Education Center, where a disaster management library for children and adults is one of its components (Asian Disaster Preparedness Center, 2008). However, these could be said to have been a response to the earlier experiences of the City. To know a few years earlier which barangays in Marikina City can be expected to be at high and very high flood risks can give the city government ample time to plan its future disaster risk reduction/mitigation programs and sustain its environment policies on public safety and quality of life. Furthermore, the city government can give priority interventions and determine some not too expensive flood mitigation strategies that can support the concerned barangays. Secondly, the study can be used by the national government, say, in the prioritized projects of the Department of Public Works and Highways (DPWH) and the MMDA that are within the flood control master plan, to solve perennial flood problems in Metro Manila (Manila Bulletin, 2012). Thirdly, both national and local governments can use the study as a guide to determining priority areas for future urban plans. Finally, as mapping can provide critical information at the barangay level, GIS-based mapping agencies can use the findings of the study to facilitate improvements in their output.

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