Work Package 2.4

Part IV:

Using GIS to Visualize Risk in Metro Manila

Introduction

Background

Metro Manila has been experiencing a variety of natural hazards including climate and weather extremes, flooding, storm surge, tropical cyclones, earthquake and others. While these hazards affect the exposed population and land use/cover types, these exposures likewise affect hazards. Also, hazards, exposures and vulnerabilities (HEVs) distribute themselves unevenly across space and time as well as interact with each other. Hazards may be considered catalysts of disasters, while exposures and vulnerabilities are root causes of disasters. The spatial relationships of these HEV variables are not always examined. Hence, this report aims to visualize and analyze the generated geospatial datasets of the HEVs. Specifically, we considered informality, critical infrastructures, and social vulnerability indicators.

Rationale

The Philippines is known to be a champion in disaster risk governance and, as such, has progressed in terms of understanding the confluence of HEVs towards integrated risk analyses. For this, downscaled climate modeling help better diagnose climate variability and extremes, as these influence exposures and associated vulnerabilities. Risk assessments are then mainstreamed into decision making through various plans (e.g., DRRM, Climate Change Action, and Local Development Plans).

Nevertheless, the failure to understand salient vulnerabilities vs. capacities of communities as well as vital socio-economic assets needed to sustain development and growth, has kept Philippine cities continually at risk to evolving hazards associated with climate change and other factors. Mapping these risks in a manner that will be visually understood by policy-makers will better facilitate solution-seeking and decision-making amongst governance actors. In the same light, deeper understanding of how the elements of risks interact to produce devastation will also allow various stakeholders to look into appropriate innovative measures to enable resilience against powerful hazards.

Definition of terms

Child - “a person below 18 years of age, or over 18 years of age but is unable to fully take care of herself/himself from abuse, neglect, cruelty, exploitation or discrimination because of a physical or mental disability or condition” (http://nap.psa.gov.ph/children/defTerms.asp) .

Older People/Elderly/Senior Citizens - “individuals belonging to the age group 60 years and over” (PSA Board Resolution No. 1, Series of 2017).

Poverty incidence - “the proportion of families/individuals with per capital income/expenditure less than the per capita poverty threshold to the total number of families/individuals” (PSA Board Resolution No. 02 Series of 2007)

Working age - “refers to population 15-64 years old at a specified time. The working age population is divided into persons in the labor force and persons not in the labor force.” (NSCB, 2003)

Youth - “individuals belonging to the age group 15 to 30 years” PSA Board Resolution No 01, Series of 2017 - 136

Visualizing Spatial Data on Risk through Mapping

Changes in Rainfall and Temperature Patterns across Metro Manila

Climate- and weather-related hazards, in particular, refer to the direct and indirect effects of observed changes and/or projected deviations from present-day conditions of natural climate events. The historical data which is the baseline used are from 1986 to 2005. It is to be noted that all the projected changes are relative to the climate of these years. There are three temporal projections, Early (2016 – 2035), Mid (2046 – 2065) and Late (2080 – 2099). Two scenarios (4.5 and 8.5) in terms of Representative Concentration Pathways (RCPs) are also mapped. RCPs form a set of greenhouse gas concentration and emissions pathways intended to support research on climate change (Moss et al. 2010). RCP 4.5 refers to a scenario where emissions peak around 2040, then decline. RCP 8.5 refers to the upper bound of RCPs which is high greenhouse gas emissions pathway that is continuously rising throughout the 21st century (Riahi et al. 2011). It does not include climate mitigation targets.

Temperature risk maps

Global warming has changed Earth’s climate. Extreme temperatures lead to extreme weather like longer heat waves and droughts, stronger but shorter rainfall, rising sea levels, worse flooding, more frequent and stronger typhoons. Countries near the equator and in Southeast Asia will suffer the most, specifically the developing countries including the Philippines. Our country has been experiencing this, however, the changes were more pronounced in terms of temperature than rainfall and the occurrence of extreme events (PAGASA, 2011). Figure 5 shows the historical annual mean temperature of Metro Manila from 1986 to 2005 and they vary from 26.7 to 27.3oC. The temperature in the Eastern part (some parts of Quezon City, Marikina City and Pasig City) is lower while in Northwestern part (Navotas, Malabon, Valenzuela, Manila) of Manila, the temperature is higher.

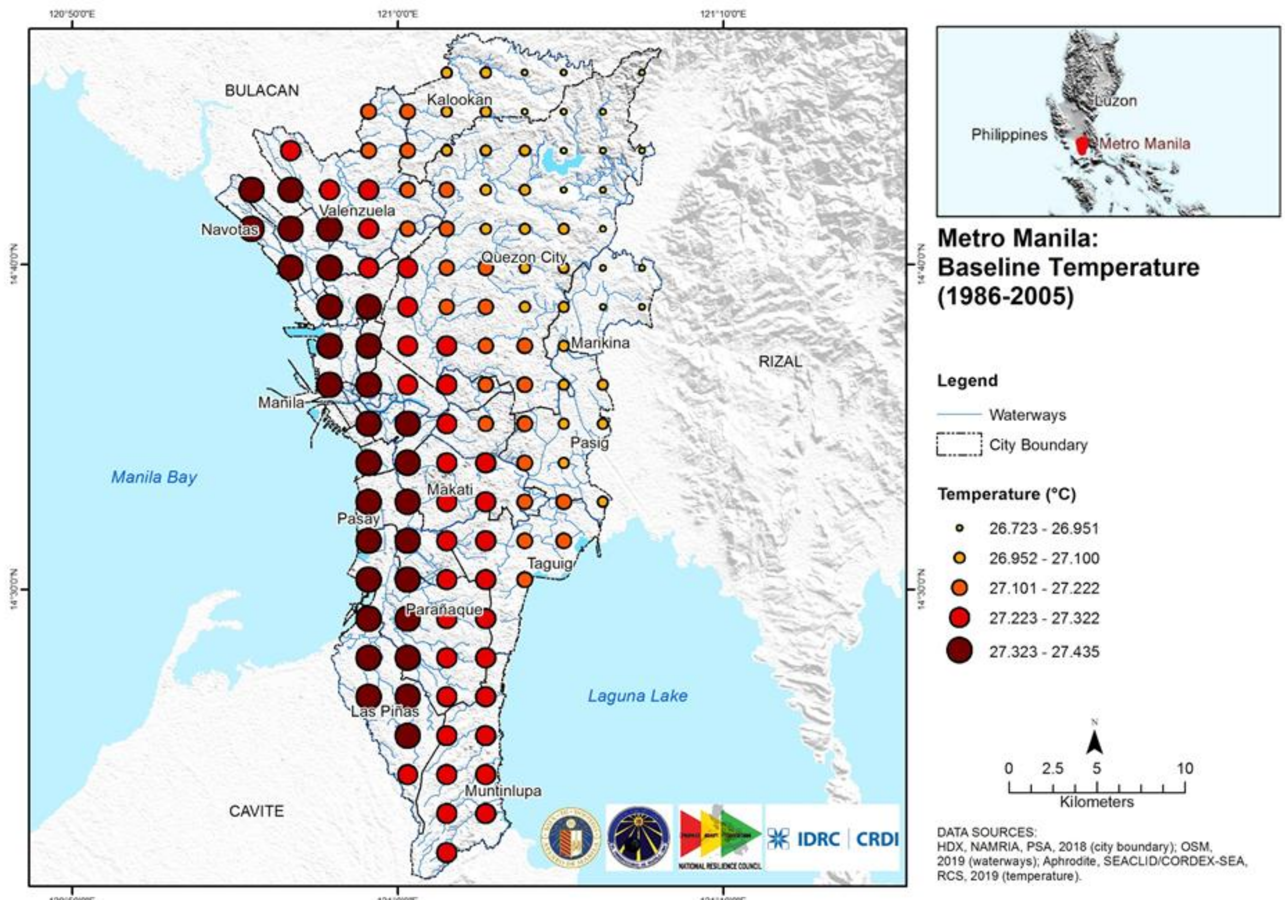

Figure 5. Baseline Temperature (1986-2005)

The projected annual mean temperature of 2016 to 2035 in Figure 6a and 6b show an increase 0.372 – 0.431 °C (RCP 4.5) and 0.372 - 0.430 °C (RCP 8.5) in temperature from baseline. The rise in temperature is much higher in Northwestern part (Navotas, Malabon, Valenzuela, Manila) of Manila.

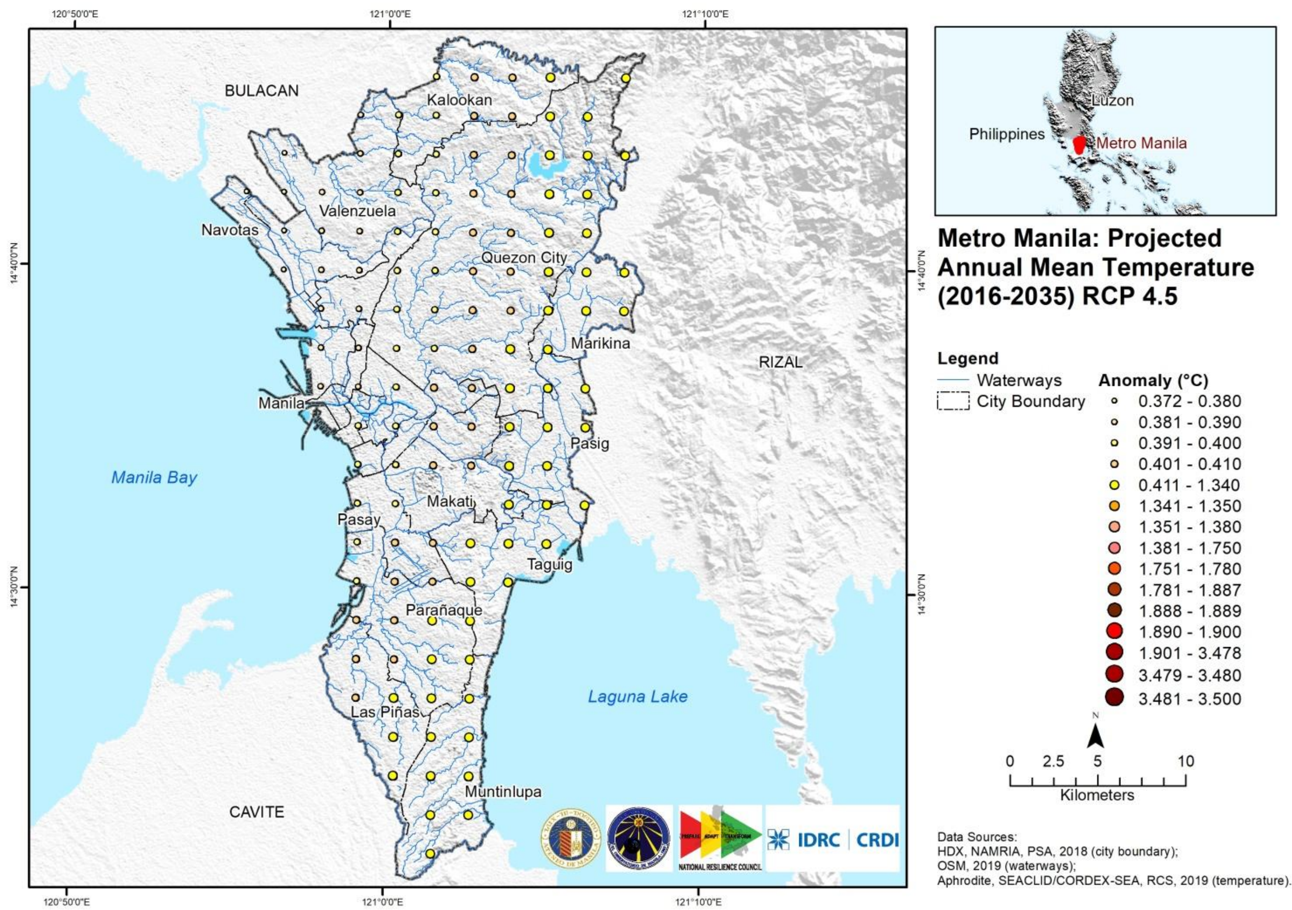

Figure 6a. Projected Annual Mean Temperature (2016-2035), RCP 4.5

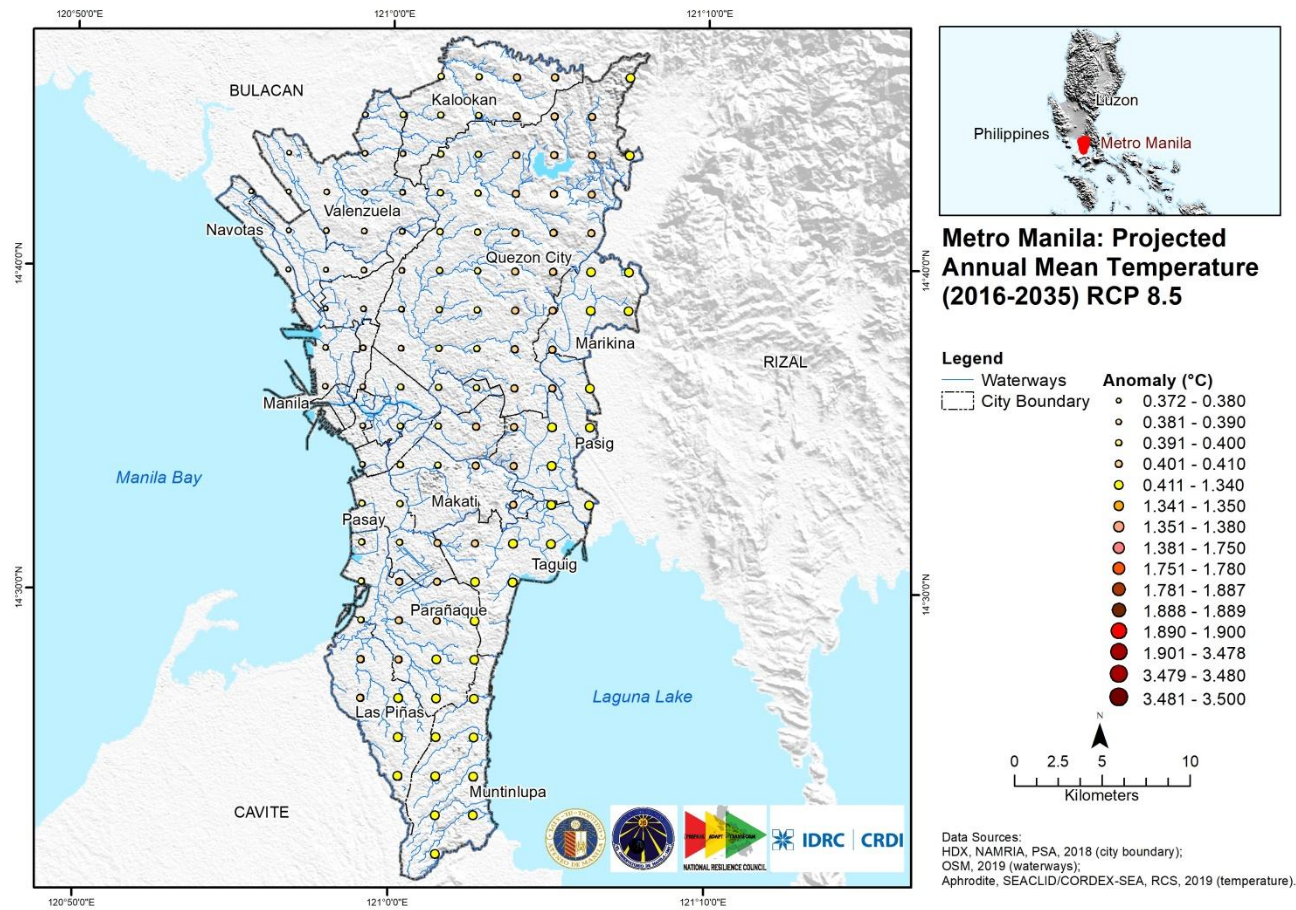

Figure 6b. Projected Annual Mean Temperature (2016-2035), RCP 8.5

Based on Figures 7a and 7b which are the projected annual mean temperature of 2046 to 2065, a higher increase in temperature than the previous years will be observed. Both RCP 4.5 and 8.5 exhibited same direction of increase which varies from 1.339 – 1.380 °C and 1.732 – 1.804 °C, respectively. Higher increase in temperature from the historical may be exhibited in the Eastern part than in other parts of the region.

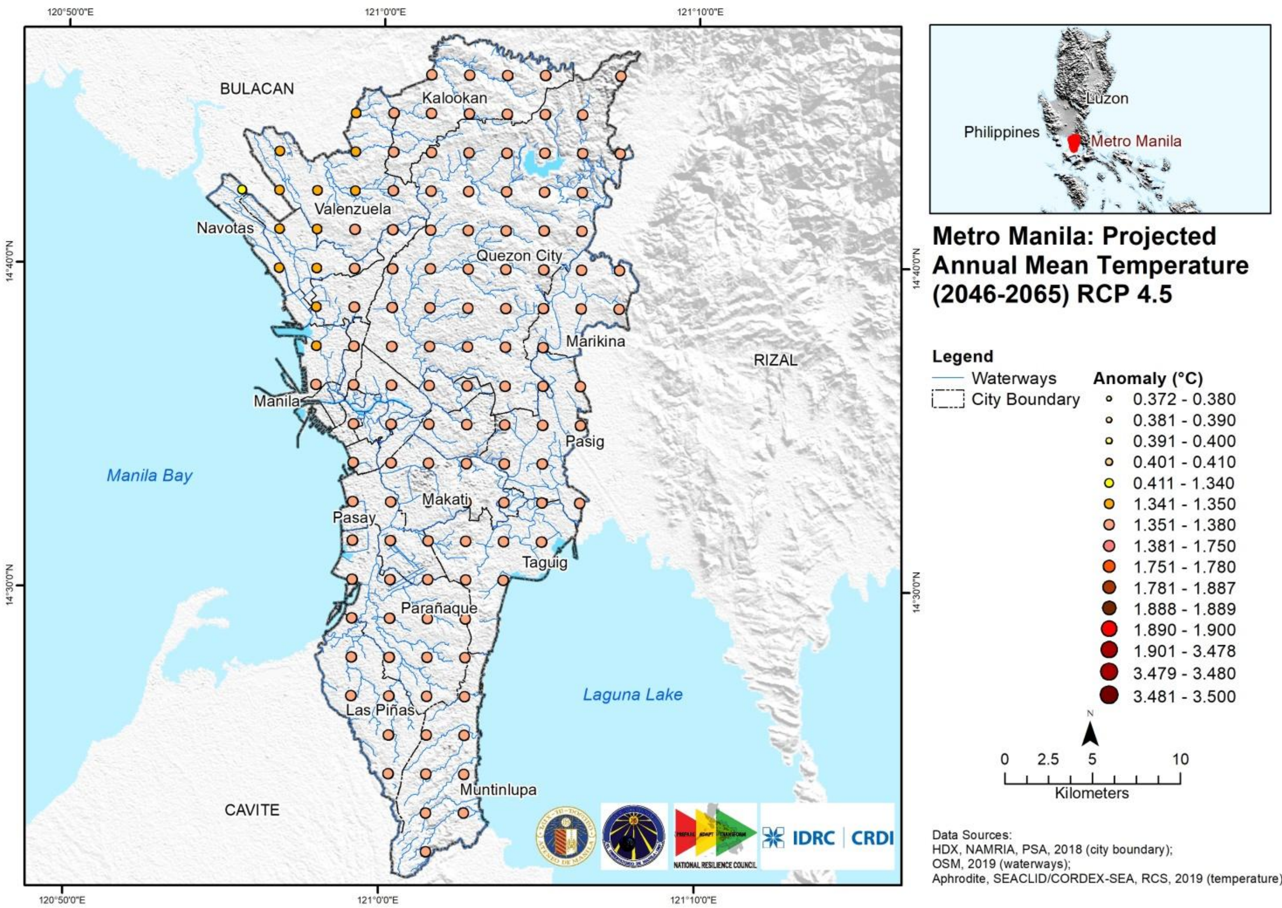

Figure 7a. Projected Annual Mean Temperature (2046-2065), RCP 4.5

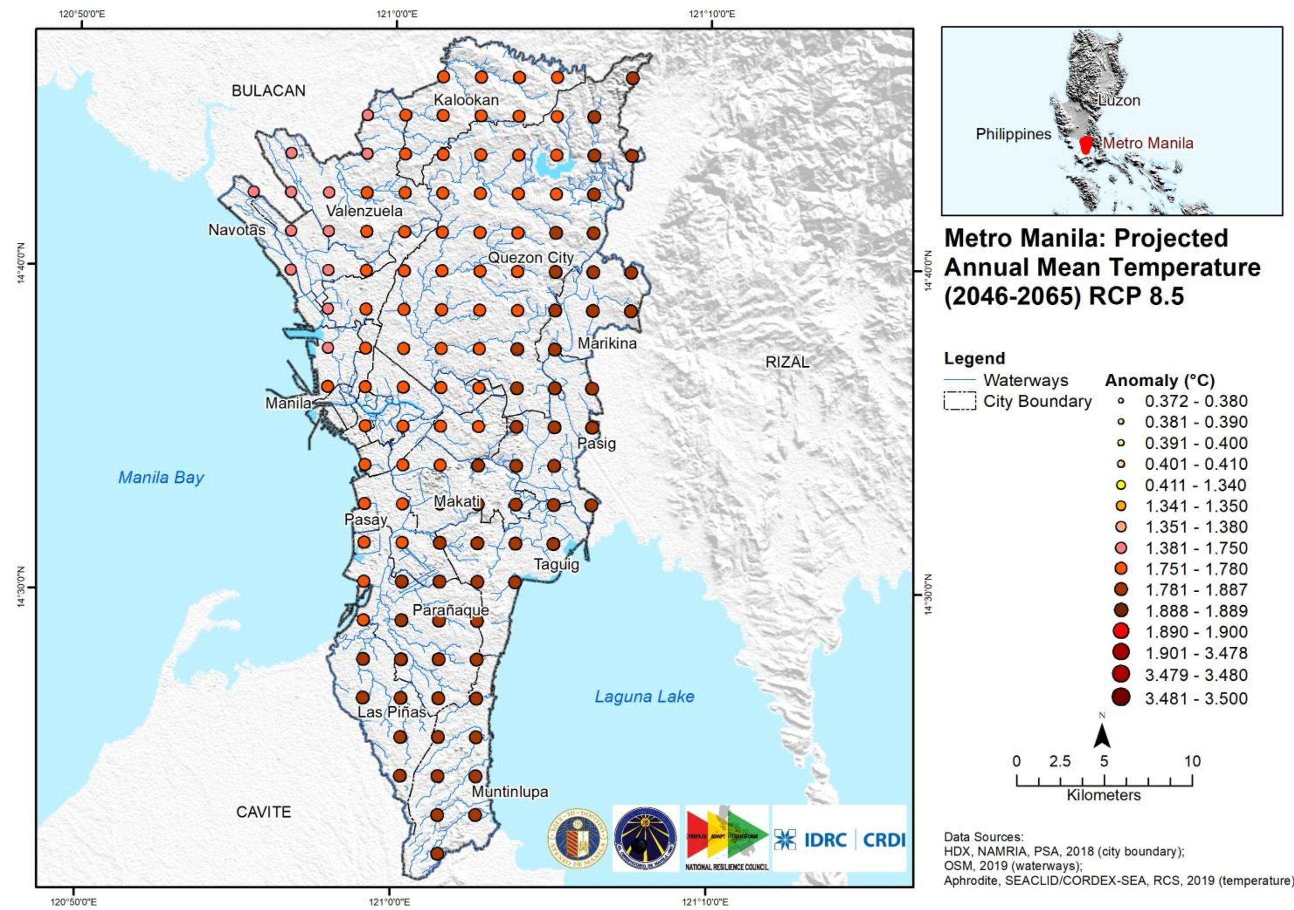

Figure 7b. Projected Annual Mean Temperature (2046-2065), RCP 8.5

Illustrated in Figures 8a and 8b are the projected annual mean temperature of 2080 to 2099 (RCP 4.5 and 8.5). Hotter climate will be experienced in these years as temperature will increase by 1.879 to 1.891 °C (RCP 4.5). A drastic increase of 3.463 – 3.494 °C from the baseline will be experienced as generated for RCP 8.5 projection. As observed in the previous projections, higher increase in temperature may be experienced by the areas on the Eastern side of Manila.

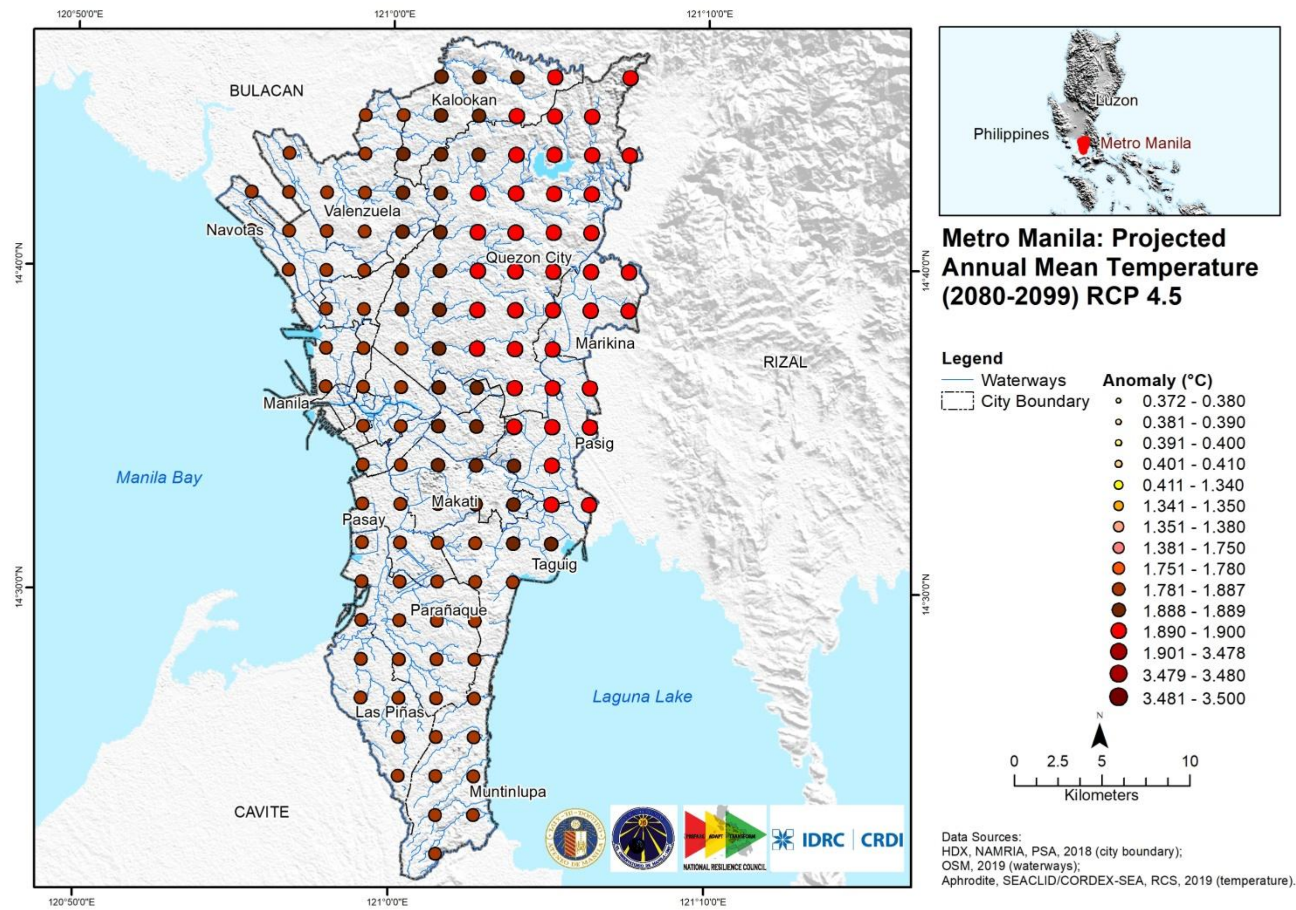

Figure 8a. Projected Annual Mean Temperature (2080-2099), RCP 4.5

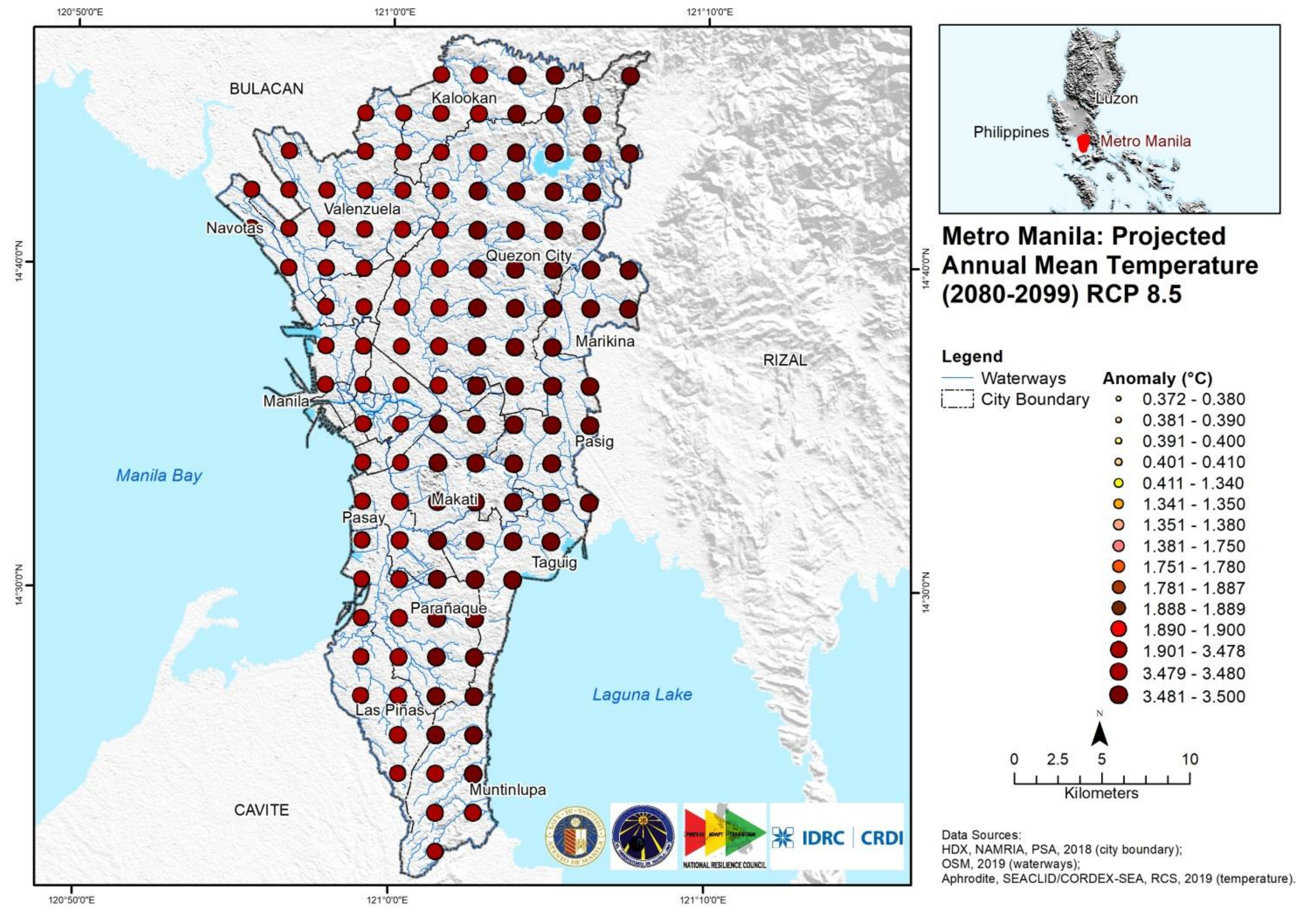

Figure 8b. Projected Annual Mean Temperature (2080-2099), RCP 8.5

Rainfall risk maps

- How is rainfall pattern going to change?
- Which parts of Metro Manila are exposed to this changing rainfall pattern?
- Overlay rainfall
- How is rainfall pattern going to change?
- Baseline Rainfall

Rainfall is the most significant climatic component in the Philippines. Rainfall distribution throughout the country differs from one region to another, depending upon the direction of the moisture-bearing winds and the location of the mountains. (“PAGASA,” n.d.).

Concerning natural hazards, trends and projections in rainfall are very important because of the risk induced. The Philippines as an archipelago and tropical country, which is situated near the Pacic Ocean, faces uncertain rainfall intensities. Figure 1 shows the historical annual mean rainfall of Metro Manila from 1986 to 2005. The amount of rainfall in the region varies from 2,000mm to 2,223mm. Based on the map, the rainfall is higher in the Eastern part of the region (some parts of Quezon City, Marikina City and Pasig City) than in other areas.

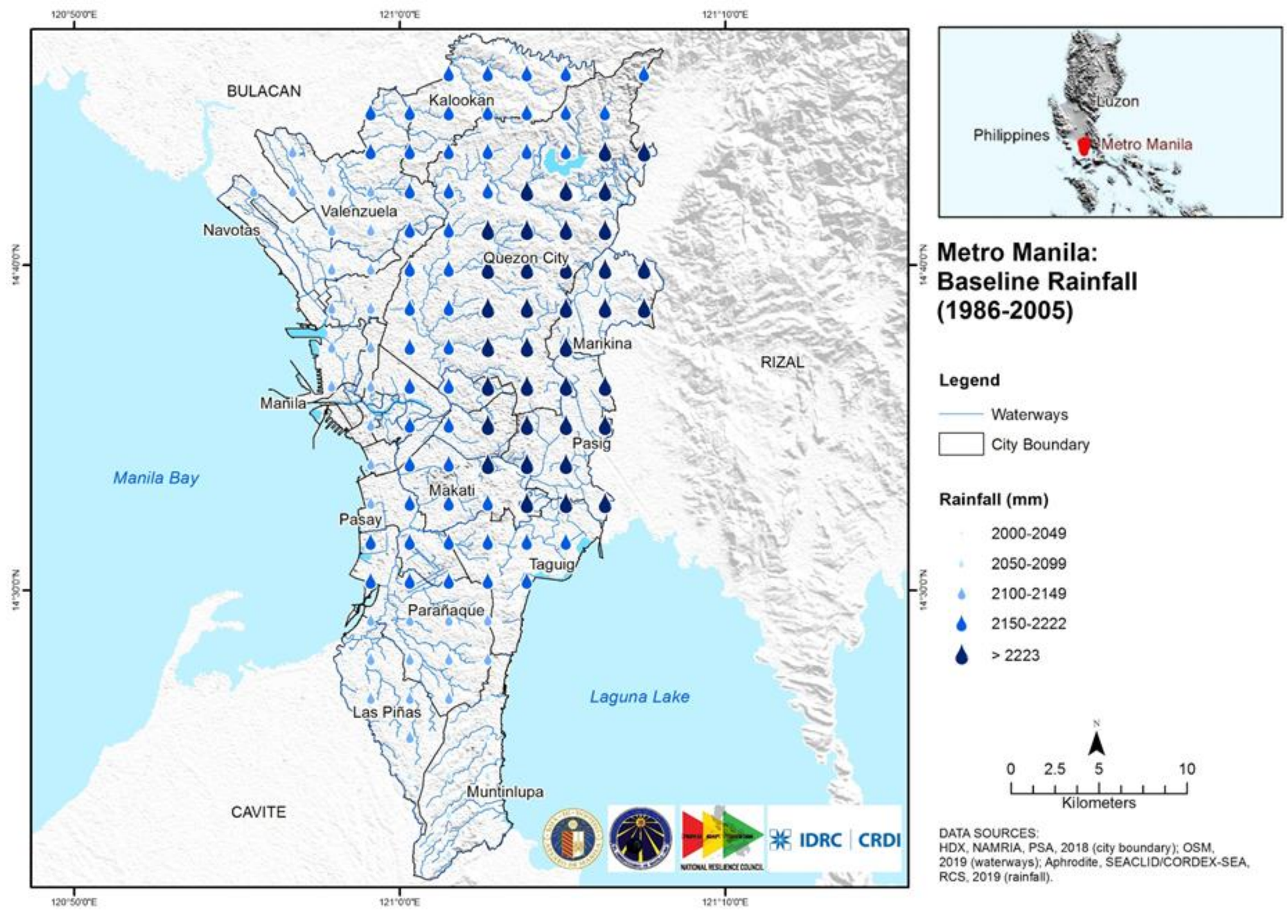

Figure 1. Baseline Rainfall (1986-2005)

The projected annual mean rainfall of 2016 to 2035 in Figures 2a and 2b show an increase of up to 7% and 4-11%, respectively, from the historical data. In the years to come, there will be a lesser increase of rainfall in the Eastern part (some parts of Quezon City, Marikina City and Pasig City) than the Western part of the area.

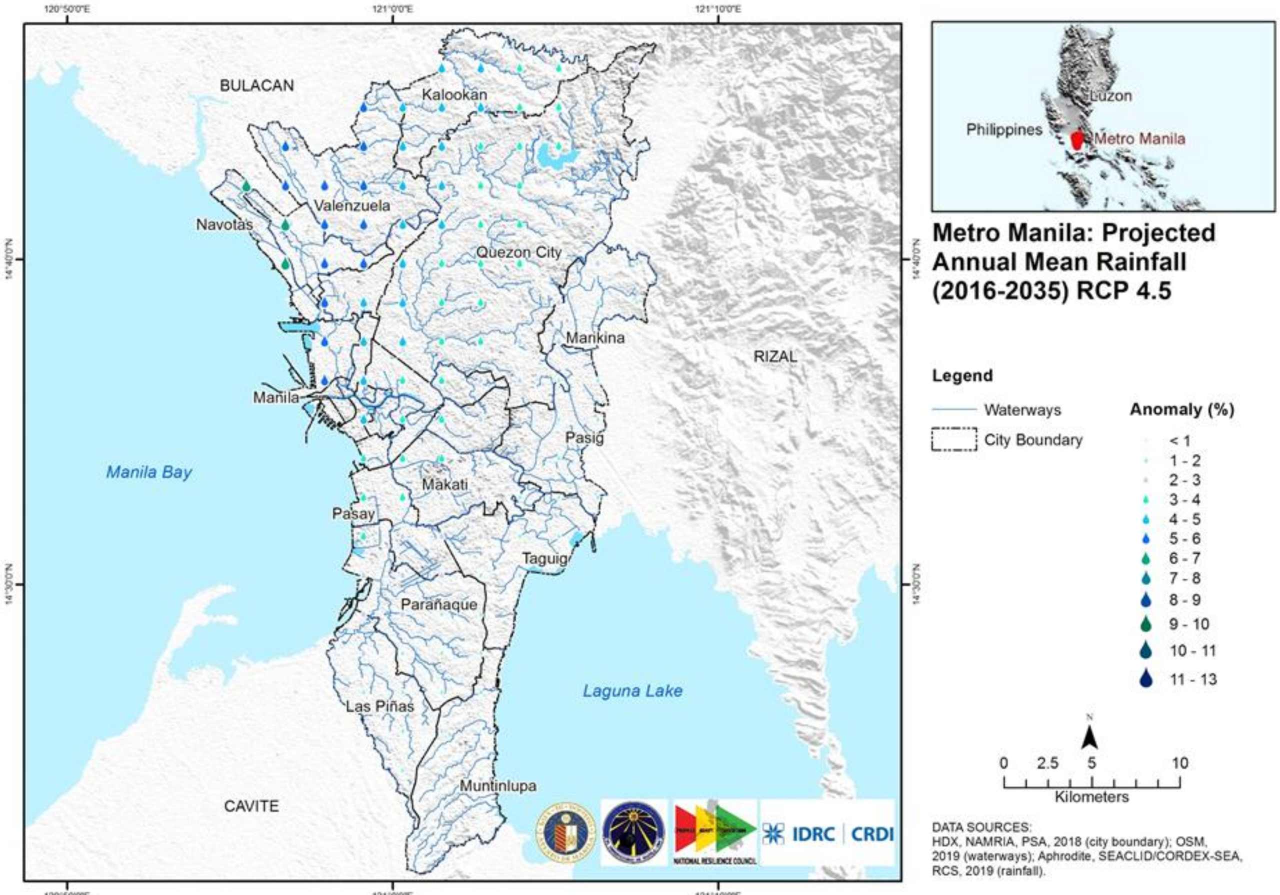

Figure 2a. Projected Annual Mean Rainfall (2016-2035), RCP 4.5

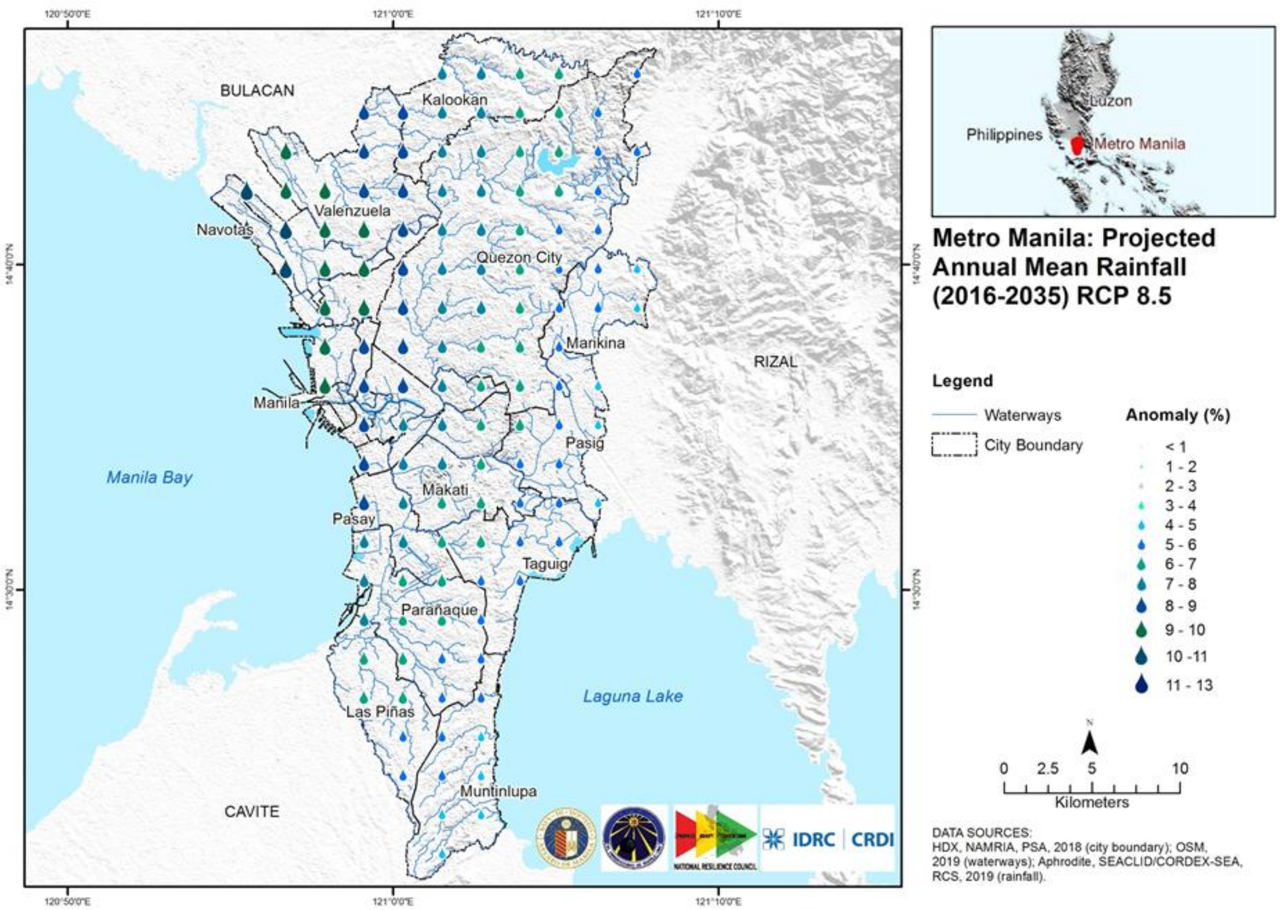

Figure 2b. Projected Annual Mean Rainfall (2016-2035), RCP 8.5

Based on Figure 3a which is the projected annual mean rainfall of 2046 to 2065 (RCP 4.5), an increase of 1-12% from historical will be observed. The anomalies are higher for the RCP 8.5 scenario (Figure 3b) which has 2-13% increase of rainfall from baseline. Higher increase in rainfall from the historical may be exhibited in the Northwestern part (Navotas, Malabon, Valenzuela, Manila) than in other parts of the region.

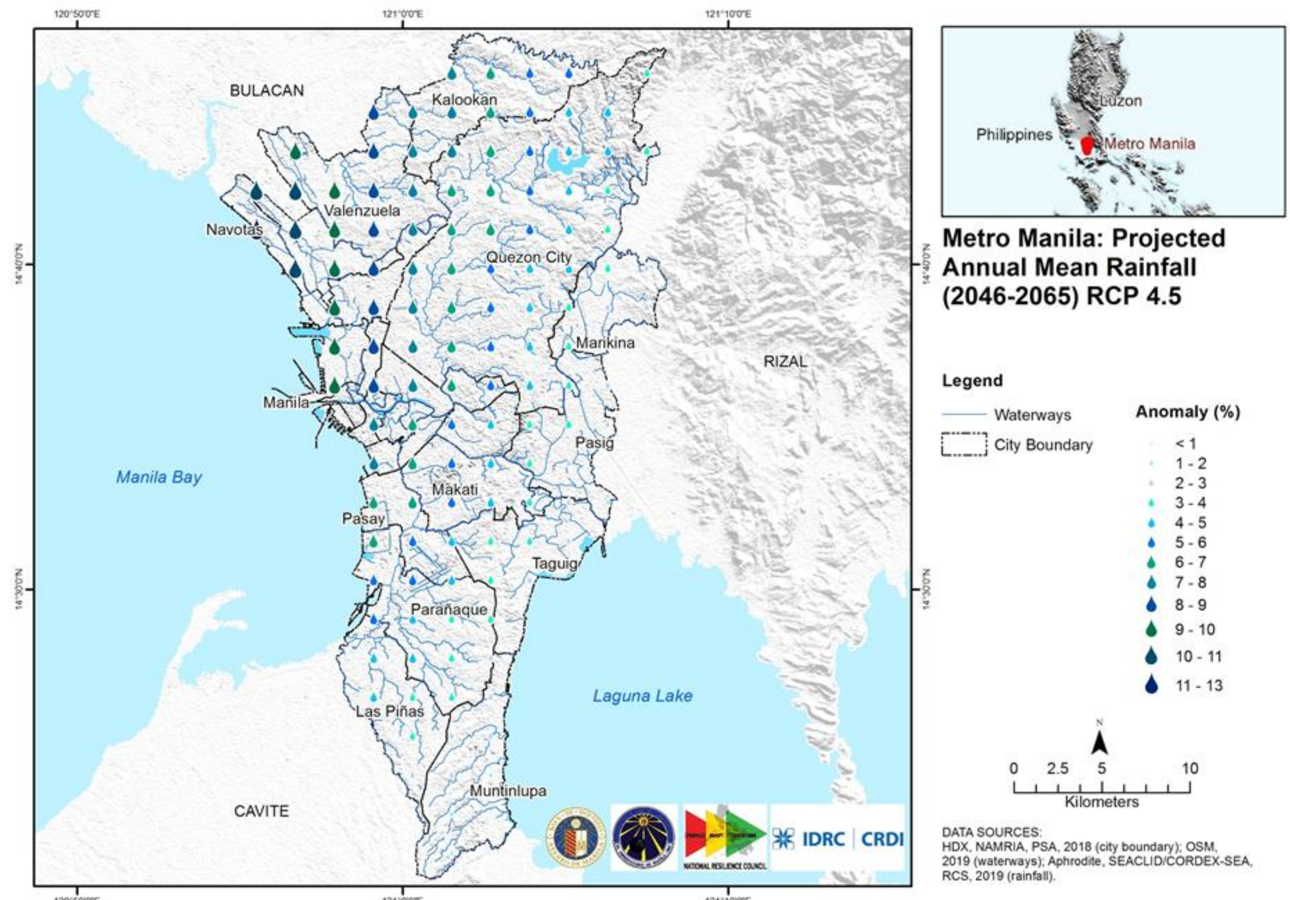

Figure 3a. Projected Annual Mean Rainfall (2046-2065), RCP 4.5

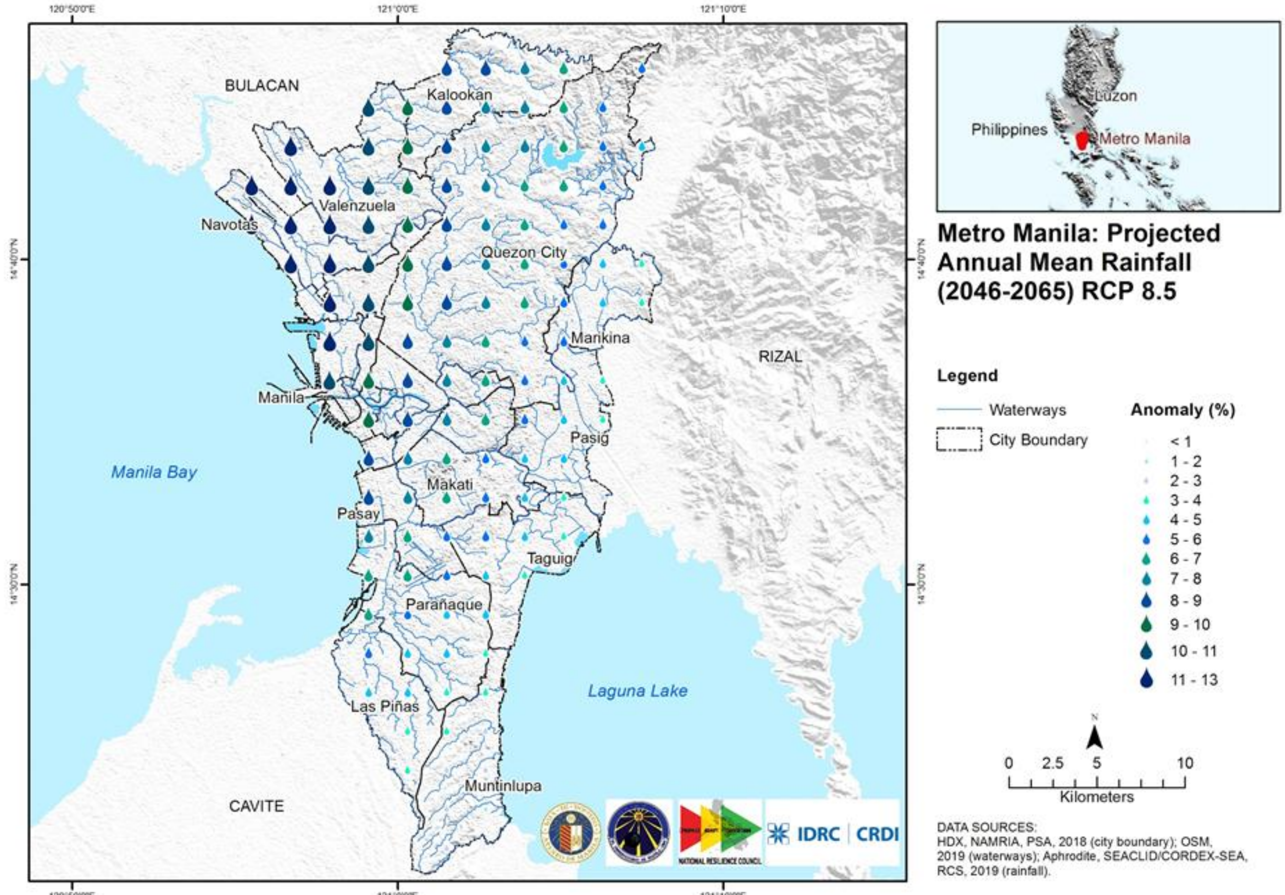

Figure 3b. Projected Annual Mean Rainfall (2046-2065), RCP 8.5

Illustrated in Figures 4a and 4b are the projected annual mean rainfall of 2080 to 2099 (RCP 4.5 and 8.5). Negative anomalies by 1-2% are observed in the Southern part of Metro Manila depicting a decrease in rainfall. An increase by up to 11% from baseline is also observed for this scenario. For RCP 8.5, the decrease in rainfall is minimal than RCP 4.5 with only <1% as shown by the negative values in anomalies but there is also an up to a 13% increase in rainfall from historical data in the area. As observed in the previous projections, higher increase in rainfall may be experienced by the areas on the Northwestern part (Navotas, Malabon, Valenzuela, Manila) of Manila. All the future projections exhibited the same trends in increase in terms of location in the region.

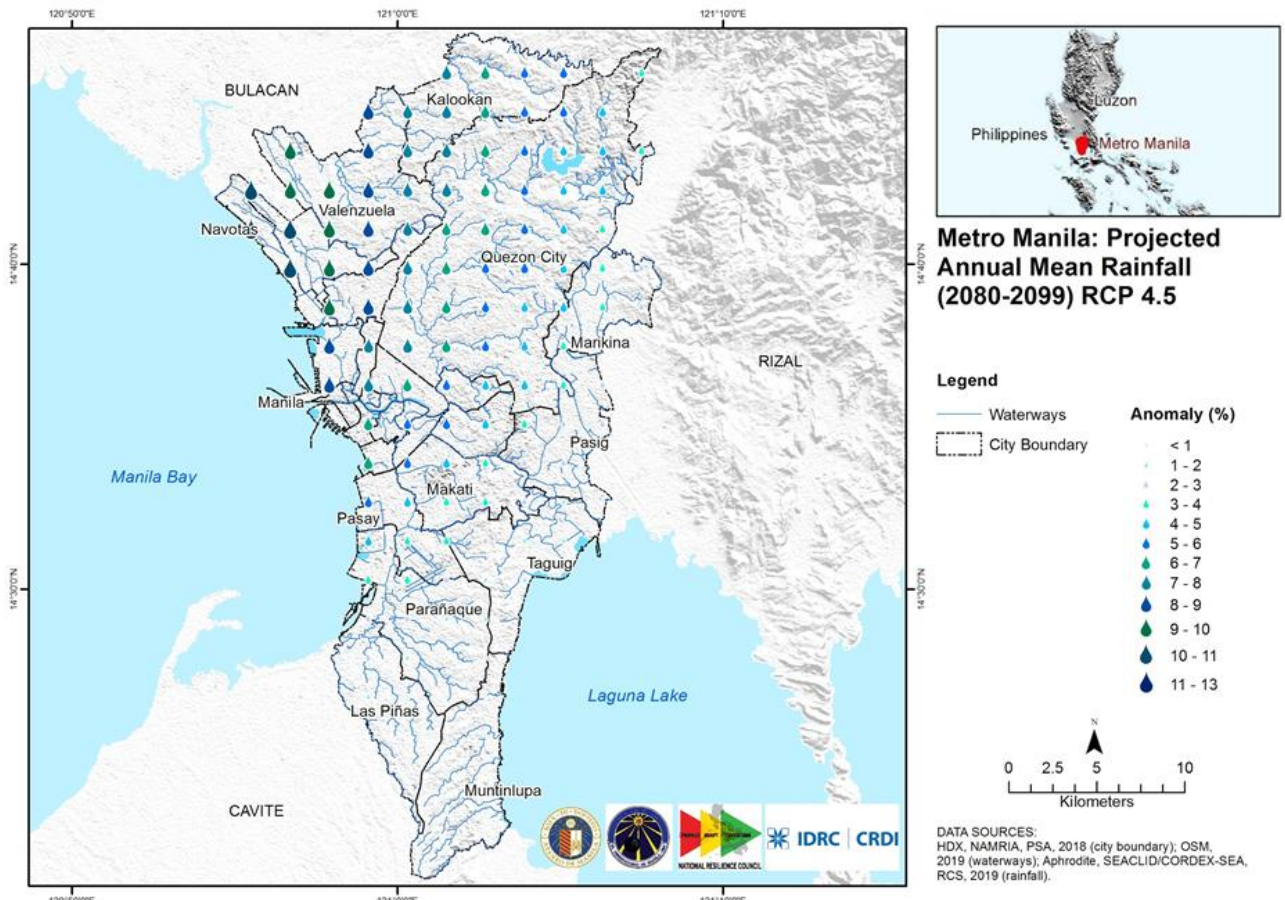

Figure 4a. Projected Annual Mean Rainfall (2080-2099), RCP 4.5

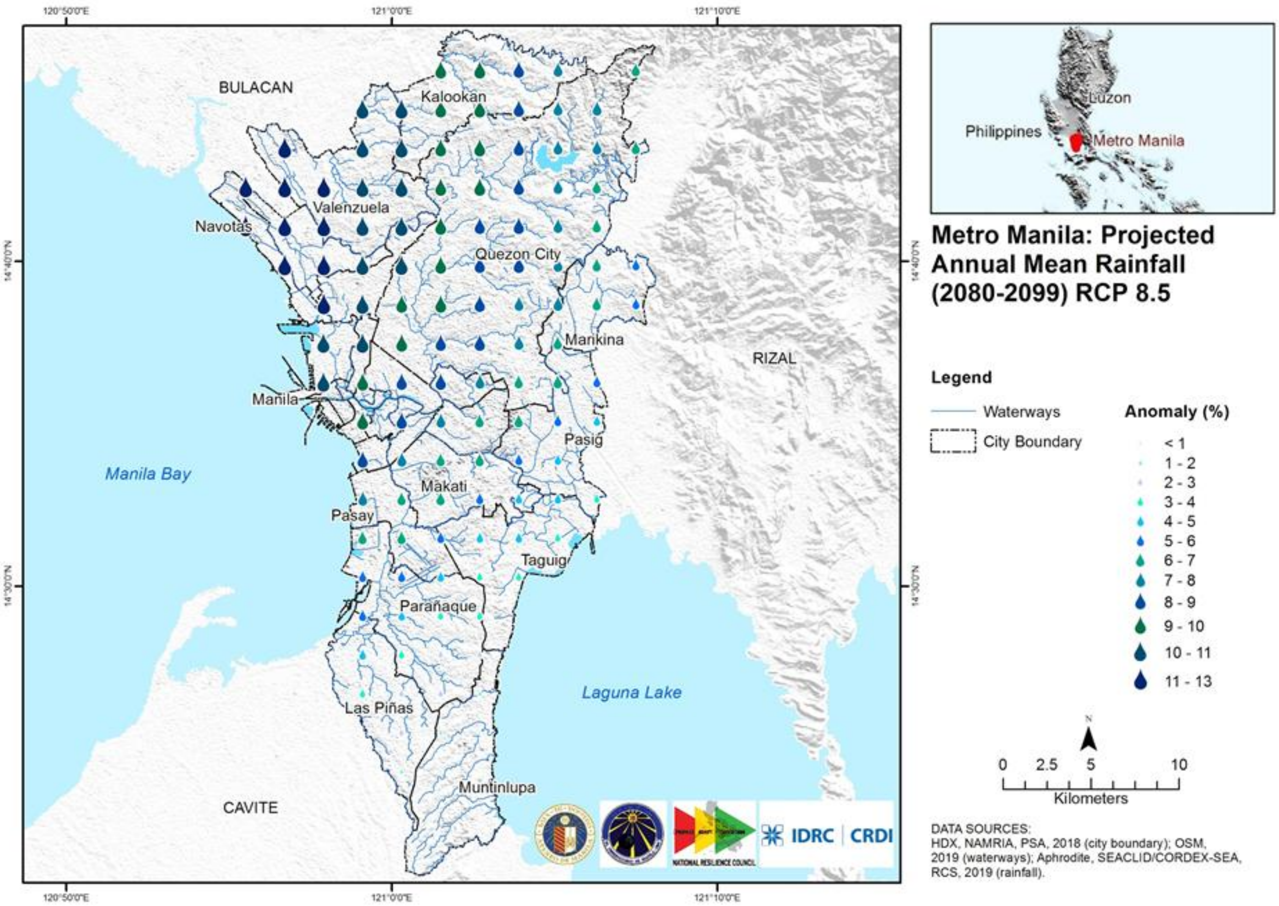

Figure 4b. Projected Annual Mean Rainfall (2080-2099), RCP 8.5

Hydro-meteorological Hazards

Tropical Cyclones

According to PAGASA, “tropical cyclones are warm-core low pressure systems associated with a spiral inflow of mass at the bottom level and spiral outflow at the top level. They always form over oceans where sea surface and air temperatures are greater than 26°C.” The air gathers huge volumes of sensible and latent heat as it spirals towards the center. It receives this heat from the ocean and the exchange can happen rapidly because of the huge volumes of spray thrown into the air by the wind. Thus, the tropical cyclone’s energy is a result of massive liberation of the latent heat of condensation.

“Tropical cyclone is defined as a non-frontal, synoptic-scale cyclone developing over tropical and sub-tropical waters at any level and having a definitely organized circulation (PAGASA, n. d.).” In other regions worldwide, these are denoted as hurricanes, typhoons or simply tropical cyclones. They are called "hurricanes”, in the North Atlantic, Eastern North Pacific and South Pacific Ocean. In the Bay of Bengal, Arabian Sea and Western South Indian Ocean, it is referred to as "cyclonic". In the eastern part of the Southern Indian Ocean, it is "willy-willy", and in the Western North Pacific Ocean, they are called "typhoons".

Tropical cyclones can only form over oceans of the world except in the South Atlantic Ocean and the south eastern Pacific where due to the cooler sea surface temperature and higher vertical wind shears, they would not form. They develop at latitudes higher than 5° from the equator. While situated over warm water in the tropics, they reach their greatest intensity. As they are near landfall, they begin to weaken, usually after being destructive (PAGASA, n. d.).

Typhoons or tropical cyclones are a perennial occurrence due to the monsoonal nature of the Philippine climate and the location of the country along typhoon paths. An annual occurrence of an average of 19.4 typhoons enters the Philippine Area of Responsibility and an average of 9 typhoons cross the country (Cinco et al., 2016). The tropical cyclones (TCs) that enter the Philippine Area of Responsibility (PAR) typically come from the east in the Pacific Ocean. Figure 9 shows the tropical cyclone tracks that crossed Metro Manila. Aside from tracks in the vicinity of Metro Manila, a total of 48 tropical cyclones crossed directly the region from 1896 to 2017. All of the cities have been hit and the paths of the cyclone have no distinct pattern. They are distributed in all areas in the region as shown in the map.

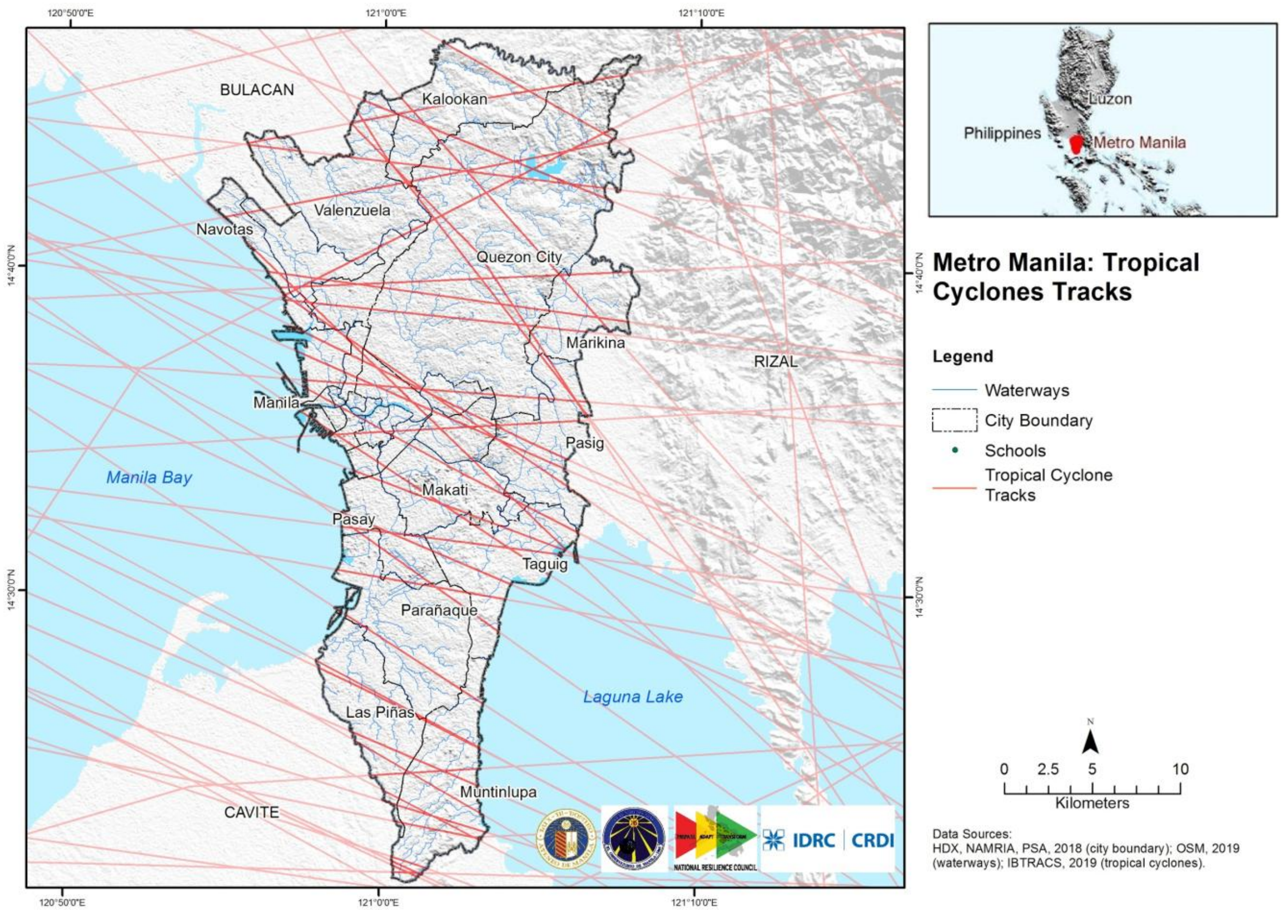

Figure 9. Tropical Cyclones Tracks

Flood Hazard

Flooding is considered as one of the most common and most destructive natural hazards, directly affecting people through fatalities and economic losses. Metro Manila is a flood-prone area due to its geographic location, proximal to river systems and coastal areas, as well as its low elevations. It lies on one of the widest floodplains in the Philippines (Cox, 2011). The region is exposed to three flood risks: riverine, coastal, and lake. Thus, it is important to illustrate the inundation extents of an area from existing hazard maps for disaster risk reduction and management. The 5-year flood hazard map (Figure 10) shows the level of hazard in terms of height if the actual amount of rain exceeds that of a 5 year-rain return period. There is a 1/5 (20%) probability of a flood with 5-year return period occurring in a single year (PHiL-LIDAR, 2017). The area coverage of the hazard level is shown in Table 1. Based on the map, Quezon City has the highest flood extent with approximately 34 km^2 covered area followed by Manila with 20km^2 coverage. According to the map, high level of hazard is observed in Quezon City followed by Marikina City which has 31% and 31.7%, respectively, of their submerged areas are >1km. This is reflected in the Typhoon Ondoy flooding where highly urbanized cities of Metro Manila in the downstream of Marikina River Basin are the most affected.

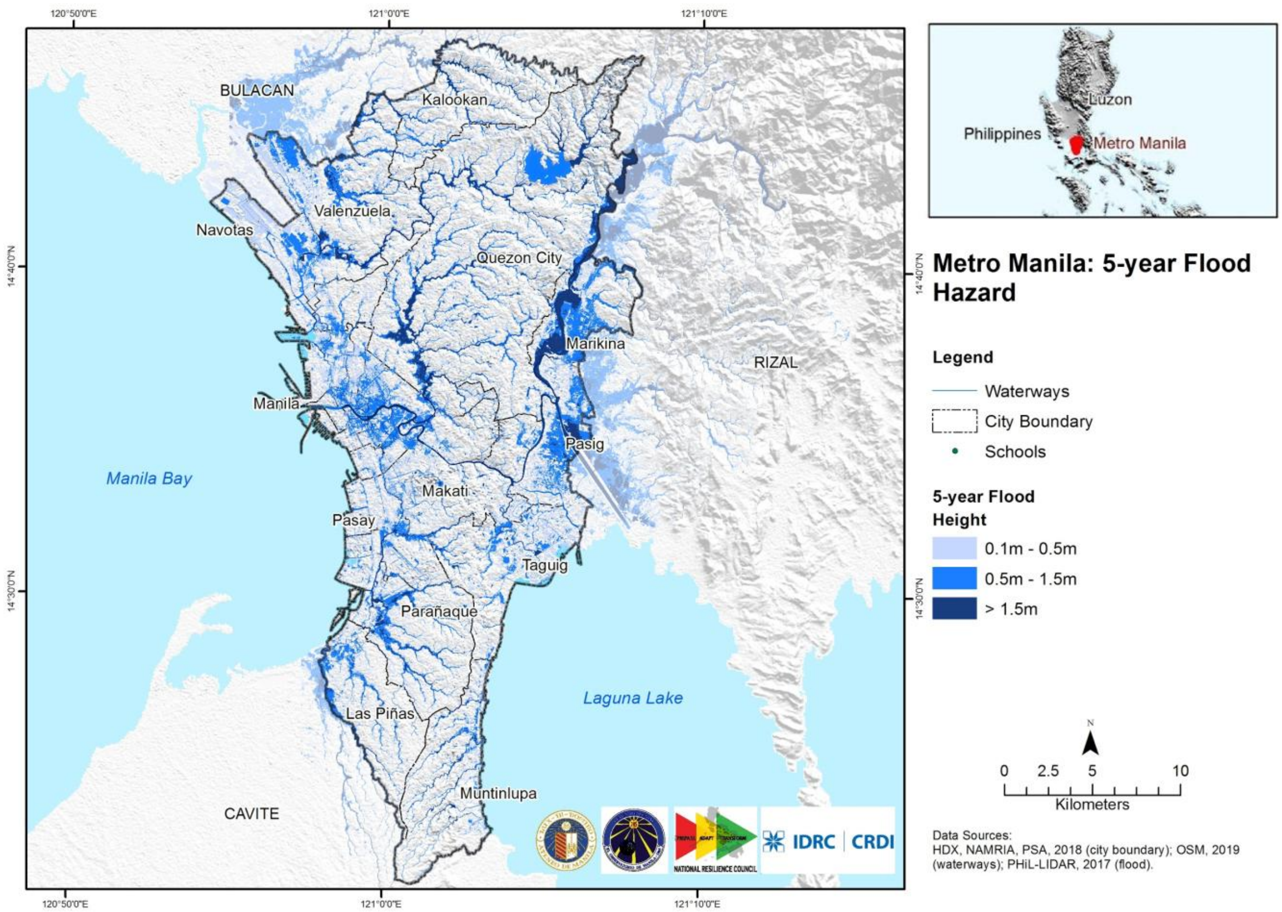

Figure 10. 5-year Flood Hazard

Figure 11 shows the inundation extents in Metro Manila if the actual amount of rain exceeds that of a 25 year-rain return period. There is a 1/25 (4%) probability of a flood with 25 year return period occurring in a single year. An increase in area coverage is observed compared to 5-year hazard map. Flood extent in Quezon City increases to 48.63 km^2 followed by Pasig City with 32 km^2 coverage.

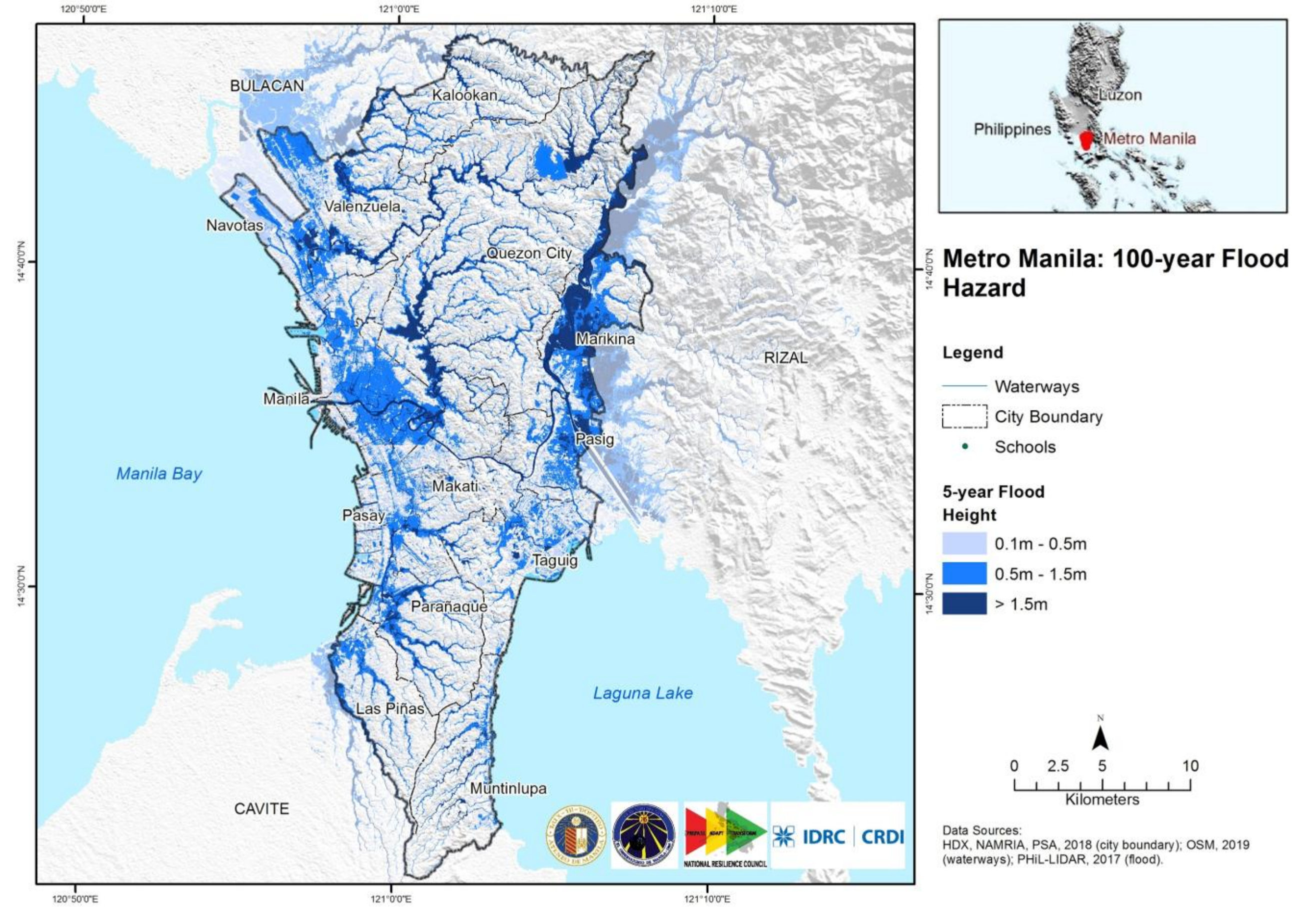

Figure 11. 25-year flood hazard

The inundation extents in region if the actual amount of rain exceeds that of a 100-year-rain return period is shown in Figure 12 (100-year flood hazard). It exhibits the highest area coverage than the previous hazard maps. There is a 1/100 (1%) probability of a flood with 100 year return period occurring in a single year. Quezon City remains the one with the widest flood extent with 48km2 followed by Manila with 28.2 km^2.

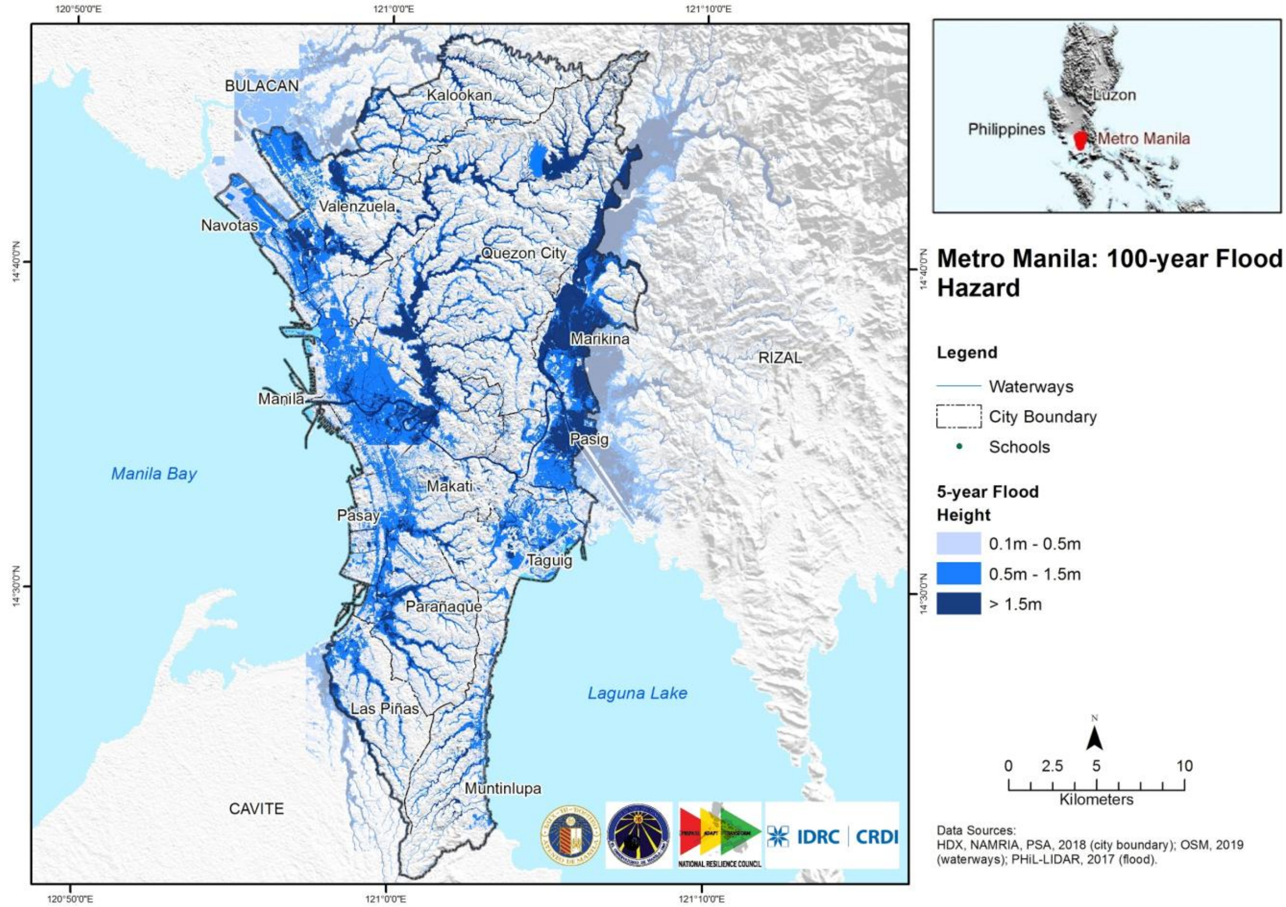

Figure 12. 100-year Flood Hazard

Table 1. Area coverage 5-year, 25-year, 100-year flood per flood height in Metro Manila

Flood height	Area Coverage (km^2)		
	5-year	25-year	100-year
0.1m to 0.5m	117.6	128.7	104.0
0.5m to 1.5m	118.4	186.0	170.5
>1.5m	53.6	122.1	123.4

3. Storm surge

The National Oceanic and Atmospheric Administration (NOAA) defines a storm surge as a storm-generated abnormal rise of water over the predicted astronomical tides. This occurrence poses a major danger to the Philippine coastal areas, as revealed by Typhoon Haiyan on November 8, 2013. Based on the maps, the coastal areas near Manila Bay is susceptible to these storm surges. This is evident in September 2011 event where, Typhoon Nesat (TY Nesat) generated one of the most destructive storm surges to ever hit the bay (Jerome and Takagi n.d.).

The storm surge levels were categorized into four groups based on their peak height to create the susceptibility maps as shown below. Figure 13 shows that the areas of Navotas and Malabon are susceptible to storm surges with peak heights of 2-3m. Based on Figure 14, areas in Malabon and Navotas that is highly susceptible from storm surges with peak heights of 3-4m increases while some areas in Manila, Kalookan City and Valenzuela City are moderately susceptible from these category of storm surges.

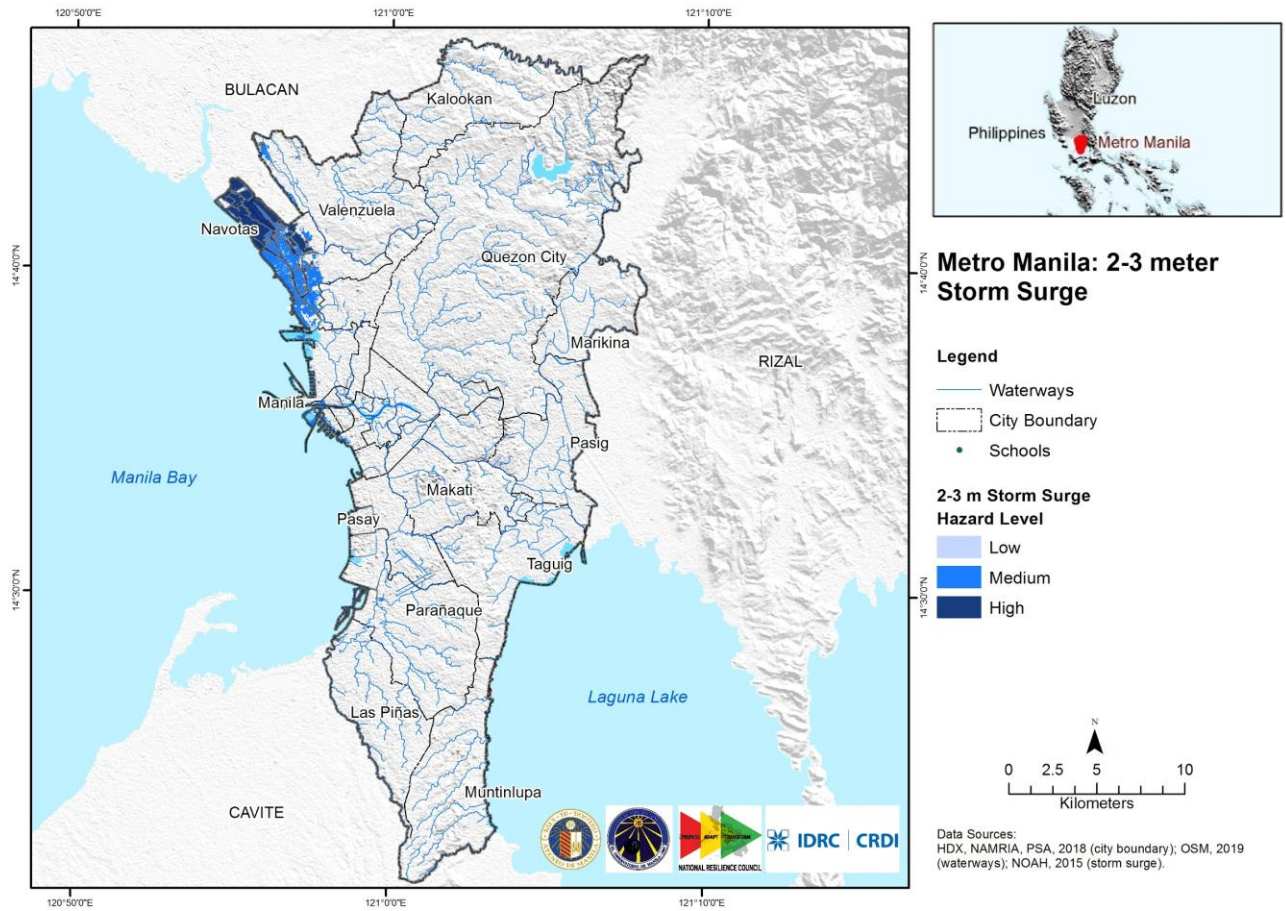

Figure 13. 2-3 meter Storm Surge

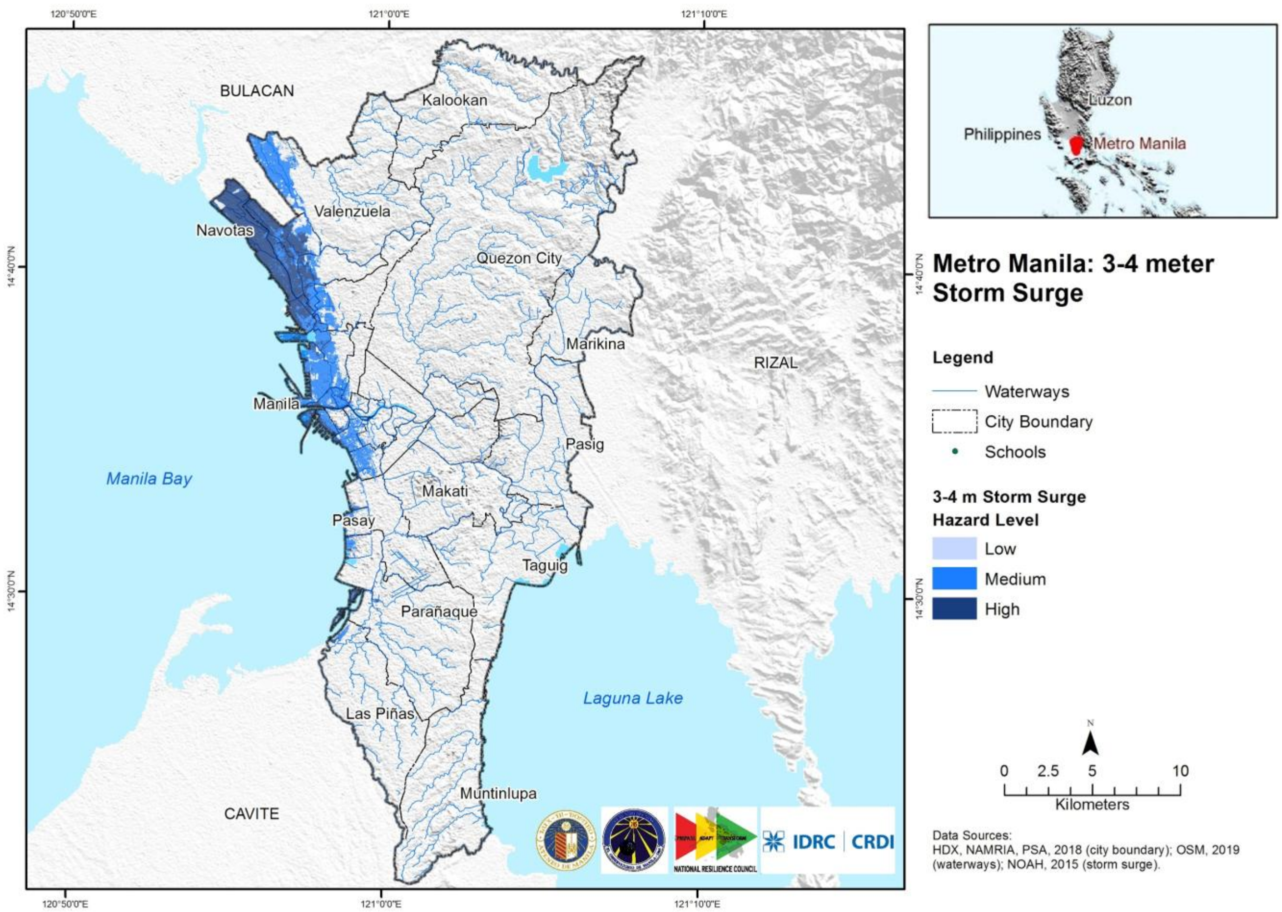

Figure 14. 3-4 meter Storm Surge

Figure 15 shows the areas susceptible to storm surges with peak heights of 4-5m. It can be observed that the whole Navotas as well as 10.5km^2 of Malabon City have a high level of hazards. The extent of high hazard for Manila also increases to 20.7km^2 compared to the previous maps.

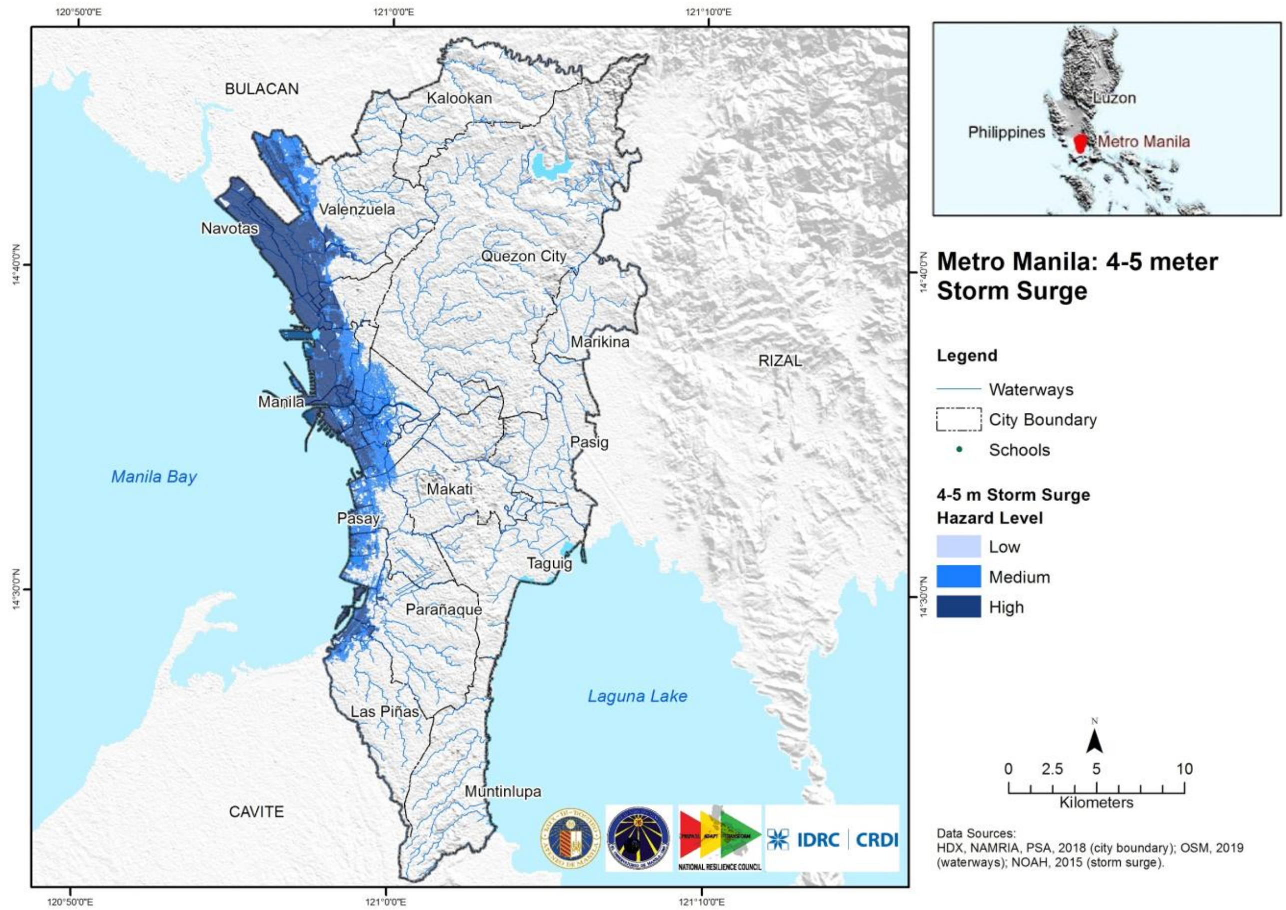

Figure 15. 4-5 meter Storm Surge

Based on Figure 16 (storm surge 5m), 28.3km^2 of Manila, 11.4km^2 of Malabon, 9.9km^2 of Paranaque City, 7.5km^2 of Pasay City, and 7.2km^2 of Navotas are the major areas that are affected by these hazards.

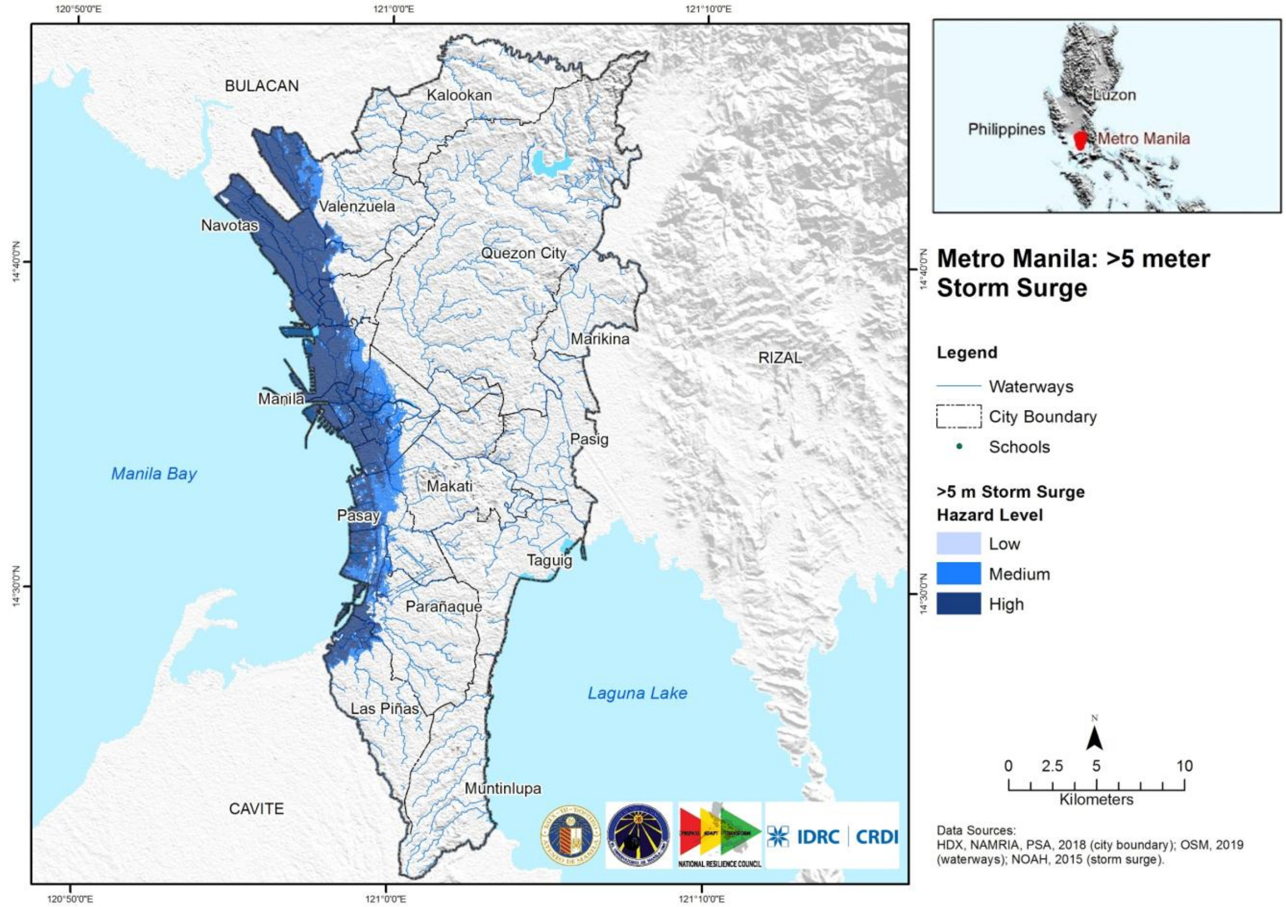

Figure 16. >5 meter Storm Surge

Landslide

"Landslide is the movement of a mass rock, debris, or earth down the slope" (Cruden, 1991). The primary reason for landslides is the action of gravity as it exceeds the strength of the Earth's materials. However, there are other contributing factors (either natural or human-induced) that can affect slope stability and cause landslides. Aside from floods, landslides are most frequently occurring natural disasters in the Philippines usually prompted by typhoons. Figure 17 shows the rainfall-induced landslide hazard map of Metro Manila developed by Project NOAH. Lateral spreads that are associated with earthquake are not included in the analysis. Results showed that the major cities that are prone to landslide in terms of extent are Quezon City, Marikina City and Muntinlupa City. High level of hazards that are required to be no dwelling zones are also observed in these locations: Quezon City (0.60km^2), Muntinlupa City (0.27km^2) and Marikina City (0.08km^2).

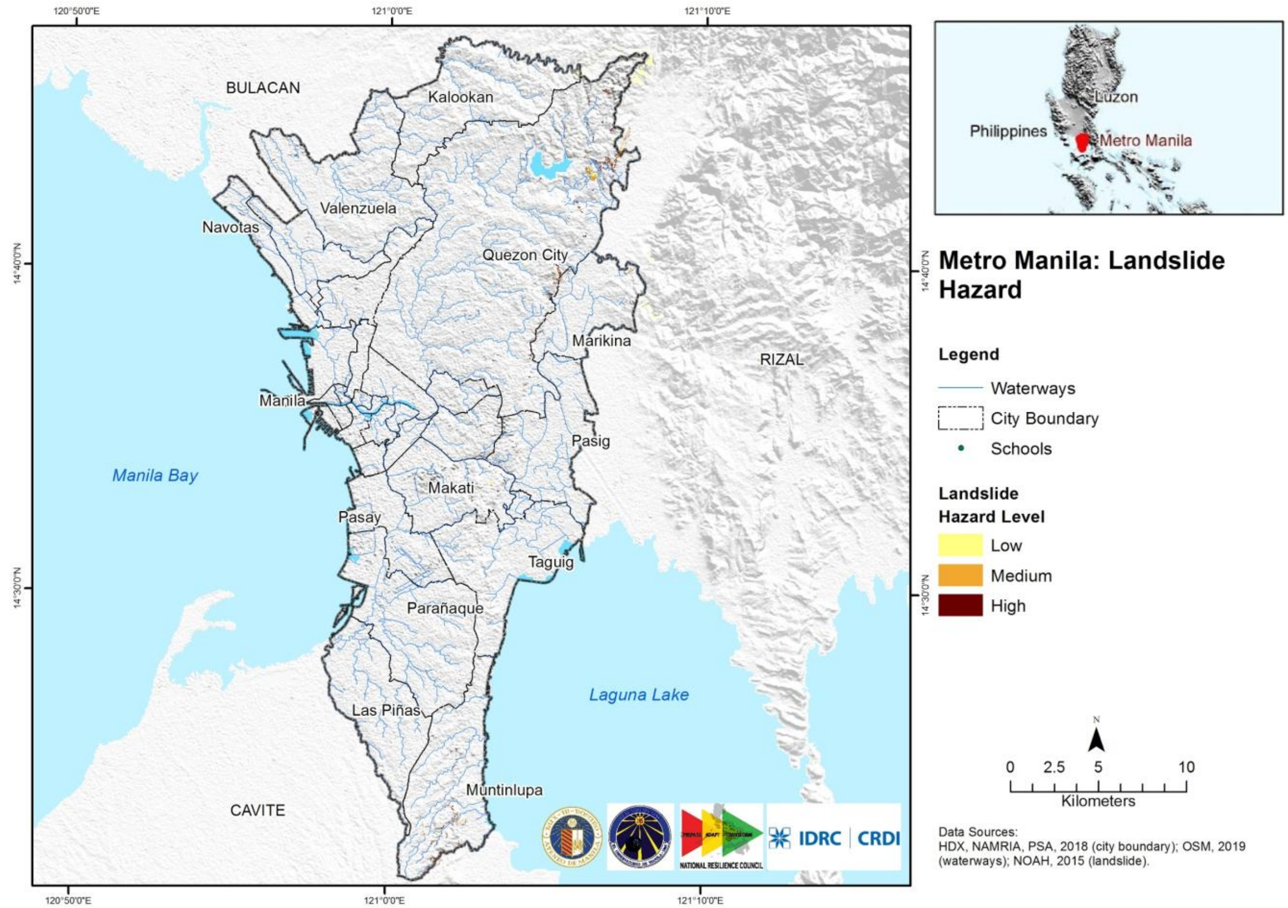

Figure 17. Landslide Hazard

Exposures and Associated Vulnerabilities

Land Use and Land Cover

Land use, defined as the function of a space for a human population, is one of the variables exposed to hazards such as extreme climate and weather, tropical cyclones, flood, and storm surge. It is important to understand which land use types are exposed to hazards as this determines the anthropogenic activities the hazard affects.

Metro Manila's 2018 land use (Figure 18) was classified as commercial, bare soil, formal residential, informal settlements, industrial, grass, tree, and water. This land cover map was generated from a combination of satellite images including 2013 IFSAR DEM and DSM data, 2017 Worldview-3, and 2018 Sentinel-2 datasets using GIS and remote sensing techniques (please see report on land use mapping Work Package 2.4 Part IIIa). The resulting land use and land cover map was ground truthed on July 8-12, 2019 and the computed accuracy for the map was 82%.

According to the classified data, majority of Metro Manila is covered with formal (40.3%) and informal (20.3%) residential areas. The large patches of informal and high density settlements occupy the coastal cities of Manila, South Caloocan and Navotas (Figure 19). Smaller patches of informal high density settlements peppered the other cities. The computed area of informal settlement per city is tabulated in Table 2. Note that informal settlements mapped here are not defined by the legality of their tenure but by the morphological characteristics resembling a slum community. These morphological characteristics include the dense clusters of small housing units and the substandard non-durable materials constructing the housing units. Formal residential areas occupy the northern, eastern and southern regions of Metro Manila.

Industrial areas cover 14.2% of Metro Manila. A concentration of large industrial establishments was observed in Valenzuela City, South Kalookan and West of Quezon City. Towards the south, large industrial structures line the major roads. Large commercial establishments like malls and commercial buildings cover over 1.6% of Metro Manila. They stand beside the major roads and cluster in business districts. The remaining area of Metro Manila is covered with grass (5.4%), tree (11.6%) and water (4.1%).

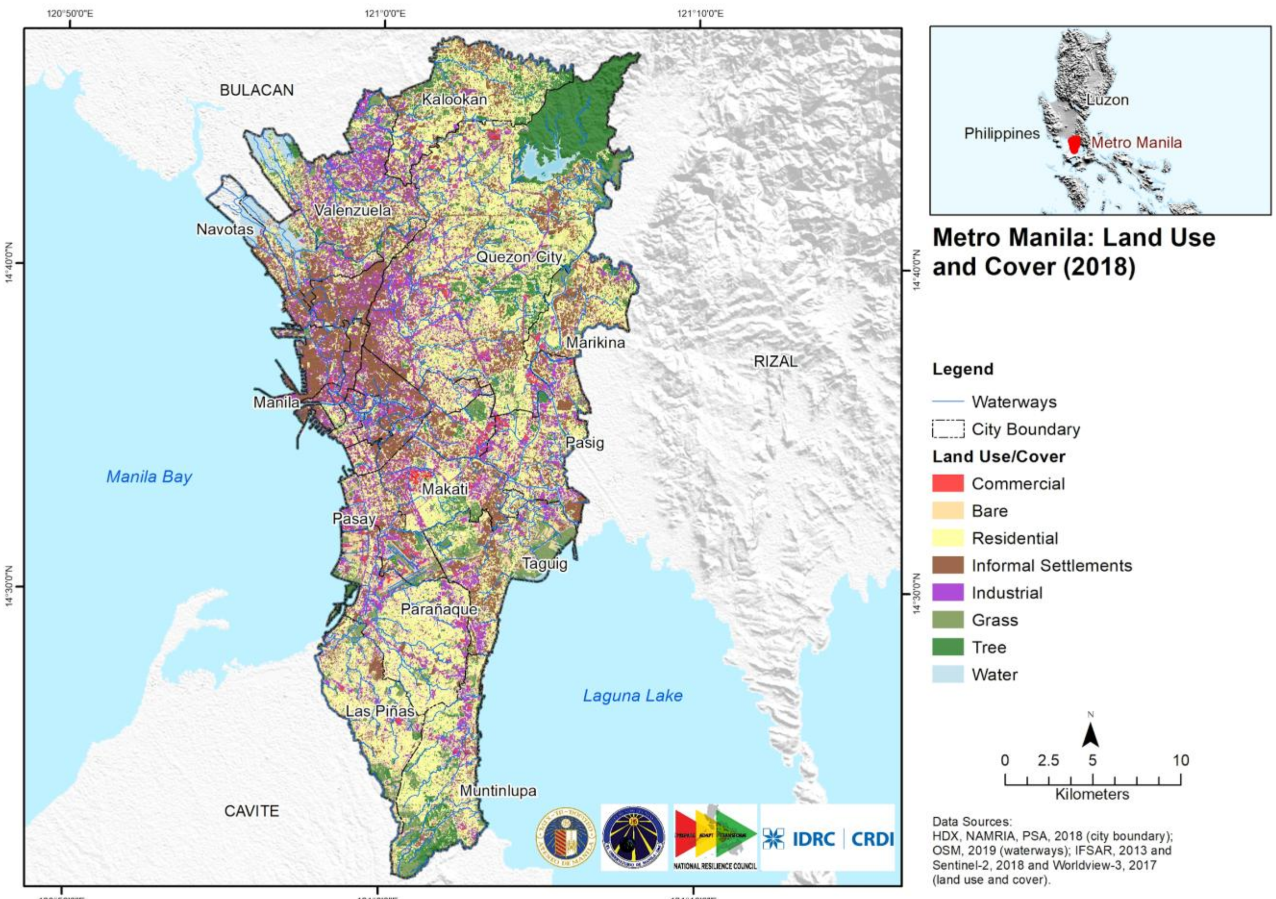

Figure 18. Land Use and Cover (2018)

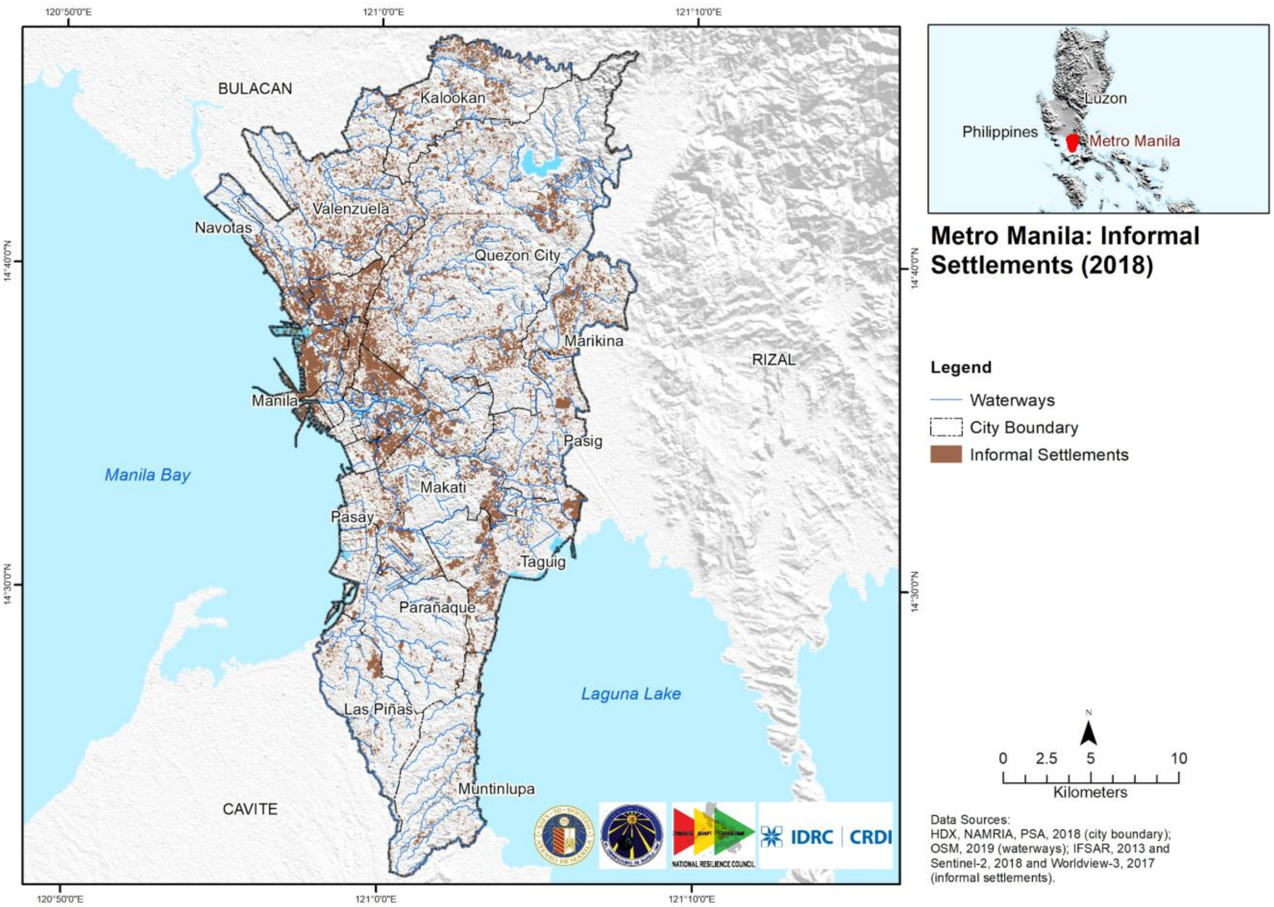

Figure 19. Informal Settlements map (2018)

Table 2: Area of informal settlement per city

City	Area of Informal Settlement (sq.km.)
Pateros	0.25
City of San Juan	0.96
City of Navotas	2.69
City of Muntinlupa	2.78
City of Mandaluyong	2.79
City of Las Pinas	3.38
City of Paranaque	3.80
City of Malabon	4.14
Pasay City	4.17

City of Makati	5.09
City of Marikina	6.21
City of Pasig	6.68
City of Taguig	7.16
City of Valenzuela	9.38
City of Caloocan	15.86
Manila	19.95
Quezon City	25.14
Total	**120.41**

* Estimates from RS-GIS data

Population (demographics) and Vulnerable Groups

Population maps highlight the most populated barangays irrespective of the barangay size. Metro Manila is home to 12.9 million people in 2015, according to census data of Philippine Statistics Authority. Census data show that Quezon City (2.9 million), Manila (1.8 million) and Kalookan City (1.6 million) have the highest total population in the region. Pateros, San Juan and Navotas are the least populated cities (PSA, 2015). Barangay 176, Commonwealth, Batasan Hills, Pinagbuhatan and Payatas are the most populated barangays (PSA, 2015). Figure 20 highlights the location of these barangays in brown. As shown in the map, all of these barangays are located near a body of water. This proximity to rivers increases the chances of flooding in these communities. Informal housing was also detected in these communities (Figure 19).

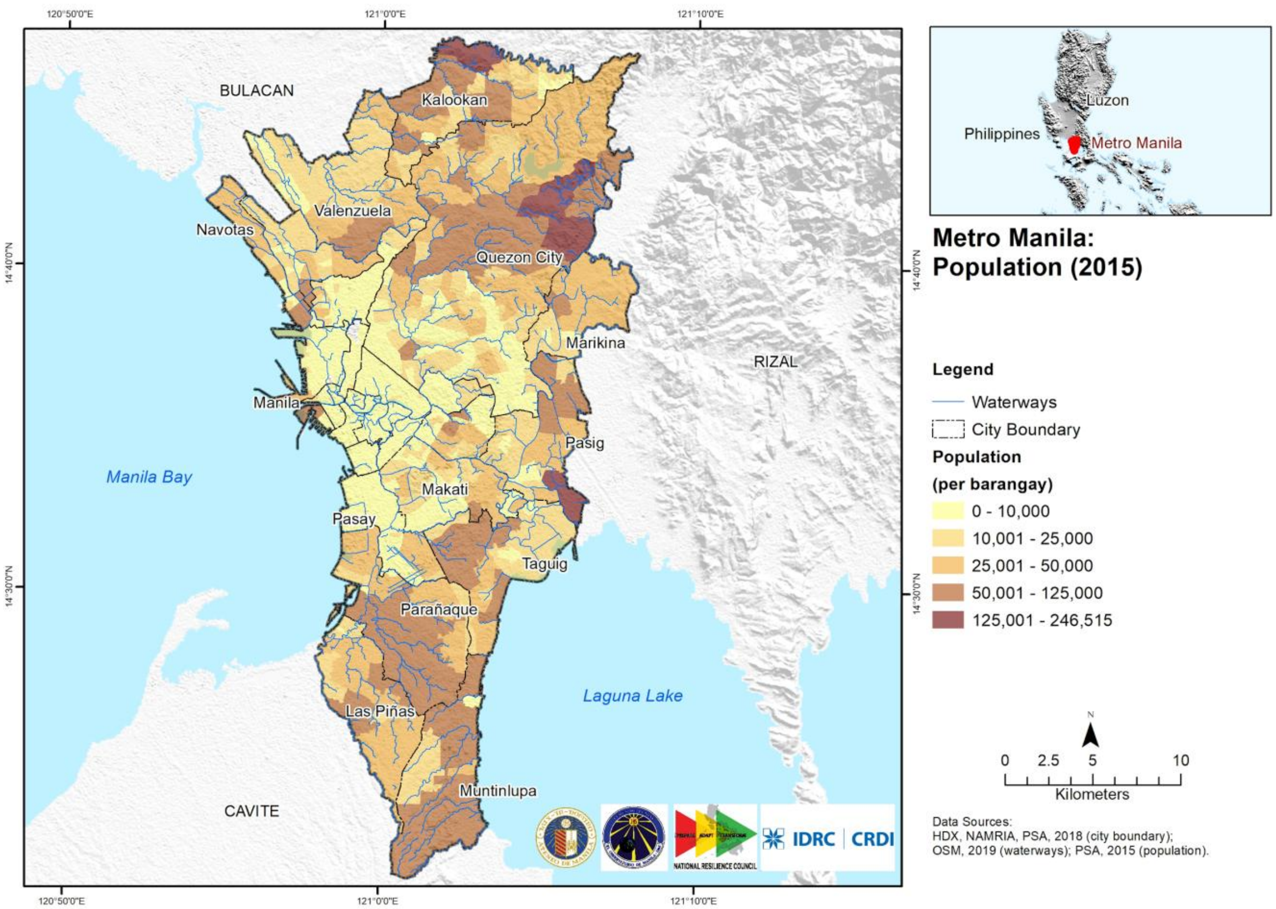

Figure 20. Population (2015)

Metro Manila has a young population. Children constitutes roughly a third of Metro Manila's population. Most children are located in barangays of Kalookan, Quezon City and Pasig City (Figure 21). Almost the same trend distribution can be observed in youth population per barangay (Figure 22). Majority (roughly 70%) of people in Metro Manila are of working age group. The highest number of working age and elderly people are also located in the most populated barangays mentioned earlier (Figure 23 and Figure 24).

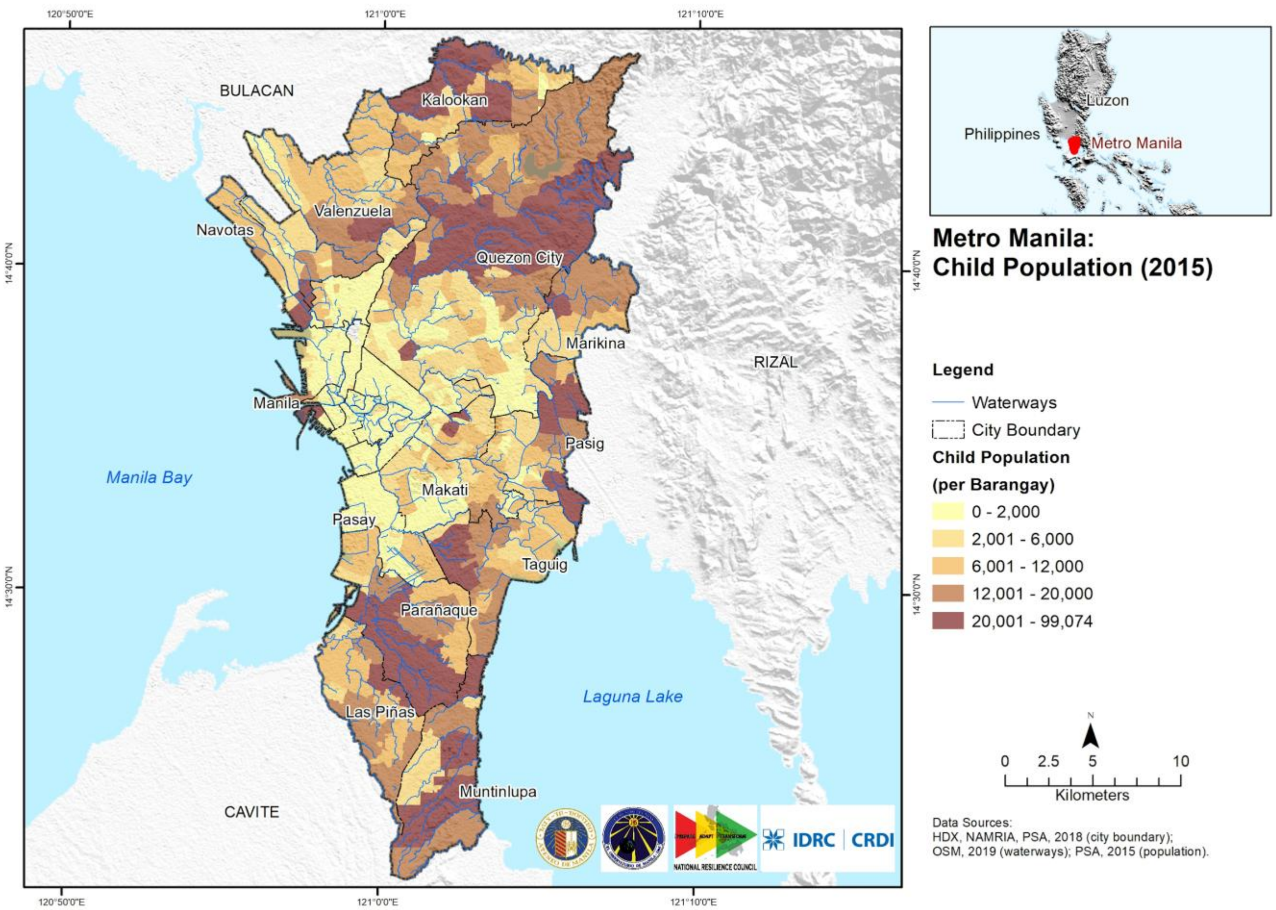

Figure 21. Child Population (2015)

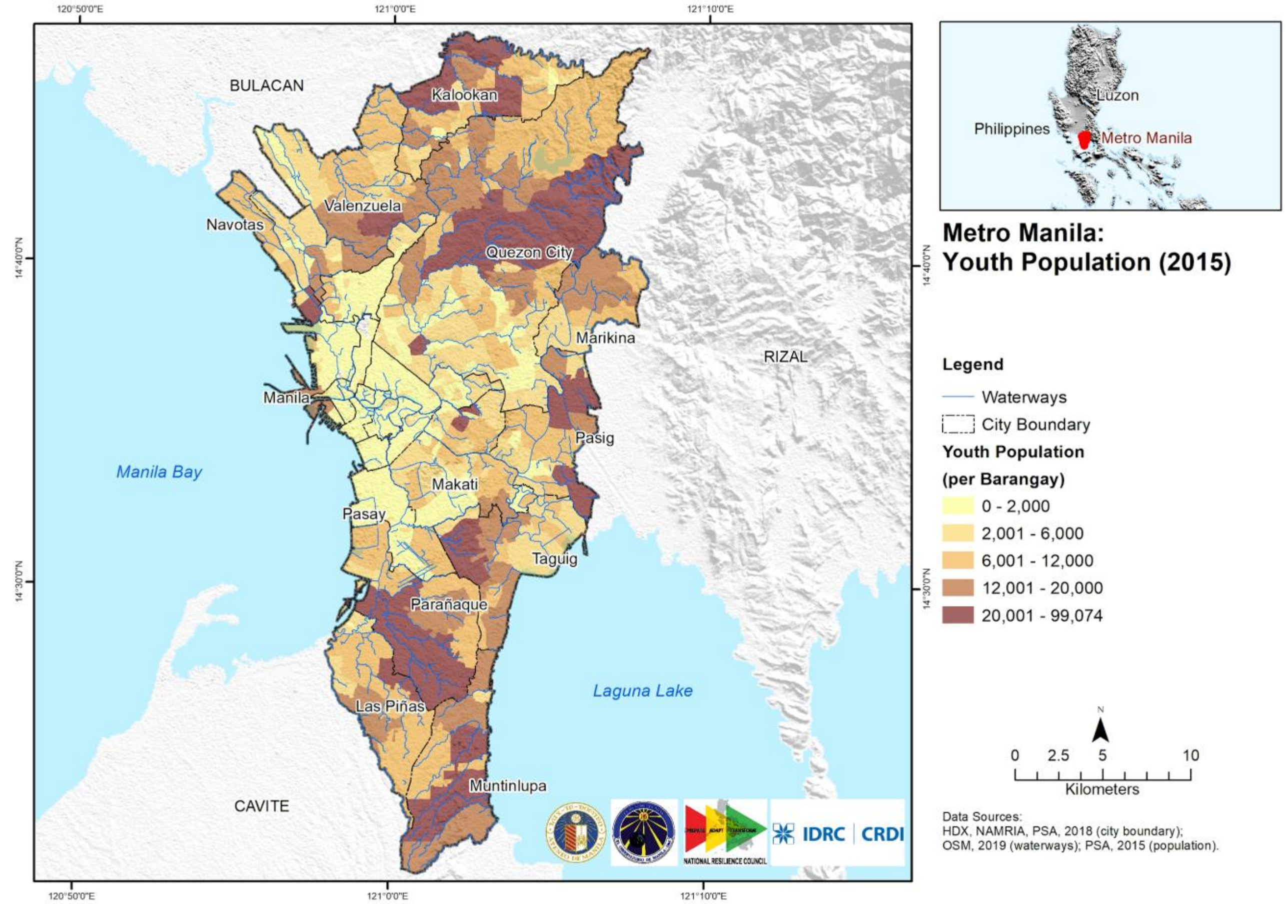

Figure 22. Youth Population (2015)

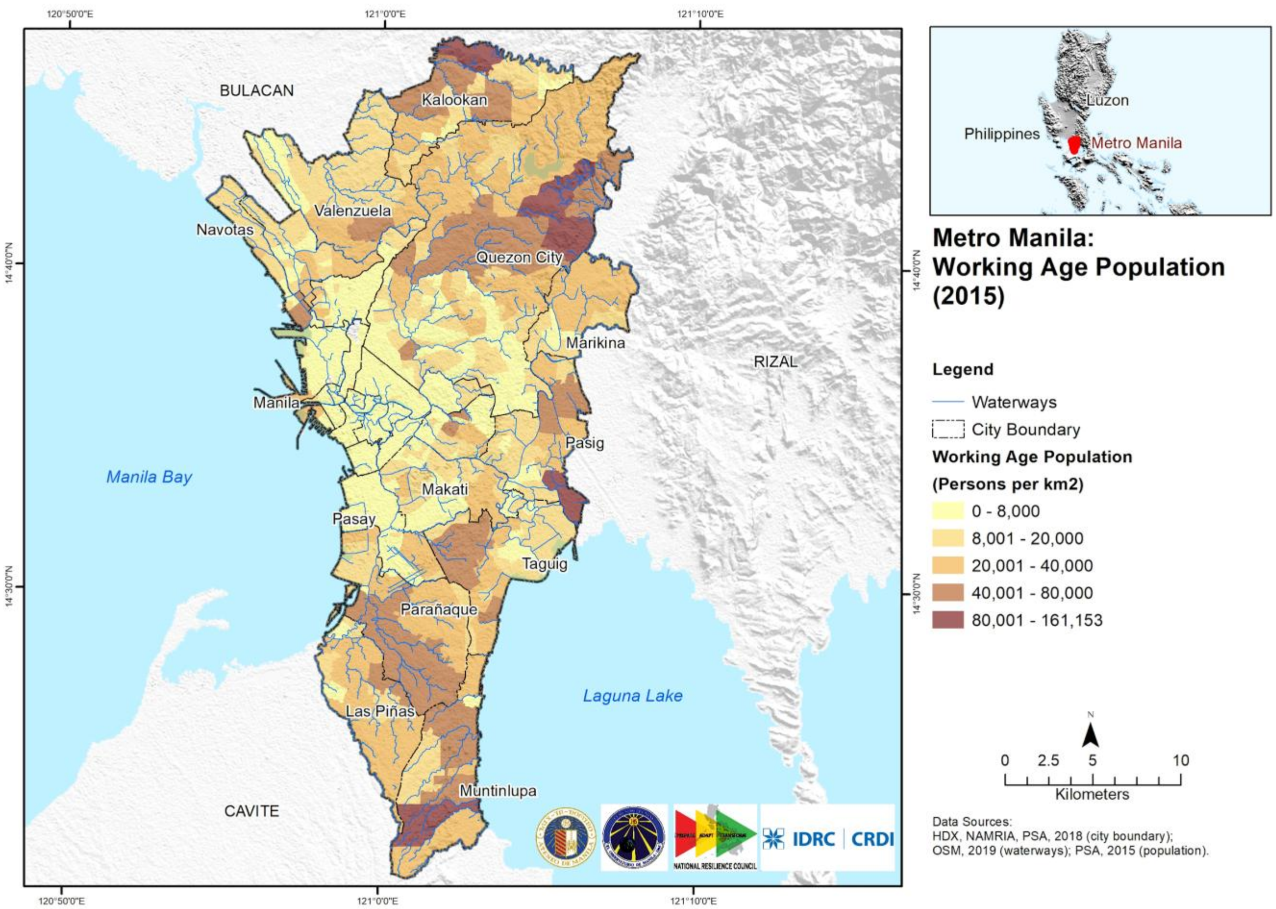

Figure 23. Working Age Population (2015)

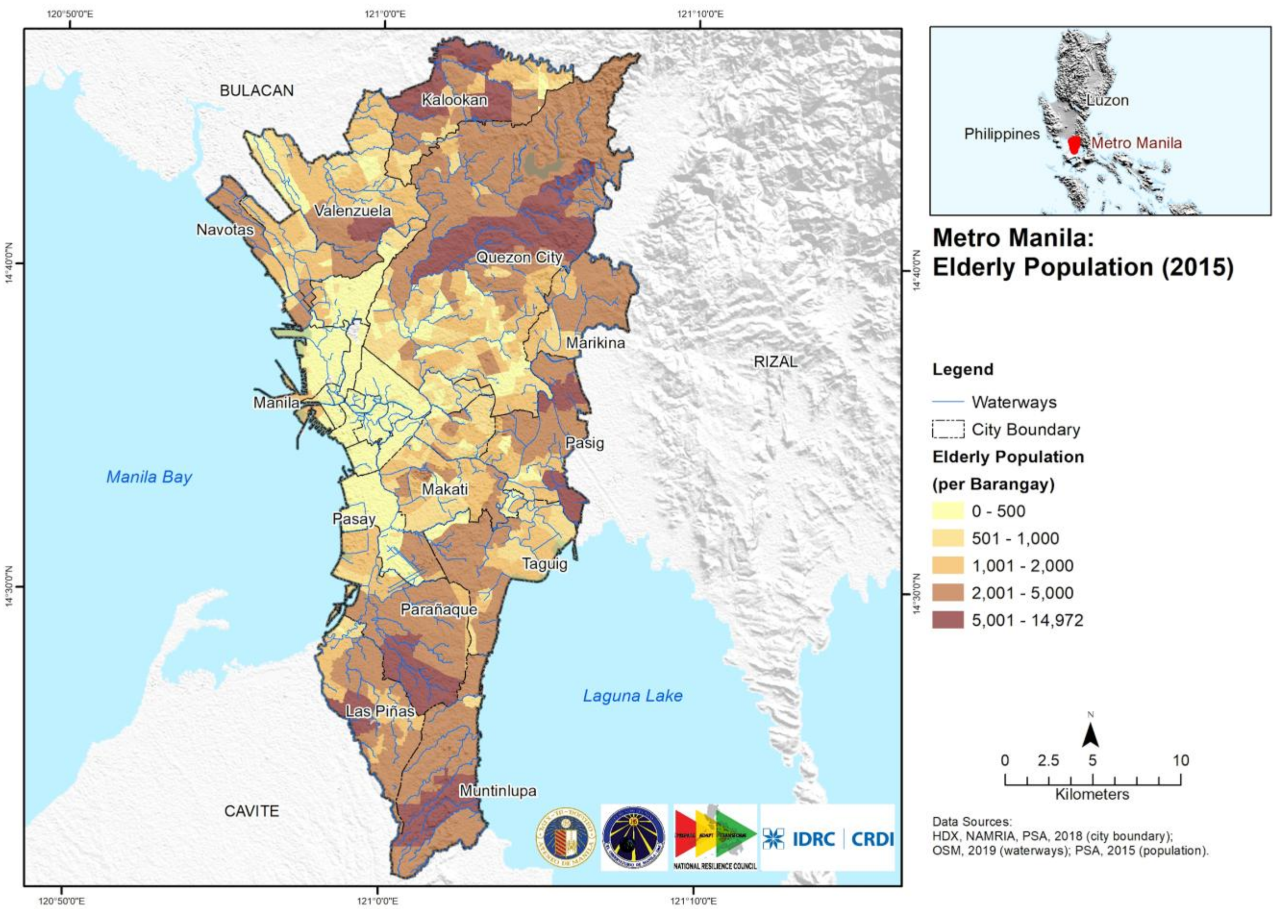

Figure 24. Elderly Population (2015)

Population Density can help in analyzing population distribution over a given space to have a sense of crowdedness. Population density maps highlight the crowded districts. The maps show that Manila has the highest population density among the cities and municipality of Metro Manila. It has an average of 42,000 persons per square kilometer. Densest barangays are in Malate District, Pasay City, Tondo District, Sta. Ana and Sta. Cruz in Manila (Figure 25). Densely populated barangays correlate with the informal settlements better than the barangay population map.

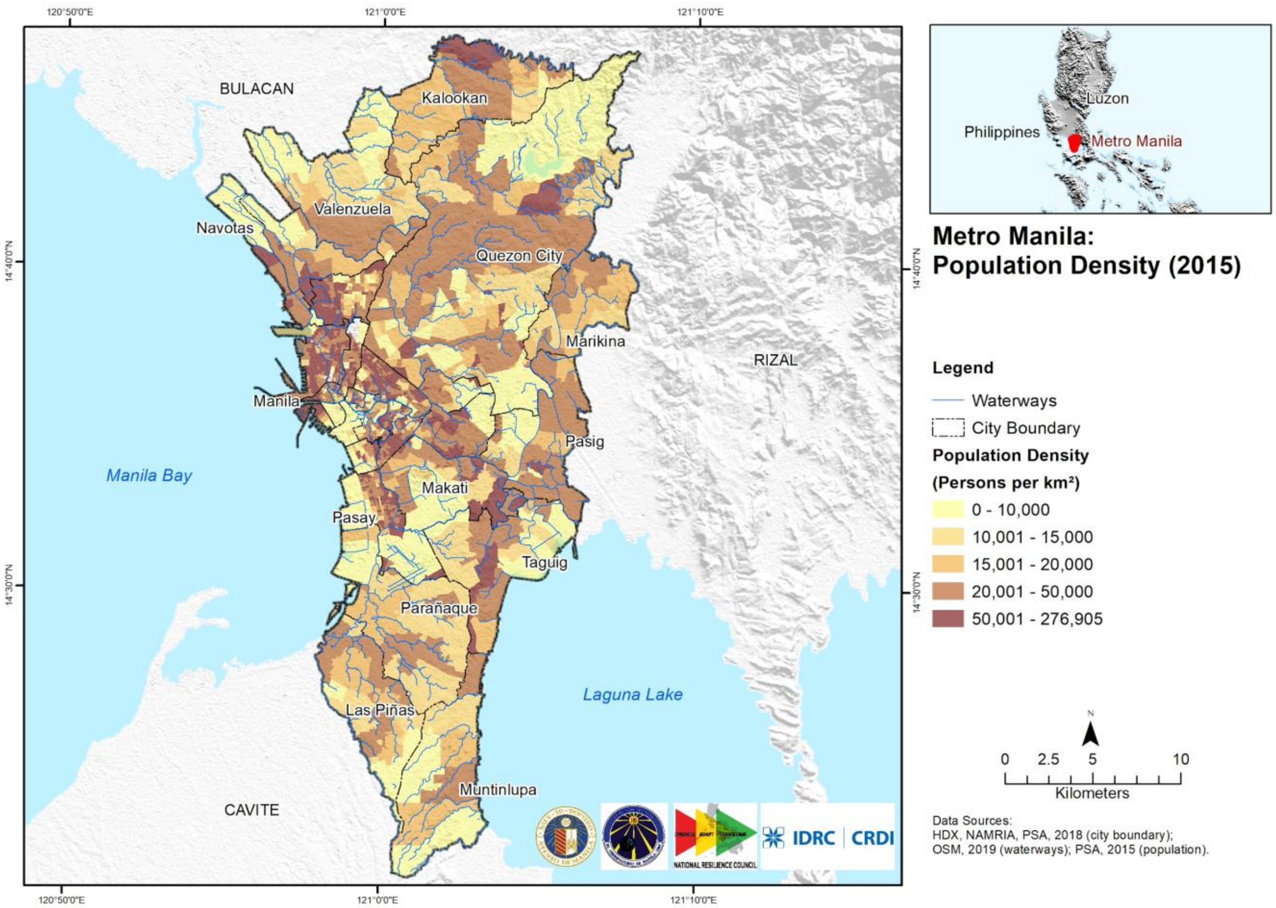

Figure 25. Population Density (2015)

The general distributional trends of child, youth, working age population and elderly population per area follows the overall population density. Child density is highest in Malate, Tondo and Pandacan district of Manila but lowest in Forbes Park in Makati (Figure 26). The same districts have the highest youth density (Figure 27), working age population density (Figure 28) and elderly density Figure 29).

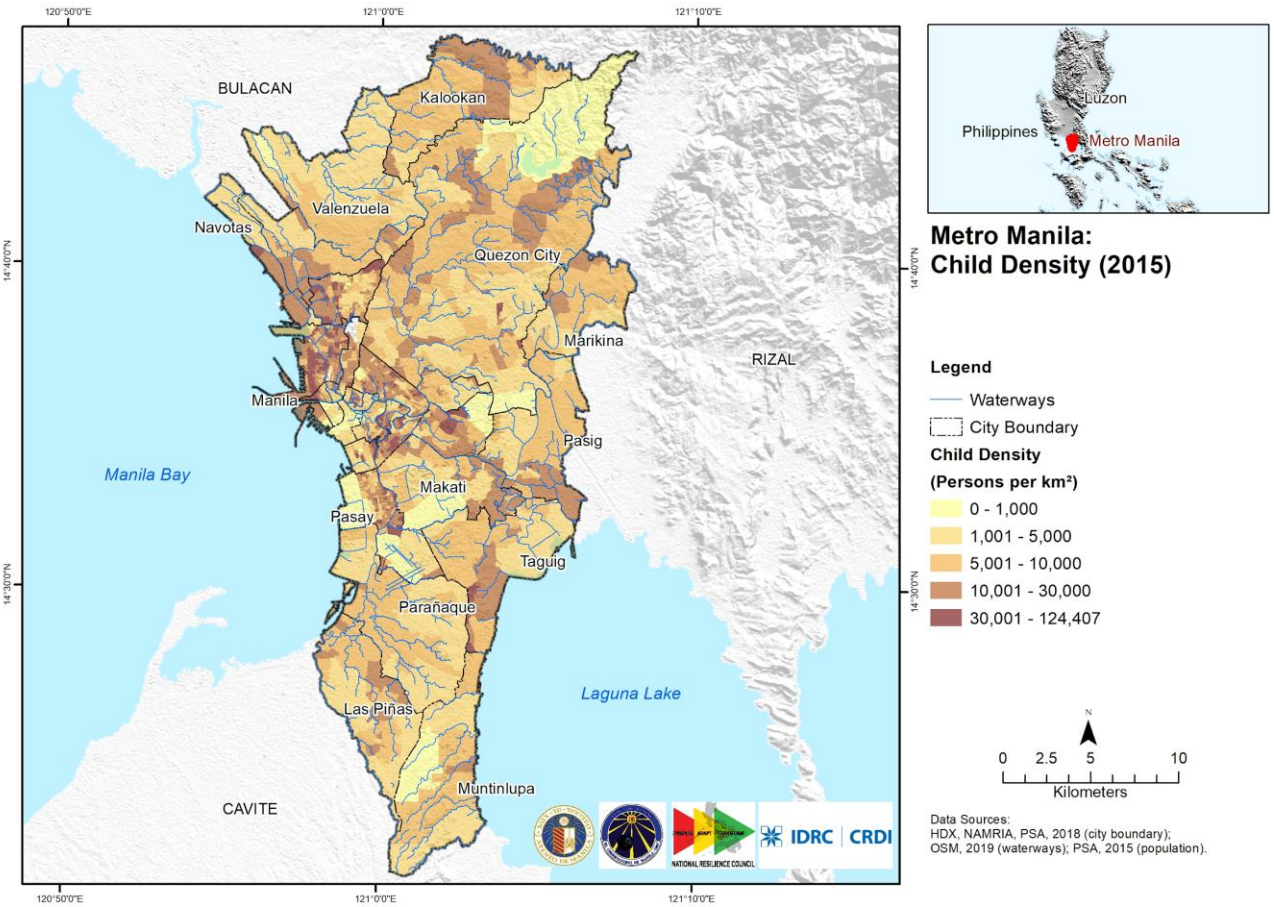

Figure 26. Child Density (2015)

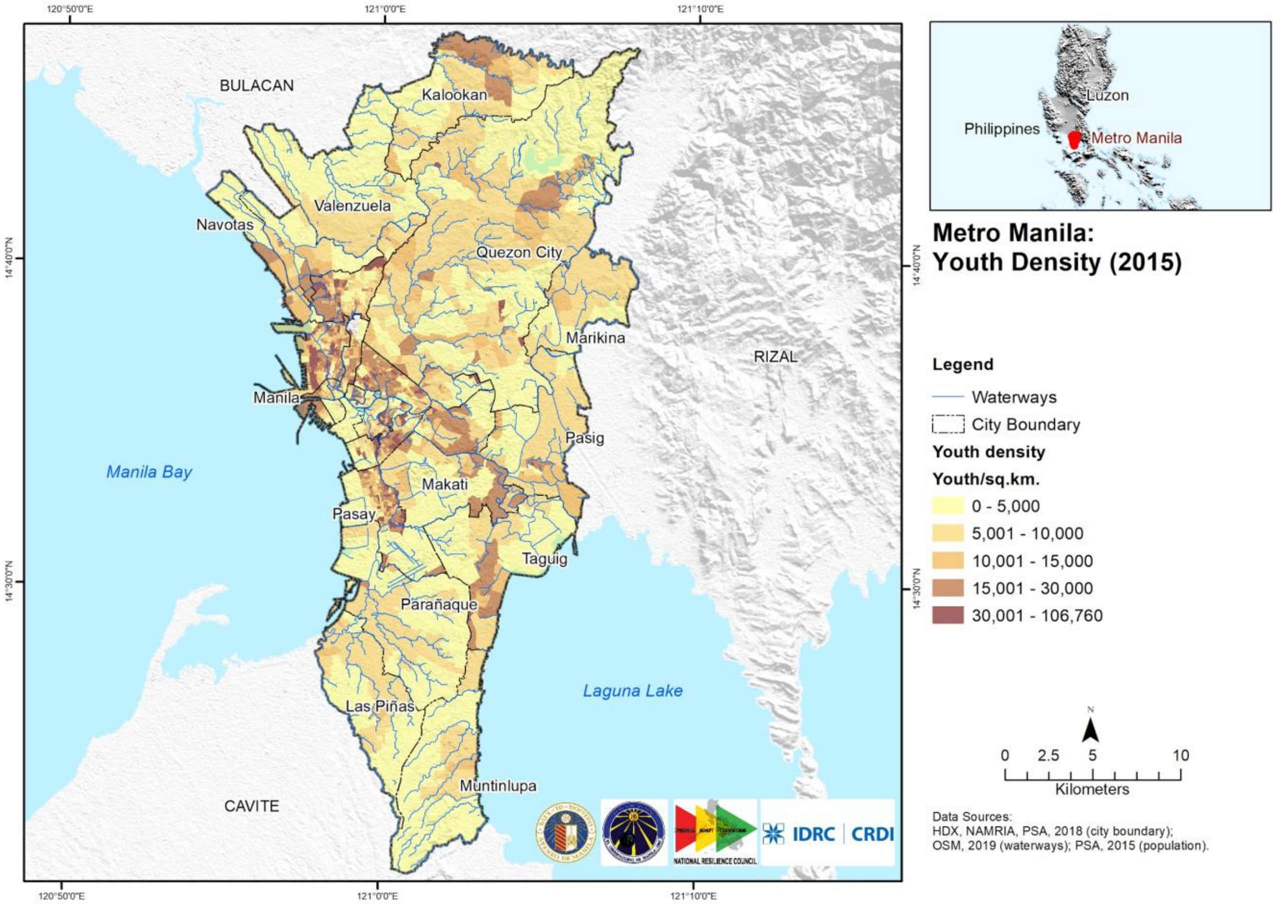

Figure 27. Youth Density (2015)

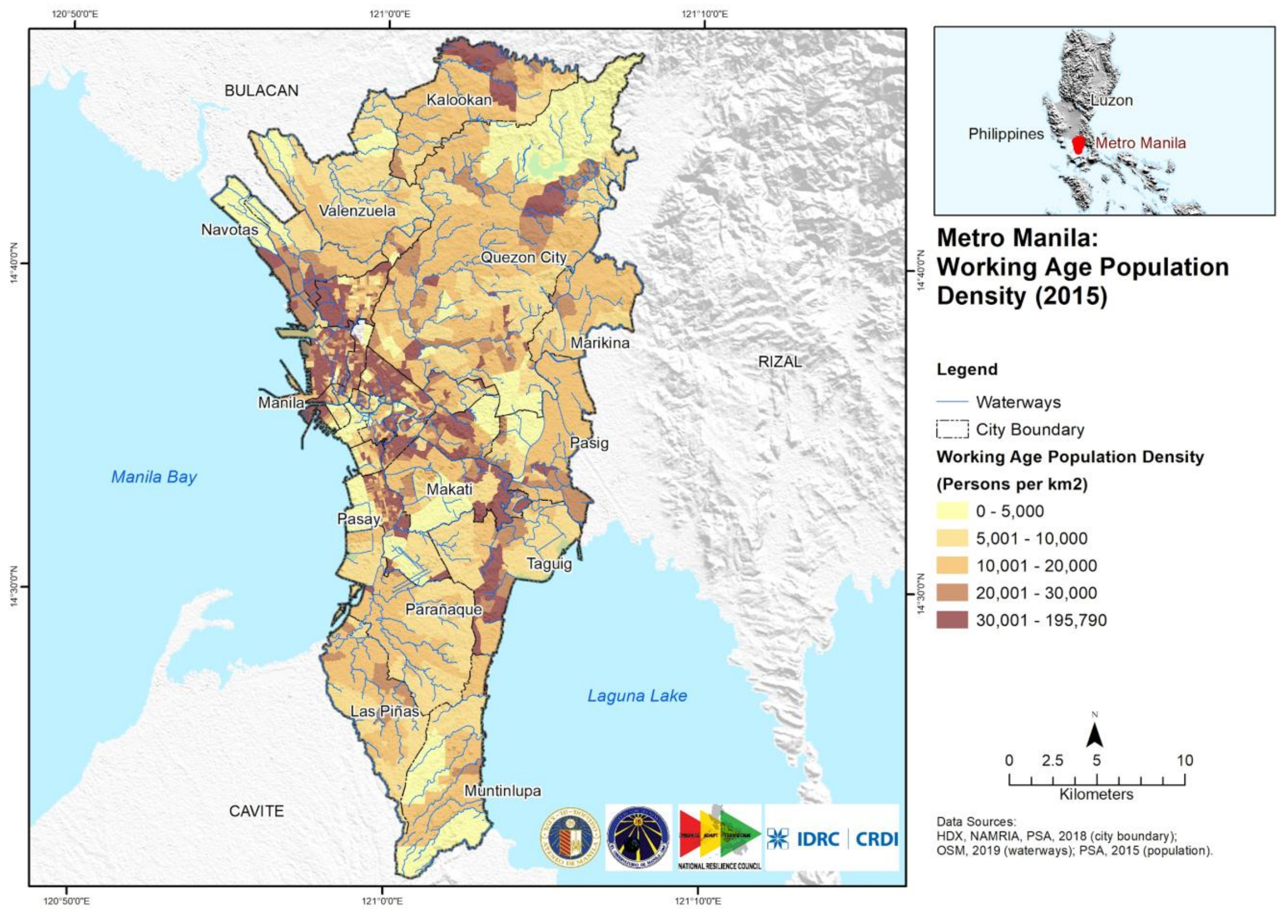

Figure 28. Working Age Population Density (2015)

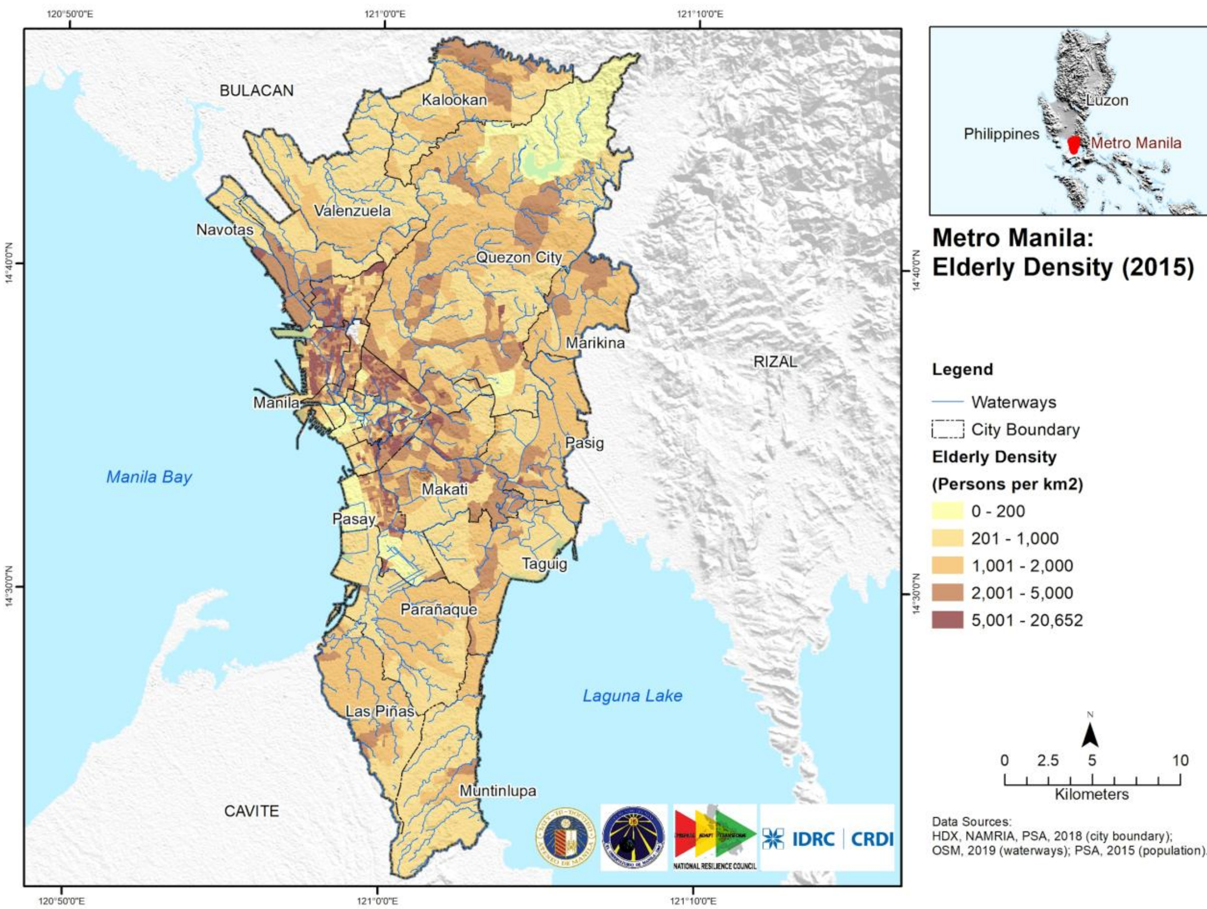

Figure 29. Elderly Density (2015)

Critical Infrastructures

Critical infrastructures are assets necessary to maintain healthy, safe, secure and productive society (Theocharidou & Giannopoulos, 2015). Zio (2016) mentioned powerlines, communication, transmission, transportation, utility networks as examples of CIs. We collected available critical infrastructure layers such as wells and water facilities from NWRB and OSM, schools from DepEd and OSM and hospitals from DOH and OSM. Wells and water (see Figure x) facilities are going to be important sources of water during water shortage events. Metro Manila’s main source of water is Angat Dam. Angat Dam collects rainwater and during dry months and drought periods, water level in the dam falls to a critical level. There are also times when the water level in Angat Dam is sufficient but water interruptions were experienced due to operation and administrative matters. Schools are important infrastructures during disasters as they tend to be evacuation centers. Hospitals provide health assistance to the hazard-affected population and were also included in our analysis. Aside from the water sources, schools and hospitals, we also plotted the location of fire hydrants and fire stations as these are important for fire events.

Susceptibility data

Susceptibility data on heart disease-caused deaths, Dengue, Leptospirosis, and diarrhea cases indicates susceptibility to hazards such as temperature, flood, storm surge and typhoons.

Social vulnerability indicators

Social vulnerability indicators include gender, demographic attributes, socio-economic status, public resources and disability and special needs (Fatemi, et al., 2017). In our study, we found available per city census data for persons with disabilities, 4Ps beneficiaries, single parents, elderly head of the family, child head of the family disaggregated according to gender and mapped these layers. These people have higher susceptibility to hazards and have lower adaptive and coping capacities.

Overlays

Visualizing the spatial and temporal impacts of rising temperature

Rising Temperature

Human activities emitting and contributing to the concentration of gases that have radiative effect like CO2, CH4, N2O, CFCs, etc. in the atmosphere has altered the planetary surface temperature (Ulrich, et al., 2013). These greenhouse gases absorb heat and cause a warming effect that can be felt globally (Ulrich, et al., 2013).

While warmer average temperature is felt globally, it is greatly felt in urban cities like Metro Manila due to urban heat island effect (UHI). Several researchers have linked rising temperature in Metro Manila to urban development (Pereira and Lopez, 2004; Tiangco, Lagmay & Argete, 2008; Oliveros, Vallar and Galvez, 2019). From 1989-2002, the urban area of Metro Manila grew at a yearly rate of 1.33% and the temperature has increased by 0.8% annually (Pereira and Lopez, 2004). The average surface temperature of Metro Manila increased from 22.5 degrees Celsius in 1989 to 32.9 degrees Celsius in 2002 due to UHI (Pereira and Lopez, 2004). Even at nighttime, UHI can raise the temperature in Metro Manila by up to 2.96 degrees Celsius especially in built-up areas (Tiangco, Lagmay & Argete, 2008). This is in contrast with the cold spots that are covered with vegetation (Tiangco, Lagmay & Argete, 2008). Metro Manila exhibited the highest minimum temperature, maximum temperature and sensible heat flux compared with selected neighboring areas (Oliveros, Vallar and Galvez, 2019). Authors (Oliveros, Vallar and Galvez, 2019) attributed this heightened temperature in Metro Manila to urbanization.

The greenhouse gas emissions, together with the changing land use, particularly the loss of natural land cover for urbanization, has increased the surface temperature. Researchers explained that removal of vegetal cover increases atmospheric carbon in the form of carbon dioxide which is a greenhouse gas because less carbon gets absorbed by the plants for photosynthesis (Ulrich, et al., 2013). Consequently, increase in carbon would lead to further warming. Urban areas also produce heat through combustion of fossil fuels for power and for mobility (Tiangco, Lagmay & Argete, 2008). In addition, materials usually seen in urbanized landscape such as cement and asphalt in buildings and roads have higher thermal capacity and conductivity that they are able to absorb more heat (Oliveros, Vallar & Galvez). Urban materials like asphalt are dark which means that they absorb heat and reflect less heat. Materials commonly found in built-up areas do not have the cooling effect from evapotranspiration that plants naturally perform. This means that built-up areas would have greater temperature due their materials' characteristics. Aside from the materials, alteration in a city's skyline due to rise of skyscrapers and tall structures keeps hot air from rising up away from the ground and heats up air by friction (Tiangco, Lagmay & Argete, 2008). Tall buildings also hinder the cooler air from mountains and other natural landscapes or seascapes from entering the cities (Tiangco, Lagmay & Argete, 2008).

Baseline temperature records average annual temperature of Metro Manila at 27 degrees Celsius (Figure 30) (PAGASA climatological normal data). Looking into the future, the projected annual mean temperatures for RCP 4.5 and 8.5 reveal that Metro Manila will experience greater warming in its eastern cities more so towards late 21st century. An increase of 1.3 degrees Celsius will be experienced in Marikina, Pasig, Taguig and Muntinlupa in 2016-2035 (Figure 6a and 6b). Those cities will be 1.8 degrees Celsius warmer in 2045-2066 (Figure 7a and 7b) and will be 3.5 degrees Celsius warmer by late 21st Century (Figure 8a and 8b) based on RCP8.5.

Exposed population to rising temperature: Older Population and Children

Temperature has a wide range and interconnected impact on population. Extremely high temperature affects the elderly. It also increases the survival of dengue mosquito. Warmer temperature would require more energy for cooling and more water for hydration. Hotter days are also linked to higher fire incidences that also require water to be extinguished.

Rising temperature and cardiovascular diseases

Extremely high and low temperatures can have detrimental effects on health. In a research conducted by Seposo, Dang and Honda in 2016, they learned that extremely-high temperature-related mortality was higher in people with respiratory diseases, women and elderly or people older than 64 years old. They said that women have greater risk to extreme temperature because of social, physical, economic, and geographic factors (Seposo, Dang & Honda, 2016). On the other hand, elderly people have decreased ability to regulate body temperature due to natural ageing process (Seposo, Dang & Honda, 2016). This ability, a process called homeostasis, deteriorates as a person gets older (Guo, Barnett, & Tong, 2012). Researchers have shown that higher temperature takes more lives through respiratory and cardiovascular diseases (Chung, Honda, Pan, Guo & Kim, 2009). Warming temperature could affect the elderly population as they have greater vulnerability to extreme climate and extreme weather (Filiberto, et al., 2010) and also because they have a higher chance of having cardiovascular or respiratory diseases (Guo, Barnett, & Tong, 2012).

According to PSA census data of 2015, elderly population was highest in Barangay 176 of **Caloocan City**, Barangays Commonwealth, Batasan Hills, Tandang Sora, and Holy Spirit in **Quezon City**, BF Homes in **Paranaque**, Gen. T. De Leon in **Valenzuela**, Poblacion and Putatan in **Muntinlulpa** and Manggahan and Pinagbuhatan in **Pasig City**. Most of these barangays were also the location of high density urban poor areas (Figure 19). According to DOH in 2016, **Quezon City, Manila, Caloocan, Valenzuela and Pasig** had the highest number of heart-disease-caused deaths. Baseline temperature was highest in the western coasts but projected temperature for the early, mid and late 21st century show increase in the eastern cities of **Quezon City, Marikina, Pasig, Taguig, and Muntinlupa**.

These separate parameters of elderly population, heart disease-related deaths and annual average temperature were visualized in a single map to see spatially overlapping patterns. Our maps show the elderly population per barangay (Figure 30), the projected temperature for 2016-2035 for RCP 8.5, and the heart-disease-caused deaths per city. The cities experiencing the increase in temperature do not exactly correspond with the cities with the most number of elderly population, nor with the most number of heart disease-caused deaths. However, **Quezon City and Pasig** were highlighted in all these three combined layers. Other cities like **Caloocan and Valenzuela** have a high population and high heart disease-caused deaths even if their cities do not have high temperature nor will not have projected high temperature. This suggests that other factors may have caused the high incidence of heart disease. Even if **Muntinlupa** comparatively has lower heart disease mortality, it also has a high elderly population and is going to experience higher temperature in the coming decades and should start taking care of the elderly to prevent cardiovascular diseases and establish health care facilities.

In Figure 31, **Manila** was highlighted as having the most barangays with the densest elderly population. Crowded spaces tend to increase risk to heart attacks (Yerebakan, 2018). These cities need more and better health facilities to attend to the elderly population.

In relation to health facilities, we plotted the location of hospitals and generated a database of hospitals within Metro Manila. This initial database is based on Department of Health's partial list of licensed level 2 and level 3 hospitals with ambulance of 2018. The list was checked with Google maps and openstreetmaps to determine the exact location of the hospitals in the list. Based on our database, there are 190 hospitals in Metro Manila (65 hospitals have ambulances). Cities of **Quezon, Manila, Pasig, Caloocan and Valenzuela** have the highest number of hospitals among the Metro Manila cities.

Most of the level 2 and 3 hospitals in the Philippines are located in Metro Manila. Even though Metro Manila has the most number of hospitals compared with other regions in the country, the reality is often troubling. In reality, the insufficient number of hospital beds are reported (de la Cruz, 2017). In terms of location, most of the hospitals we mapped are oftentimes clustered along major roads and business districts and sometimes far from the places where many elderly people live. Closer examination of their distribution reveals that residential areas, especially informal settlements lack a nearby hospital. This could mean greater travel time and distance from their residences to the hospitals. This trip to the hospital is oftentimes compounded by traffic, lack of transport vehicle, lack of financial resources and other road hazards that could add to the difficulty experienced by the elderly. Other factors such as the quality of medical service, the availability of doctors and necessary medical equipment, tests, and treatment have to be considered for further studies.

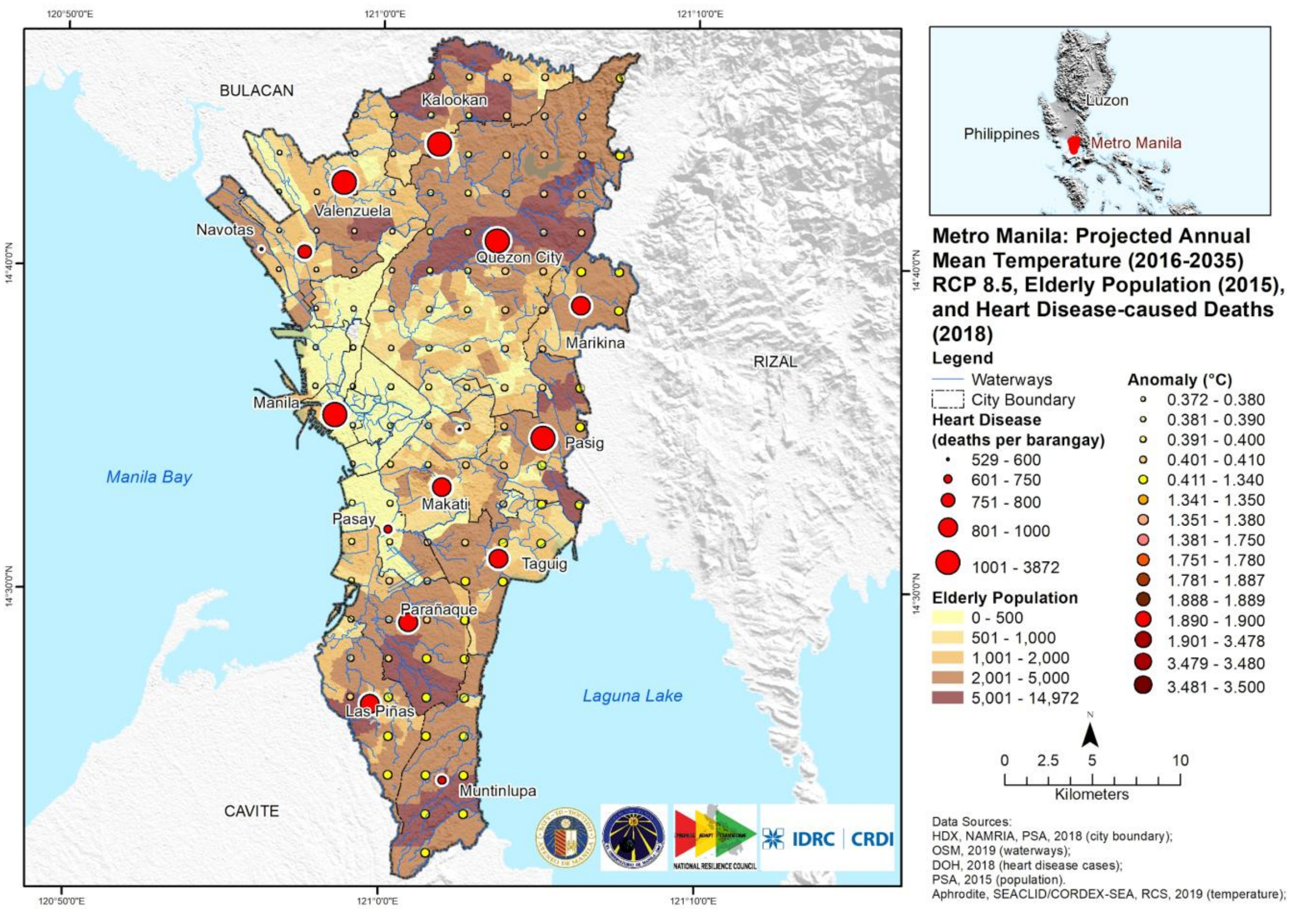

Figure 30. Projected annual mean temperature (2016-2035) RCP 8.5, elderly population (2015)and heart disease-caused deaths (2018)

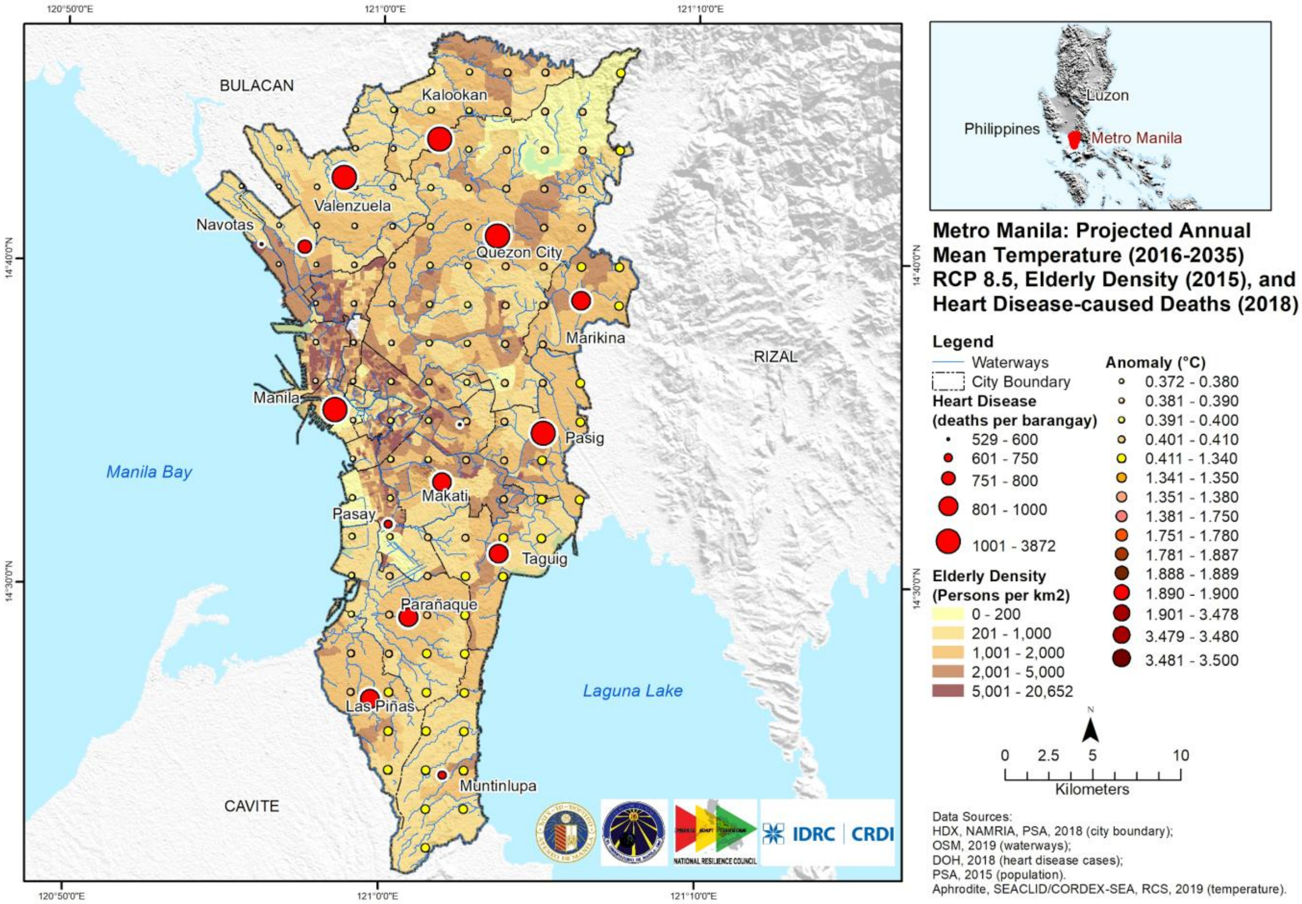

Figure 31. Projected annual mean temperature (2016-2036) RCP 8.5, elderly density (2015), and heart disease-caused deaths (2018)

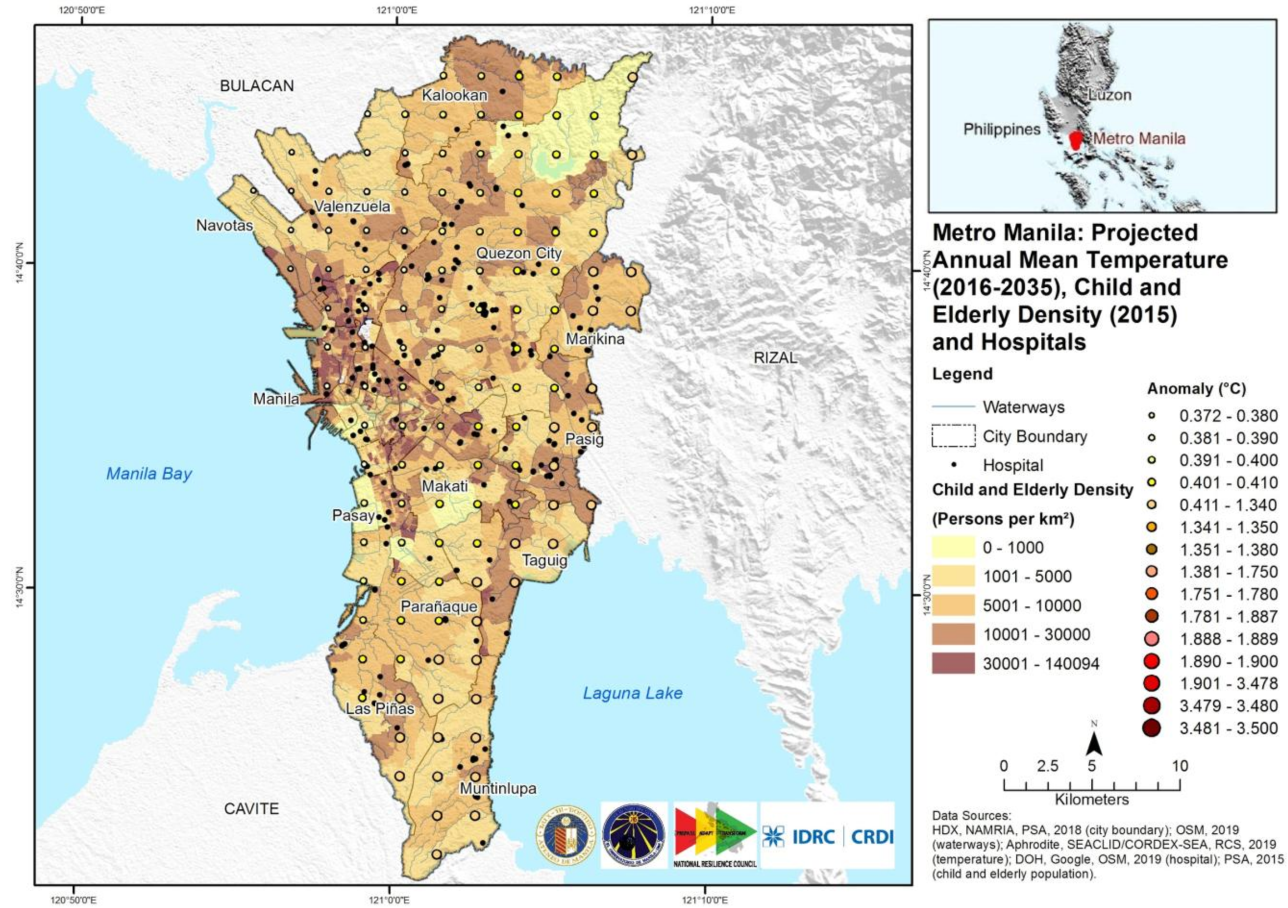

Figure 32. Projected annual mean temperature (2016-2035), child and elderly density (2015) and hospitals

In the Philippines, there is 1 doctor for every 33,000 residents. This is far from the ideal 1:1,000 doctor-population ratio. In Metro Manila, there is 1 doctor per 1,072 people. However, few cities in Metro Manila including Manila, Makati, Muntinlupa, Paranaque, and San Juan have met the 1:1,000 ratio. Navotas, Malabon and Pateros have the least number of doctors per population.

Rising temperature and dengue incidences

Aside from cardiovascular diseases, vector-borne diseases tend to rise due to warmer temperature. One disease favoring rising temperatures is Dengue. Dengue is a viral disease transmitted through the bite of a female adult *Aedes aegypti* and *Aedes albopictus* mosquito carrying the virus. These mosquitoes have infected 200 million people globally (Murray, Quam & Smith, 2013). Most infected people live in the tropics and subtropics (Gubler, 1998). Several factors have increased the incidents of dengue. This includes **overseas traveling, urban development, population growth, sanitation, socio-economic factors and extreme weather events and changing climate** (Morin, Comrie & Climate, 2013; Ebi & Nealon, 2016; Naish, et al., 2014; Gubler, 1998, 2002, 2009; Tatem, et al., 2012; Raisen, 2013).

Several researchers (Li, et al., 2018; Duarte, et al., 2019; Choi, et al., 2016; Naqvi et al., 2019) identified **changing climate, particularly warmer temperature and uneven rainfall pattern** as a supporting factor to the proliferation of dengue virus. Suitable temperature is necessary for *Ae aegypti* to survive its various life stages from egg to adulthood (Couret & Benedict, 2014; Brady et al., 2013; Rueda, et al., 1990; Yang et al., 2009; Marinho et al., 2015; Byttebier et al., 2014; Christofferson, 2016; Beserra et al., 2009; Robert, et al., 2019). Dengue mosquitoes incubate faster at warmer temperature (Naqvi, et al., 2019). A seven degree Celsius increase in temperature from 27 degrees Celsius reduces the incubation time of mosquitoes by three days (Naqvi, et al., 2019). Faster incubation period means more mosquitoes in a short timeframe. Even the development of larva and the adult life require a suitable range of temperature (Brady, et al., 2013; Rueda et al., 1990; Yang, et al., 2009; Christofferson, 2016). The virus also incubates faster in the host at warmer temperature (Chan and Johansson, 2012; Watts et al., 1987; Carrington et al., 2013; Robert, et al., 2019). Once the virus was contracted, the infected person experiences symptoms similar to flu including fever reaching 40 degrees Celsius, headache, nausea, vomiting, rash, painful muscles, joints, and back of the eyes. If not treated, the illness would get more severe and the patient would experience more complications caused by internal bleeding and organ damage. At the advanced stage, the infected person might experience painful abdomen, plasma leakage, continuous vomiting, bleeding gums, tiredness and fast breathing, and bloody vomit.

According to WHO, dengue mostly occur on children. They explained that younger population tends to have greater risk to dengue because they still lack the capacity to resist broken capillaries (WHO, 2009). DOH national data (2018) shows that while dengue affects people from different age groups, most infected people (73%) are below 19 years old (Figure 33). A fifth of the dengue cases in the Philippines are in Metro Manila (DOH, 2018). In Metro Manila, roughly three-fourths of the cases are under 19 years old. Dengue affects more males than females. In 2019, a national dengue epidemic was declared as dengue took the lives of more than 700 people nationwide, as of July 2019 (WHO, 2019). WHO reports that Dengue cases in the Philippines as of July 2019 (167,607) is almost twice that of 2018 (85,011).

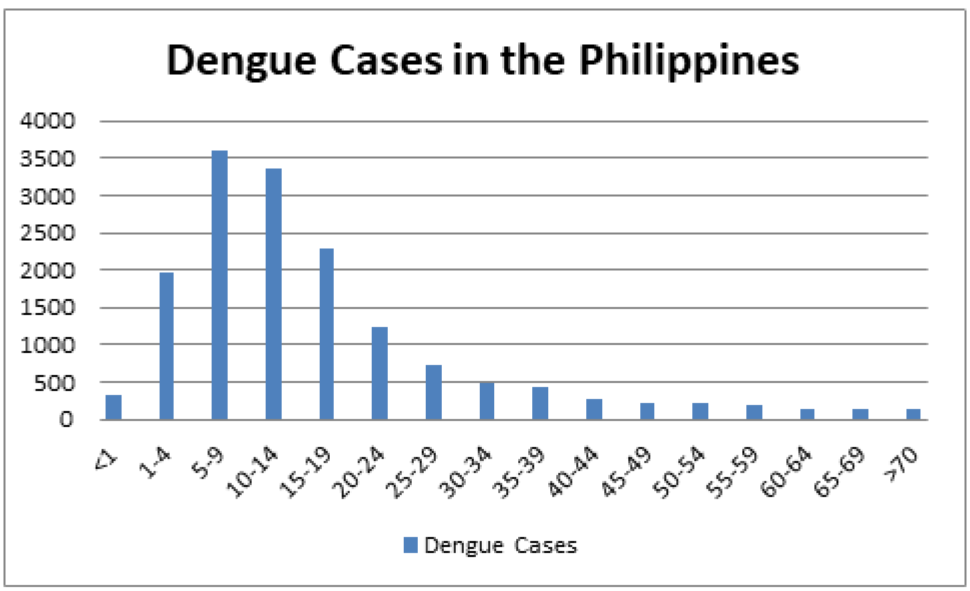

Figure 33. Dengue Hemorragic Fever Cases in the Philippines (2018) per age group (source: DOH)

We mapped the projected mean annual temperature for early, mid and late 21st century over the child population and dengue cases to visualize the spatial distribution and find overlapping spatial patterns among these layers (Figure 34). Child population was highest in **Barangay 176 of Caloocan, barangay Commonwealth of Quezon City, Pinagbuhatan of Pasig and Batasan Hill and Payatas of Quezon City**. Our data shows that the highest dengue cases are in **Manila (73%), Muntinlupa (16%), Quezon City (7%), Mandaluyong (2%), Pasig (2%), Taguig (<1%) and Pasay (<1%).** There are no recorded dengue cases in other cities. Literature suggests that population density has a positive correlation with dengue cases (Sirisena, et al., 2017). This could explain the disproportionately high number of dengue cases in the densely populated Manila compared with other cities. One study conducted in Vietnam found out villages and peri-urban areas with population density ranging from about 3000 to 7000 person per square kilometer without individual household water connections are more prone to dengue outbreaks (Schmidt, et al., 2011). While the range of population density according to Schmidt, et al., (2011) did not apply to Metro Manila as Metro Manila have much denser population, there is still a strong positive (r-value of 0.77) correlation between population density and dengue cases. Dengue cases have a weak negative correlation (-0.22 r-value) with piped water sources according to our computation.

However, when dengue cases and child population were mapped over climate projections, the cities affected with dengue do not correlate exactly with the cities experiencing higher temperature. Of the dengue-affected cities, only **Quezon City, Muntinlupa, Pasig and Taguig** have higher temperature (Figure 35 and Figure 36). This suggests that dengue spread in Metro Manila is not solely dependent on temperature. Cities with dengue cases also vary per year. In 2017, only Taguig, Paranaque and Pasay City have dengue cases. In 2016, it was Pasig City that had the highest number of Dengue cases. In 2015, dengue cases were highest in Las Pinas City.

Contrary to some of the literature, Sia Su (2008) correlated climate variables with dengue incidence and found out that temperature has no significant correlation with dengue cases. Instead, rainfall had better correlation with the dengue cases. It would be better to overlay the dengue cases with actual temperature and rainfall data. Other factors such as rainfall, sanitation, urban development and socio-economic factors can influence dengue occurrence.

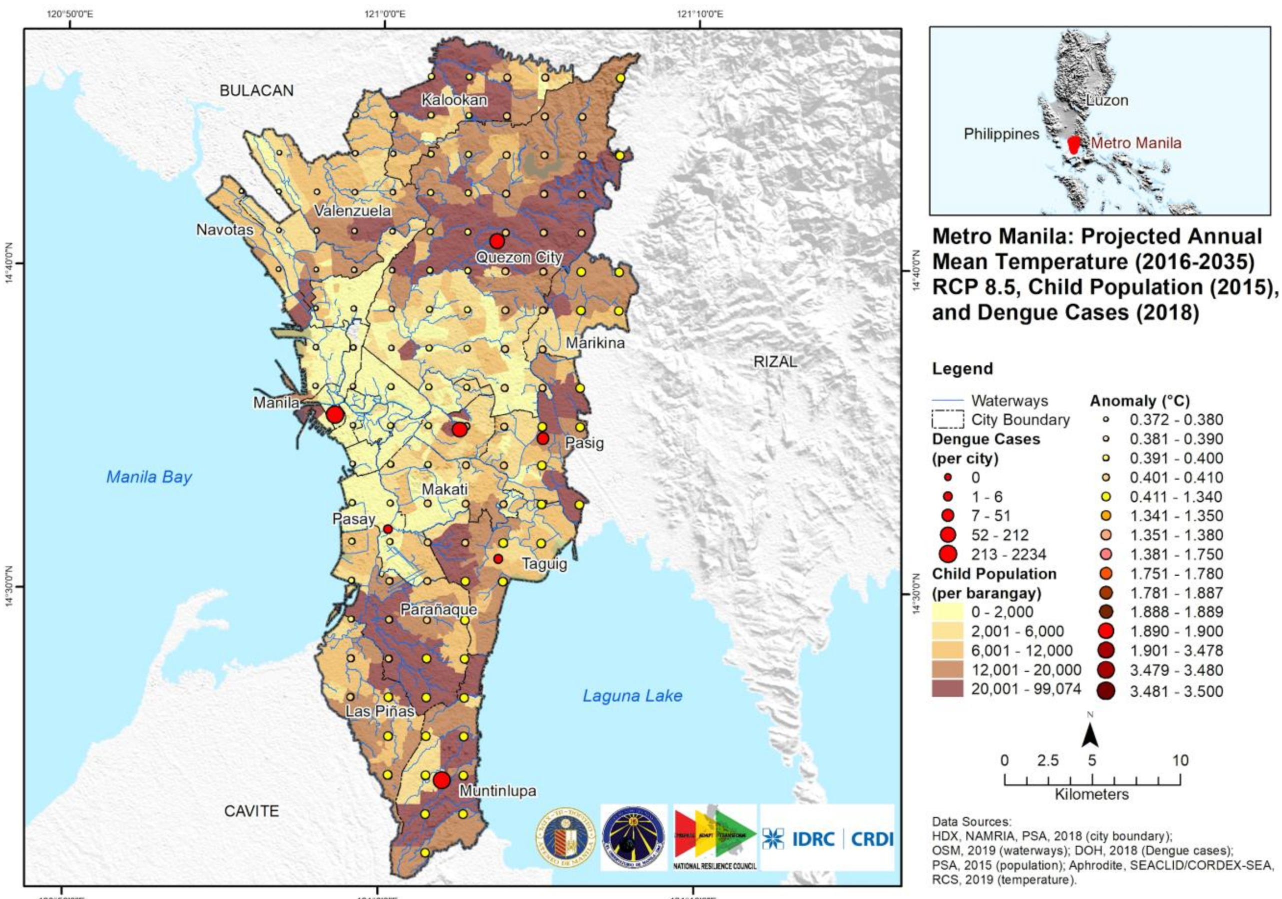

Figure 34. Projected annual mean temperature (2016-2035) RCP 8.5, child population (2015), and dengue cases (2018

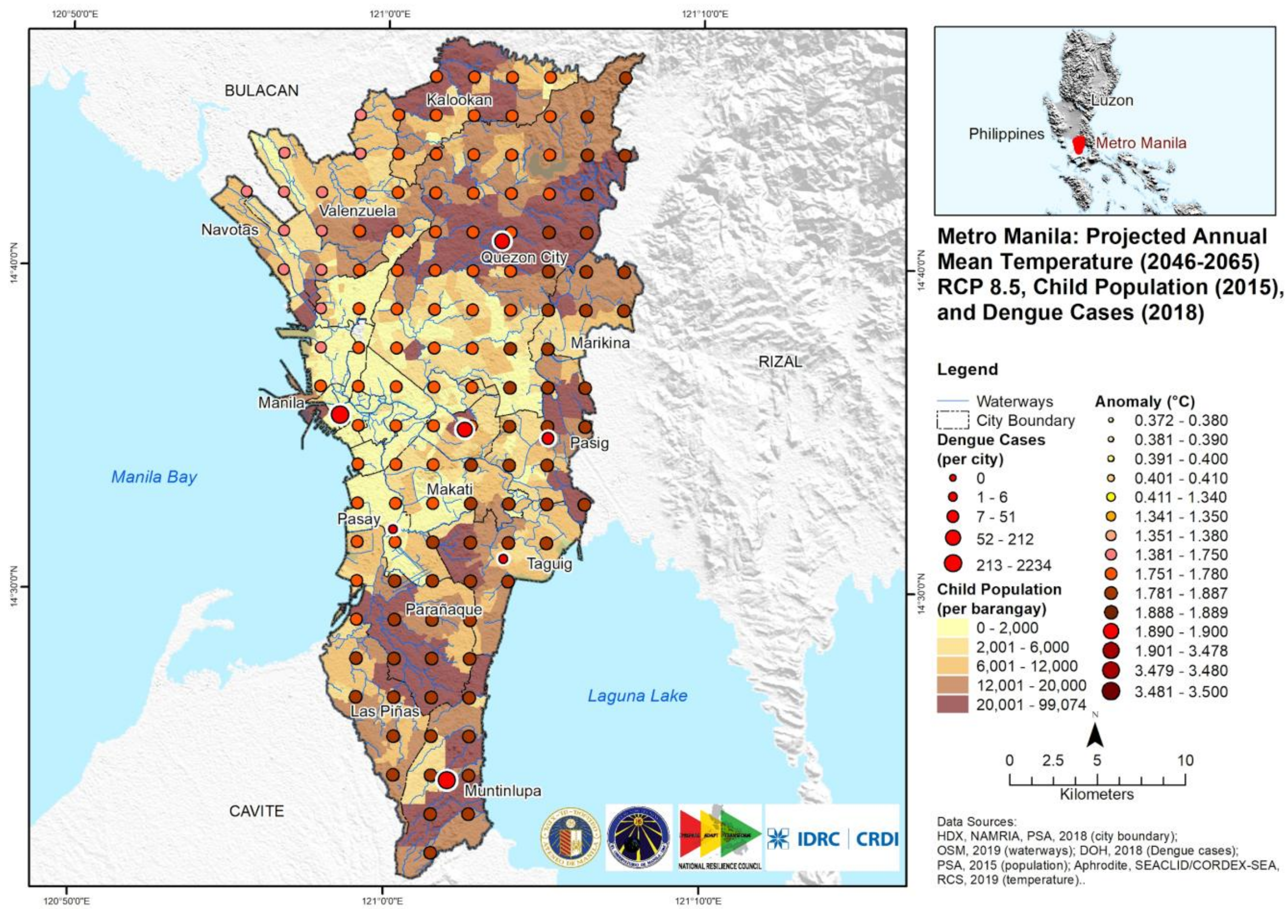

Figure 35. Projected annual mean temperature (2046-2065) RCP 8.5, child population (2015), and dengue cases

(2018)

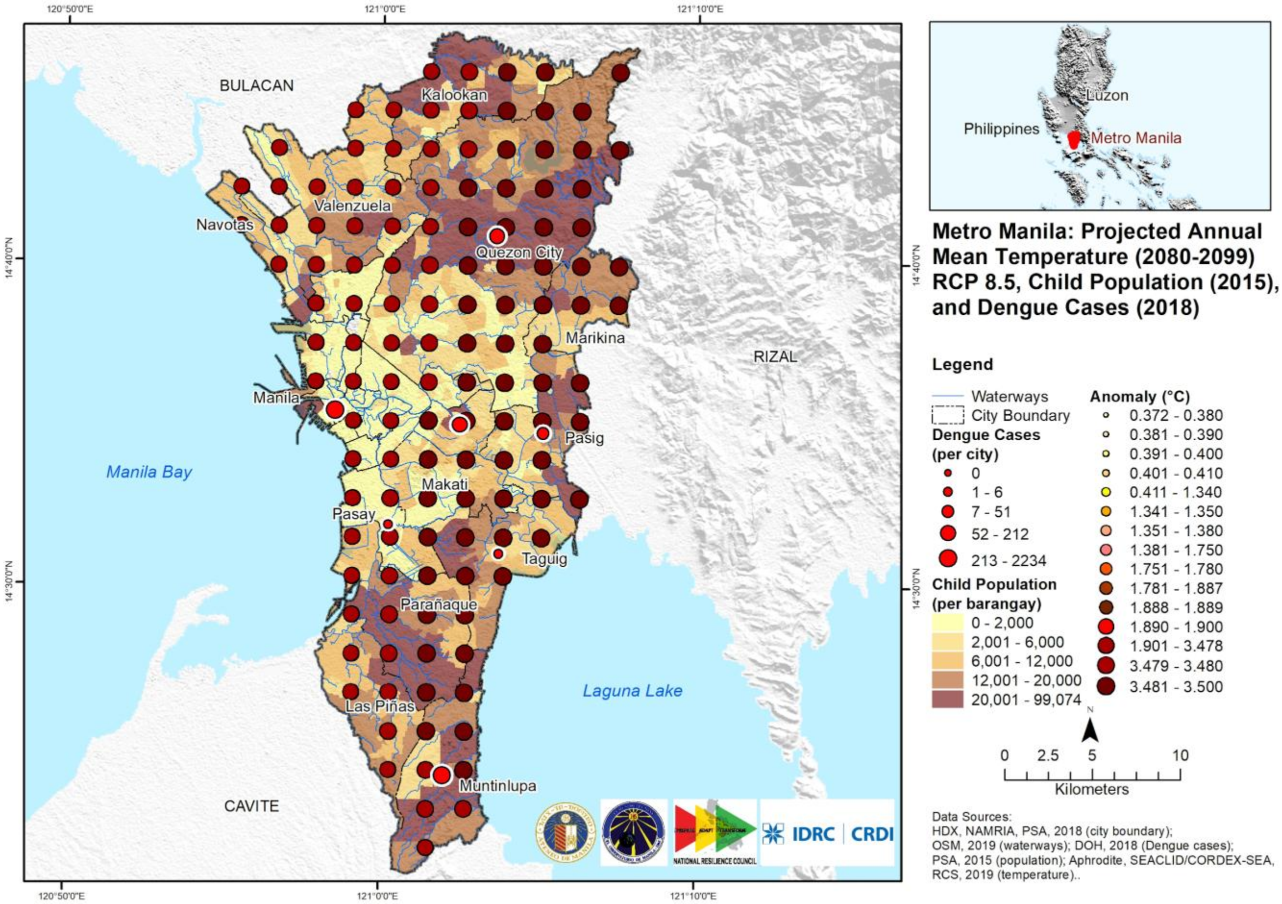

Figure 36. Projected annual mean temperature (2080-2099) RCP 8.5, child population (2015), and dengue cases (2018)

Rising temperature and associated hazard: fire incidences

Temperature is one important element affecting fire incidences. Warmer ambient temperature means less heat is required for ignition which is the starting point of a fire. In recent years, there has been an increase in fire incidences in Metro Manila (Table 3). A study conducted in the city of Manila in 2015 attributed the temporal pattern of fire with the cause, temperature and population (Balahadia, Trillanes & Armildez, 2015). This study found out that temperature and population are highly correlated with fire incidents (0.72 and 0.84, respectively). Moreover, their temporal analysis reveals that fire occurrences are highest during hot and dry months of March to May. They explained that during these months, the most common cause of fire is faulty electrical connections as people use more electricity for cooling that may lead to overloading of electrical connections (Balahadia, Trillanex & Armildex, 2015). They noted the informal settlements and electrical connections in homes as important factors leading to the fire incidents.

Table 3. Fire incidences, injuries, deaths and damage in Metro Manila per year

Year	2012	2013	2014	2015	2016
Fire incidents	3,424	3,691	4,438	4,374	5,121
Injuries	268	304	302	319	346
Deaths	75	58	30	154	67
Damage (million php)	495	286	459	607	601

Source: Bureau of Fire Protection

We mapped the fire incidences per city in Metro Manila together with the baseline and projected temperature in the early 21st Century and interpreted with the location of slum areas. Temporal trend shows an increase in fire incidences and injuries from 2012 to 2016. Spatial analysis of fire incidence revealed that consistently from 2012 to 2016, Manila and Quezon City had the most number of fire incidence in Metro Manila. These are also the two cities with the highest area of informal settlements (25.14 sq.km. in Quezon City and 20.3 sq.km. in Manila). Starting 2014 until 2016, Valenzuela City started having more than 400 fire incidences per year. In 2016, a lot of cities including Kalookan City, and the eastern cities of Marikina, Pasig and Taguig that are going to have a relatively higher temperature anomaly in 2016-2035, including Makati, Paranaque and Las Pinas City have increased fire incidences. Using these datasets alone could not give an exact correlation to fire incidences and temperature changes as the time scales and time frame varies. This risk overlay analysis is limited to simple visual interpretation of spatial trends and average annual temperature anomaly data. We recommend further analysis using statistical tools and models to better understand fire occurrences. Nevertheless, we can extract other insights from this method.

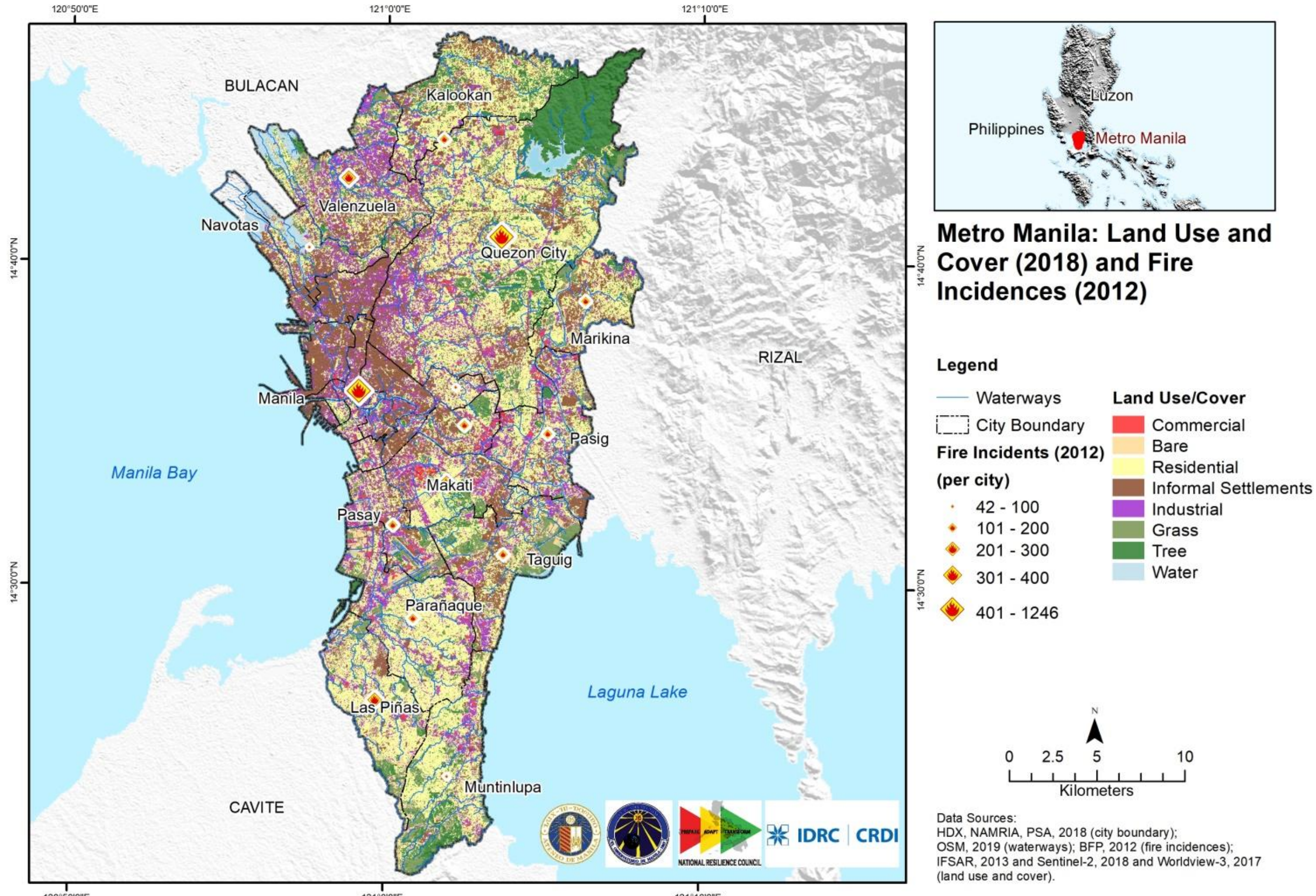

Figure 37. Land use and cover (2018) and fire incidence in 2012

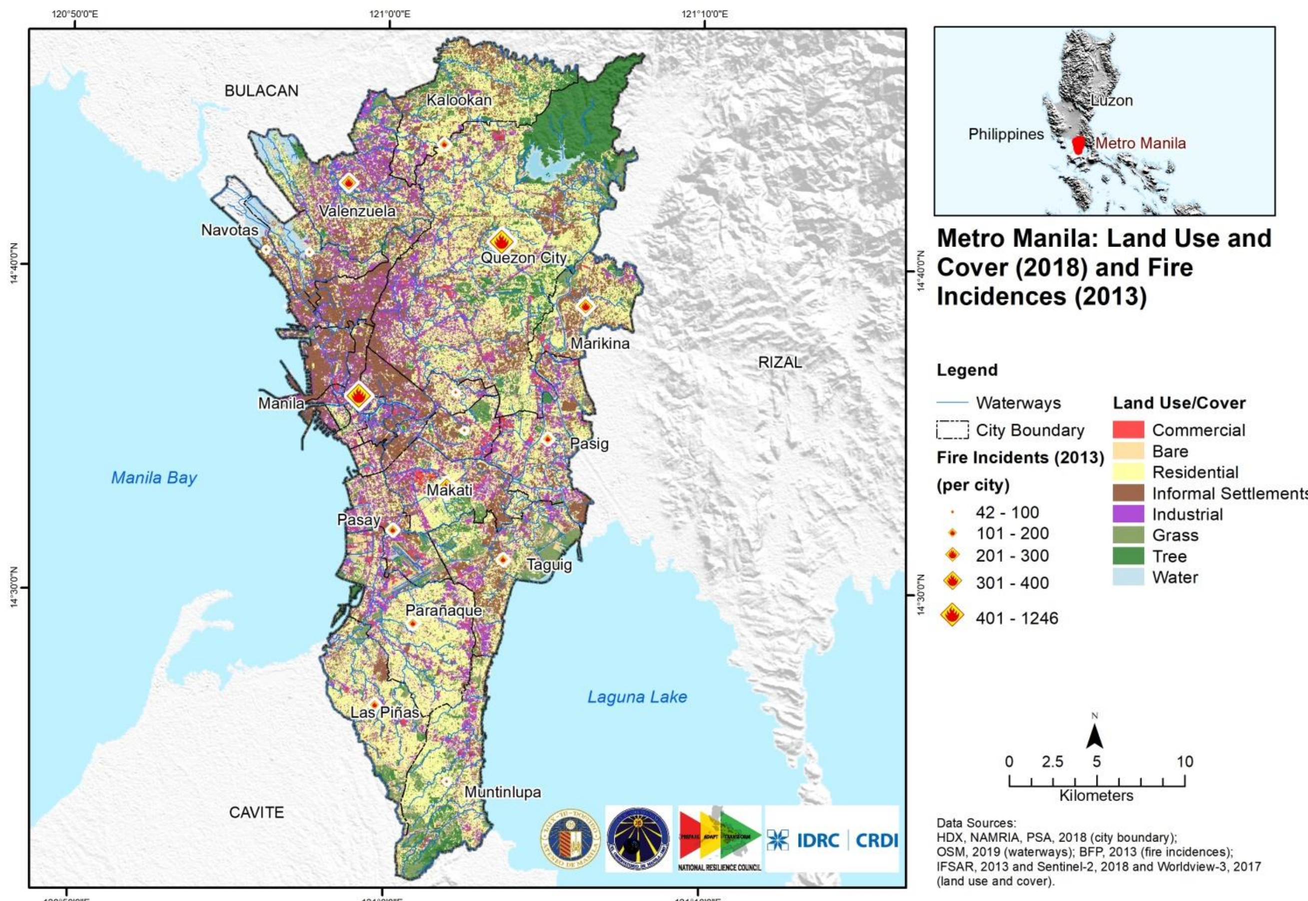

Figure 38. Land use and cover (2018) and fire incidence in 2013

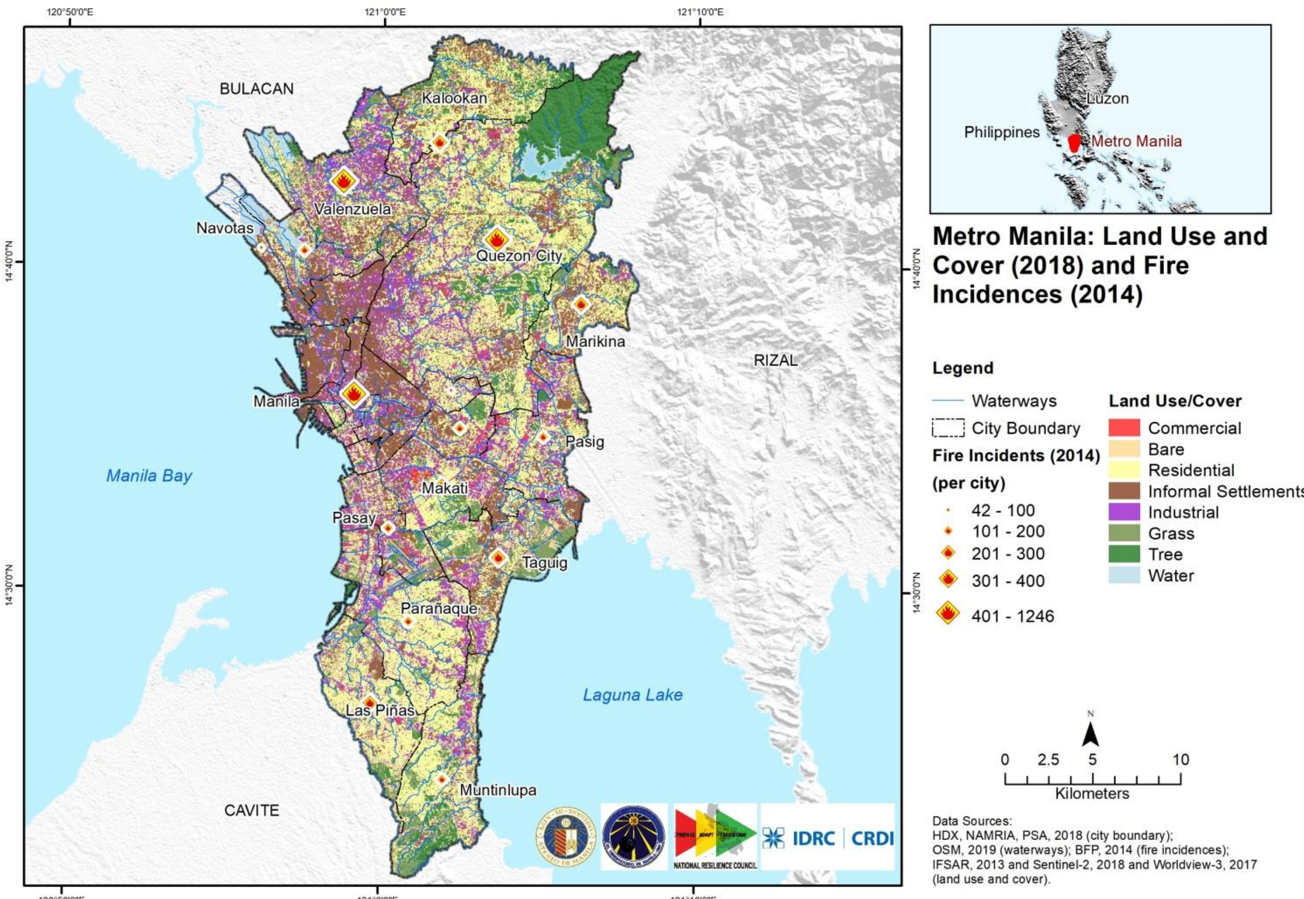

Figure 39. Land use and cover (2018) and fire incidence in 2014

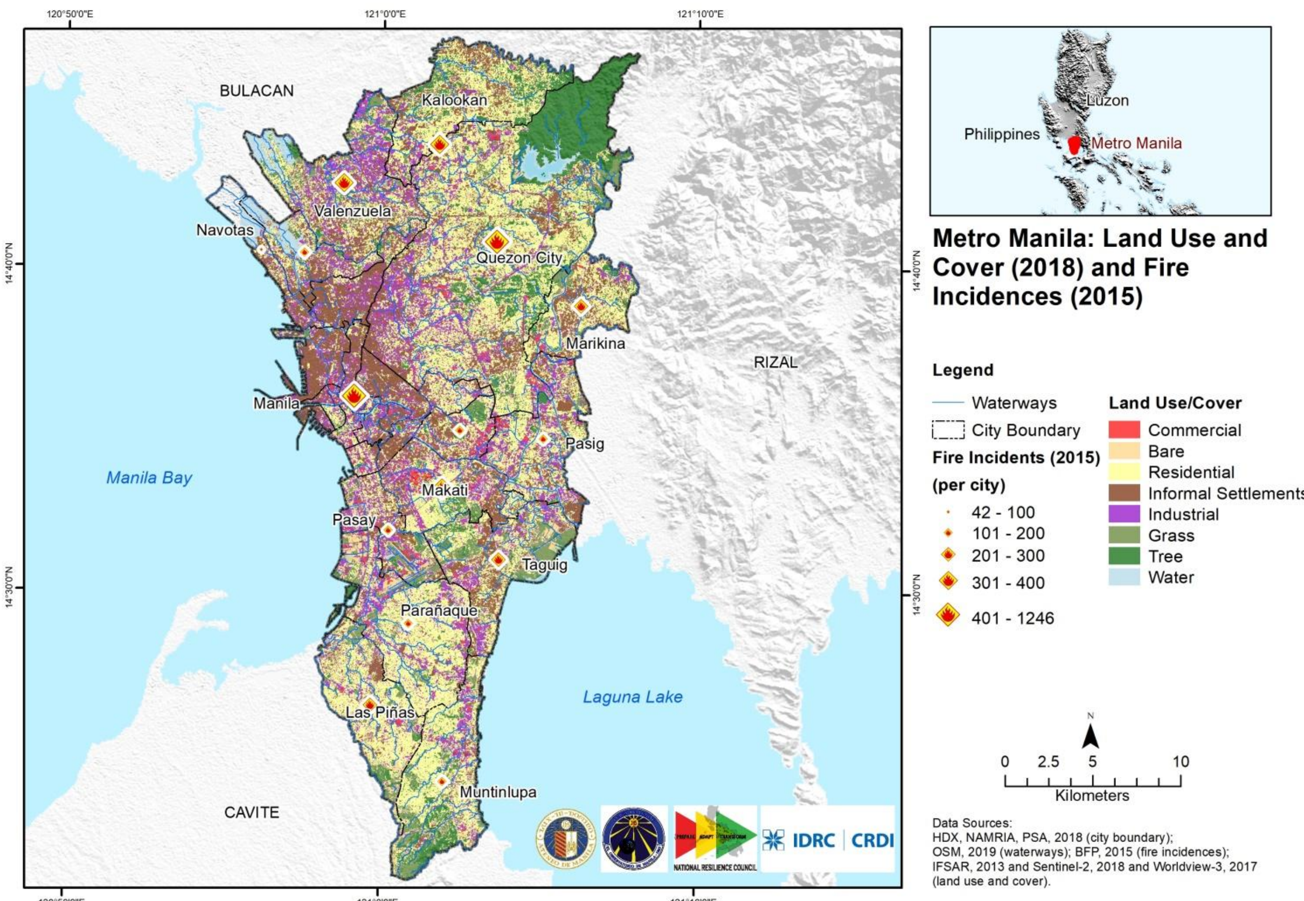

Figure 40. Land use and cover (2018) and fire incidence in 2015

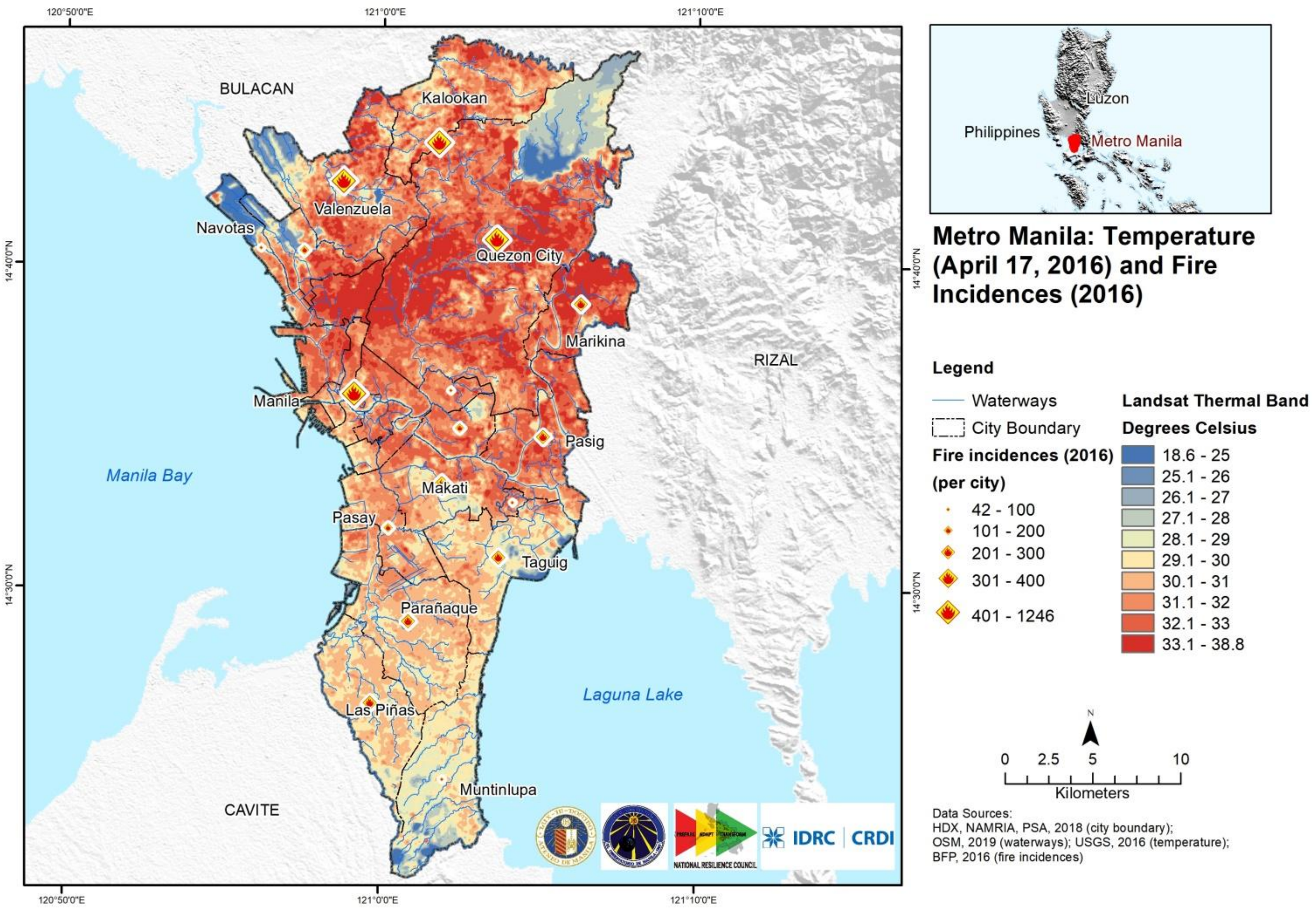

Figure 41. Fire incidence in 2016

We mapped the location of fire stations and noticed that fire stations are clustered in Manila with some scattered stations in other cities. The location of fire stations was plotted over the location of informal settlements. Most of the fire stations in Manila are less than 5 kilometers away from the informal settlements (Figure 42). However, some informal settlements in north Kalookan, and Valenzuela are more than five kilometers away from the nearest fire station. The farther one is from Manila, the sparser the fire station gets. The same pattern applies to fire hydrants. Figure 43 reveals that fire hydrants are mostly located outside a slum area and are clustered around a business district, in Manila, San Juan and Taguig.

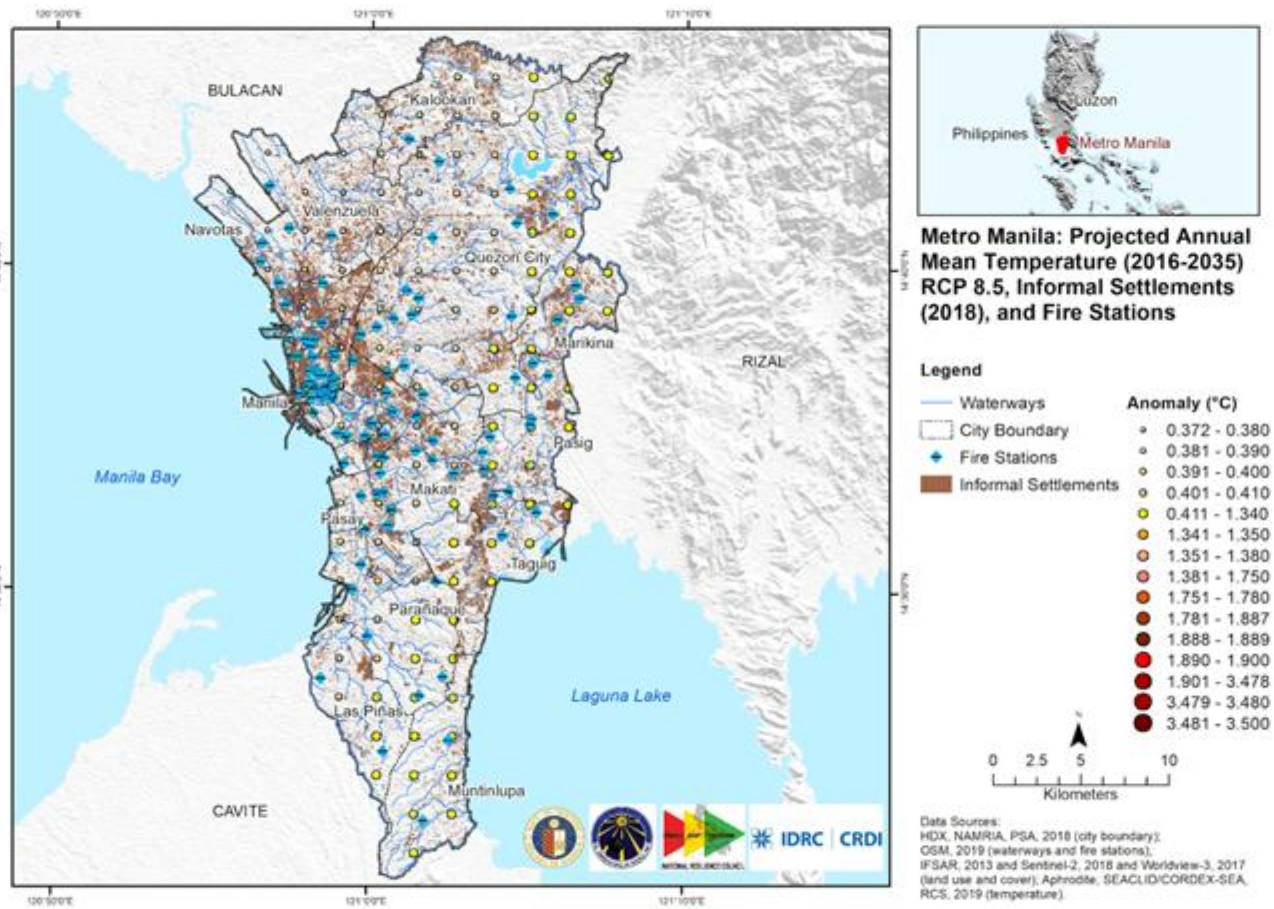

Figure 42. Projected annual mean temperature (2016-2035) RCP 8.5, informal settlements (2018) and fire stations

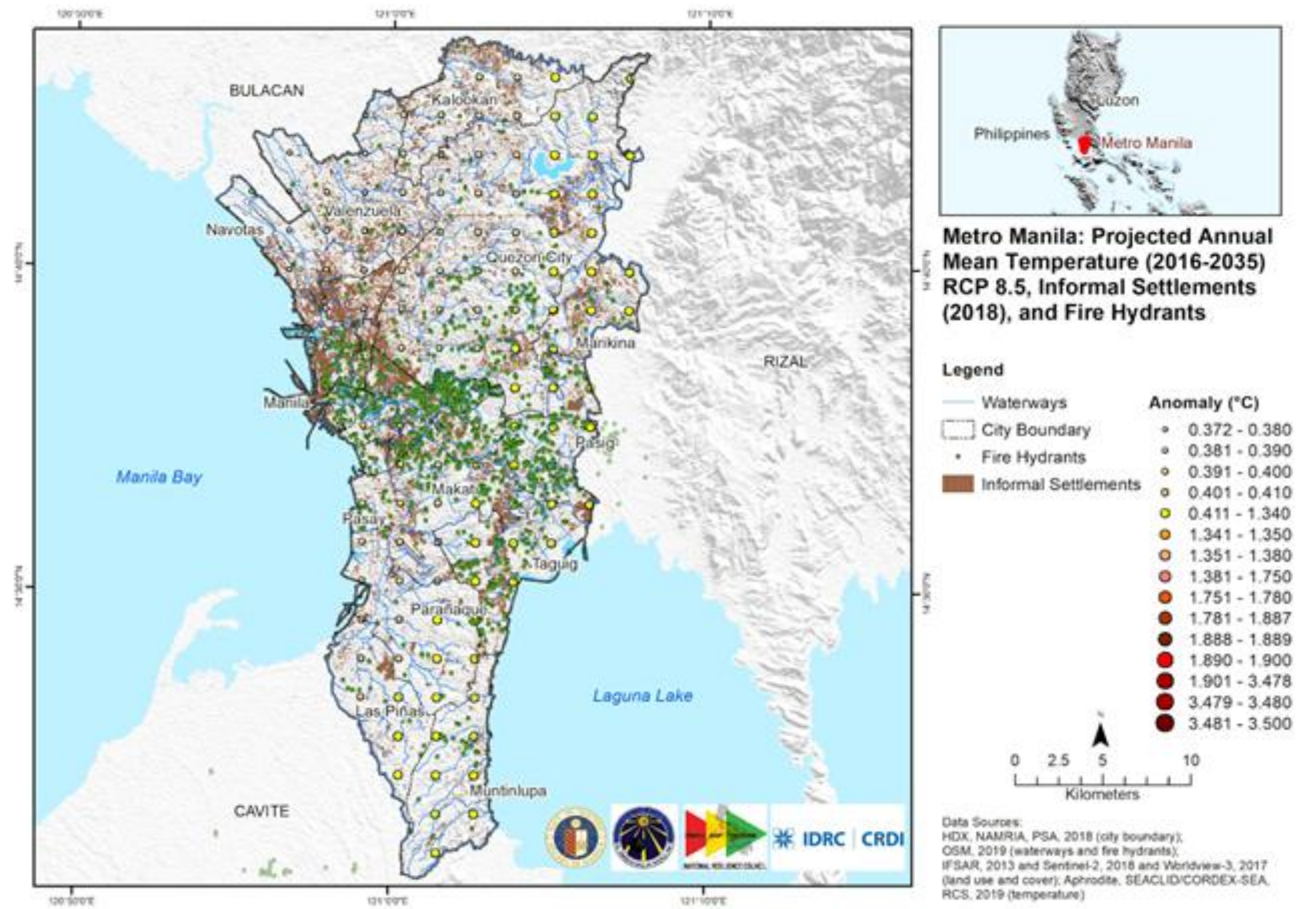

Figure 43. Projected annual mean temperature (2016-2035) RCP 8.5, informal settlements (2018), and fire hydrants

Slum areas have a compounded vulnerability to fire due to their density, hazardous electrical connections, construction materials, narrow pathways and lack of fire prevention and fire-fighting facilities. Urban slum areas are usually the densest parts of the city. A lot of people live in a limited space. In a typical slum area in Metro Manila, houses are next to each other and road access is so limited. Often times, roads are obstructed by parked vehicles, tables, chairs, stores, umbrellas, etc. (Figure 49). In times of fire incidents, these obstructions make fire truck mobility problematic. The high density of households also means that there are more households cooking, using gas, electricity, appliances, and more people smoking cigarettes and throwing cigarette butts. Cigarette butts are the second leading cause of fire in Metro Manila, according to BFP (Tupas, 2018). In short, there are more causes of fire. Slum areas also have hazardous electrical connections characterized by webbed orange and black electrical wirings leading to a collection of electric meters attached to the top of an electric post (Figure 44). A dangling broken wire is common in a slum area (Figure 45 and Figure 46). Moreover, electric connections inside each household mimic this scenario. With this description, it would be understandable how and why faulty electric connection and neglected overheating appliance are the leading causes of fires in Metro Manila. Hazardous electric connections with overheating appliances, cigarette butts, dense households cooking and houses built of light materials (Figure 48) that burn easily all compounds the vulnerability of slum areas to fire. Fire sensors, alarms and sprinklers are a luxury in slum areas as water supply can oftentimes be limited. In times of fire, the narrow pathways (Figure 47) are the only ways of escape for residents. One recommendation is the clearing of roads. It is also recommended to have fire prevention seminars and programs for the residents and for the cities to invest in emergency devices, equipment (fire stations, fire trucks, fire sensors, fire alarms, fire hydrants), training and services.

Figure 44. A web of electric wires cover the walls of these housing units

Figure 45. Dangling electric wires along the road of a slum area in Commonwealth, Quezon City

Figure 46. Electric meters on top of posts

Figure 47. Narrow pathways in a slum area in Baseco, Manila.

Figure 48. Houses in Quezon City built of light materials.

Figure 49. Narrow streets with varied road obstructions

Rising temperature and water resources and supply

Normally, as temperature rises, humans need more water for hydration, sanitation, and other activities. Water becomes more important during hot dry summer days. The higher demand for water during summer months becomes more difficult to meet due to challenges in supplying affordable water for cities (Porio, et al., 2019). This problem puts greater pressure on the population under poverty as water prices surge (Porio, et al., 2019).

We mapped the projected annual temperature anomaly over the informal settlements and water sources in Metro Manila (Figure 50). Overlay analysis show that the cities that are going to experience greater temperature increases especially in the mid and late 21st century like Muntinlupa, Las Pinas and Paranaque are mostly relying on bottled water for drinking. Muntinlupa has less piped water connections. Bottled water could be more expensive for households but it could mean that they are not relying on water supply from water concessionaires that get water from surface water bodies like Angat Dam and La Mesa Watershed that could be more prone to drying up during hot dry seasons. The cities mentioned also have more wells that extract ground water and would not be directly affected by warmer temperatures (Figure 51). There is a clustering of wells in the north and south district of Manila. Figure 50 and Figure 51 show that the southern cities of Metro Manila relying more on bottled water for drinking are also the cities with most number of wells. This indicates an underground source of water for the southern districts. However, water level of the wells must be monitored and ground water extraction should be regulated to prevent over extraction and land subsidence.

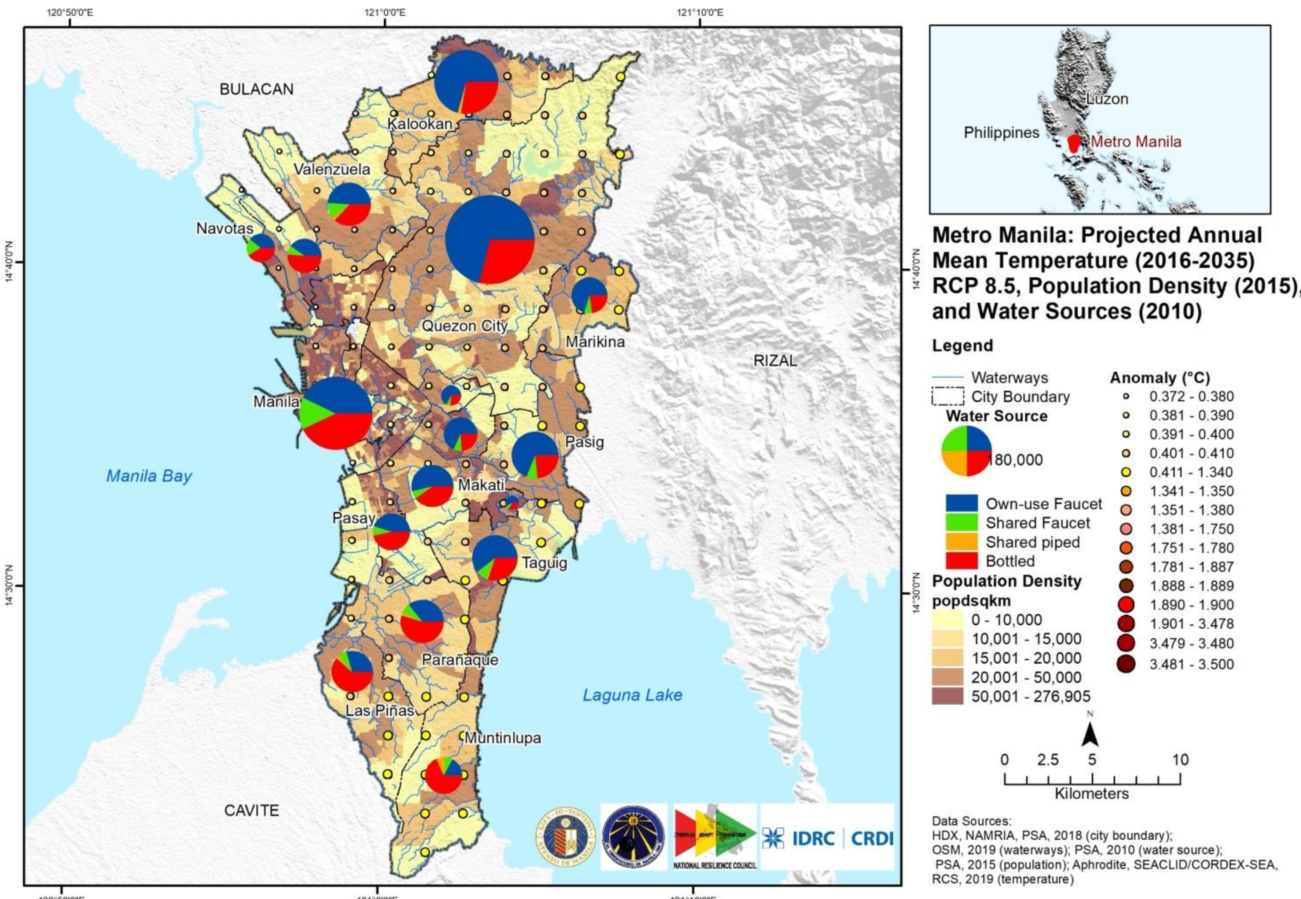

Figure 50. Projected annual mean temperature (2016-2035) RCP 8.5, population density (2015), and water sources (2010)

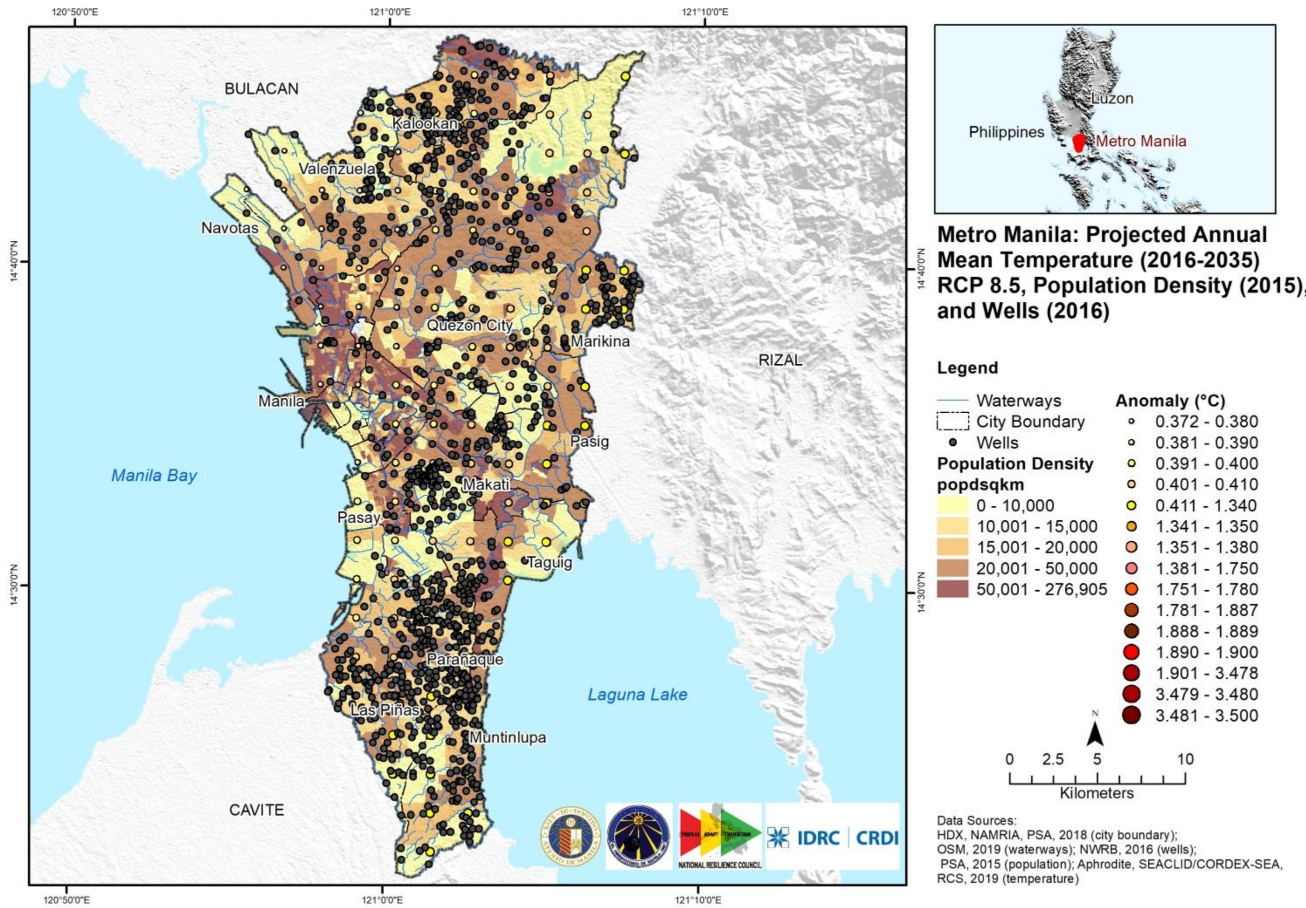

Figure 51. Projected annual mean temperature (2016-2035) RCP 8.5, population density (2015), and wells (2016)

The impact chain (Figure 52) summarizes the causes of rising global temperature and its associated impacts on the general population and land use. The most vulnerable population identified includes the elderly because they are prone to heart disease and children because they are prone to dengue. Informal settlers are also prone to fire hazards and to insufficient water supply. The critical infrastructures identified are the hospitals, fire stations, fire hydrants, water sources, water facilities and wells.

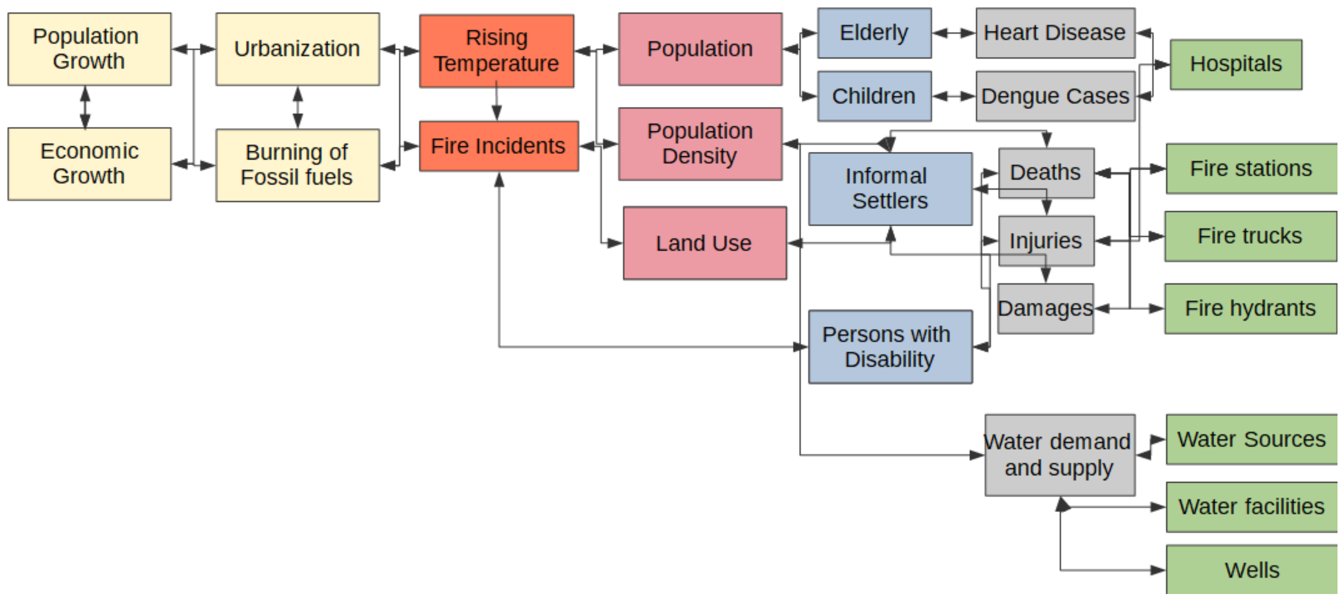

Figure 52. Impact chain on rising temperature color-coded in yellow (causes), orange (hazard and associated hazard), pink (exposed units), blue (vulnerable population), grey (impacts) and green (critical infrastructures related to the hazard)

Visualizing the spatial and temporal impacts of rainfall

Rainfall and flooding hazard

Rainfall is considered as one of the major drivers and the triggering mechanism of flooding. Thus, the increase in rainfall in three projections may produce flooding in Metro Manila given the structure and geographical location of the city. These are recognized in the series of maps below where the projected rainfall maps and 5, 25, 100-year flood hazards (Figure 53-55) are overlain with each other. Given the entire region is composed of one major catchment called the Marikina River Basin, eight smaller, river sub-basins, and between Manila Bay and Laguna de Bay, flooding may occur in coastal areas. As shown in the maps, majority of flooded areas are near Marikina, Pasig, San Juan and Tullahan rivers indicating rivers exceed their capacity, overflows and inundates urban areas. Street floods in Metro Manila do not happen everywhere but are mainly found at intersections of streets and creeks of the major rivers and topographic lows. One worst such event in Metro Manila which indicates the relationship of these hazards occurred during the weekend of August 11-12, 2018 when Tropical Storm Karding (international name Yagi) brought excessive monsoon rains and submerged large areas of Metro Manila ("Philippines," n.d.).

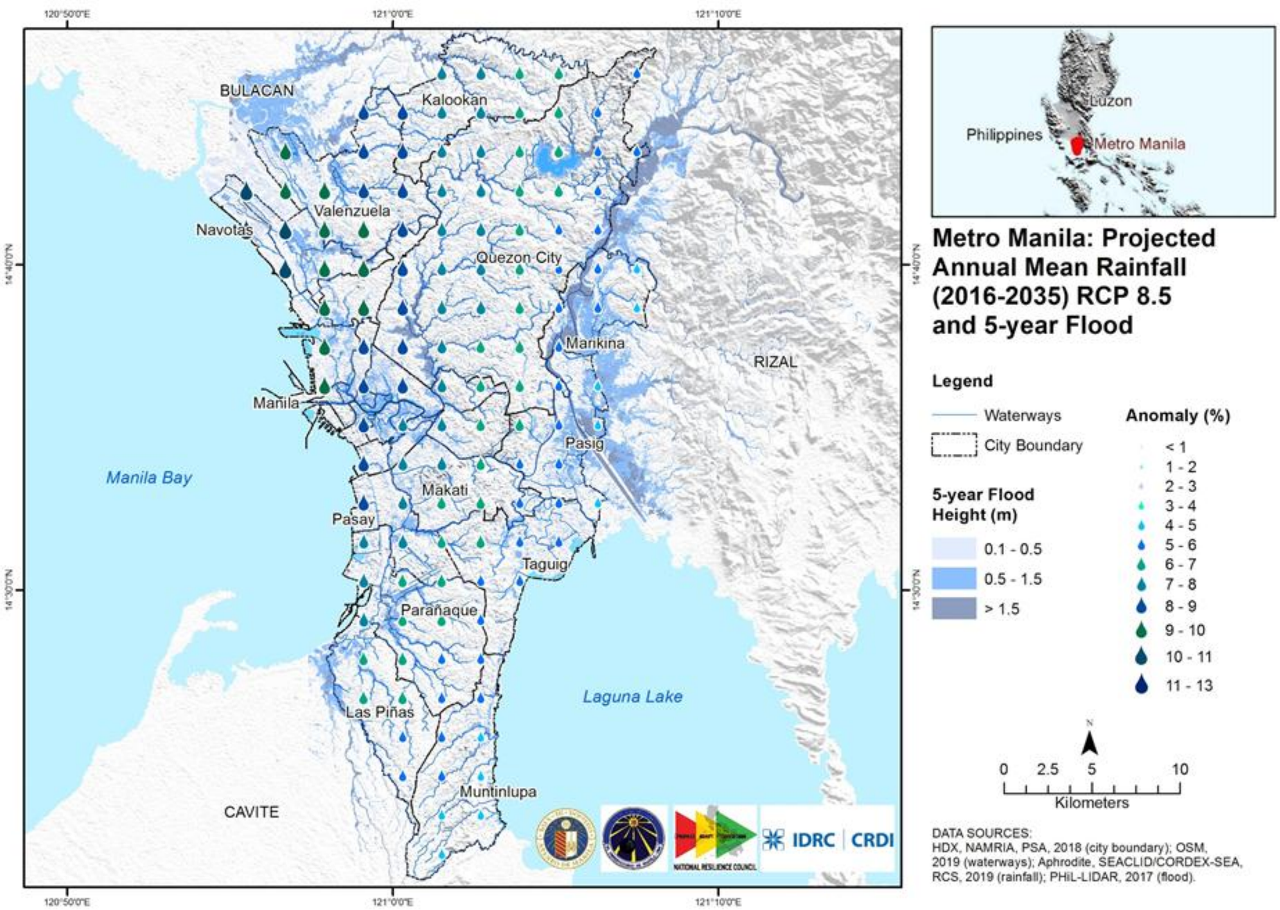

Figure 53. Projected Annual Mean Rainfall (2016-2035) RCP 8.5 and 5-year Flood

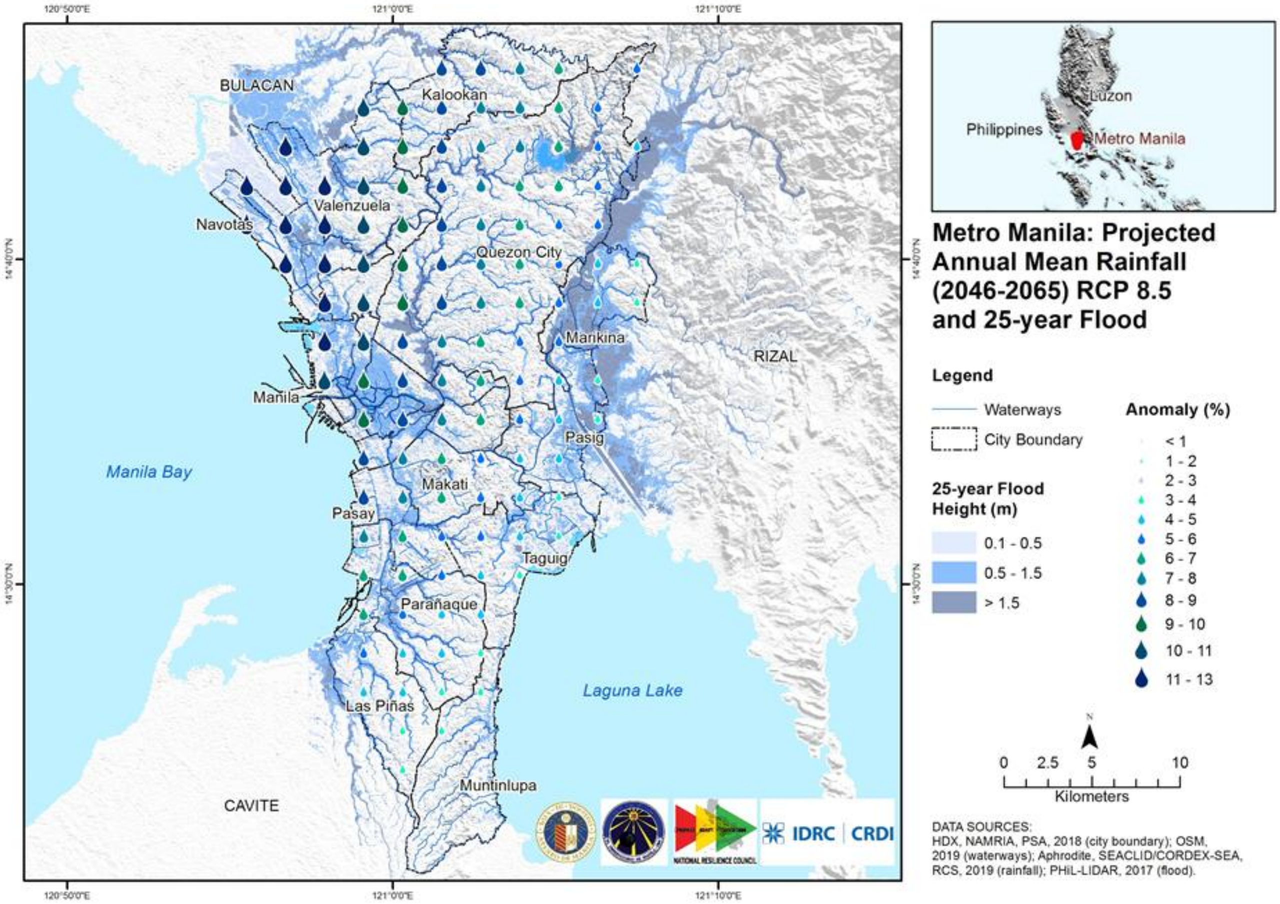

Figure 54. Projected Annual Mean Rainfall (2046-2065) RCP 8.5 and 25-year Flood

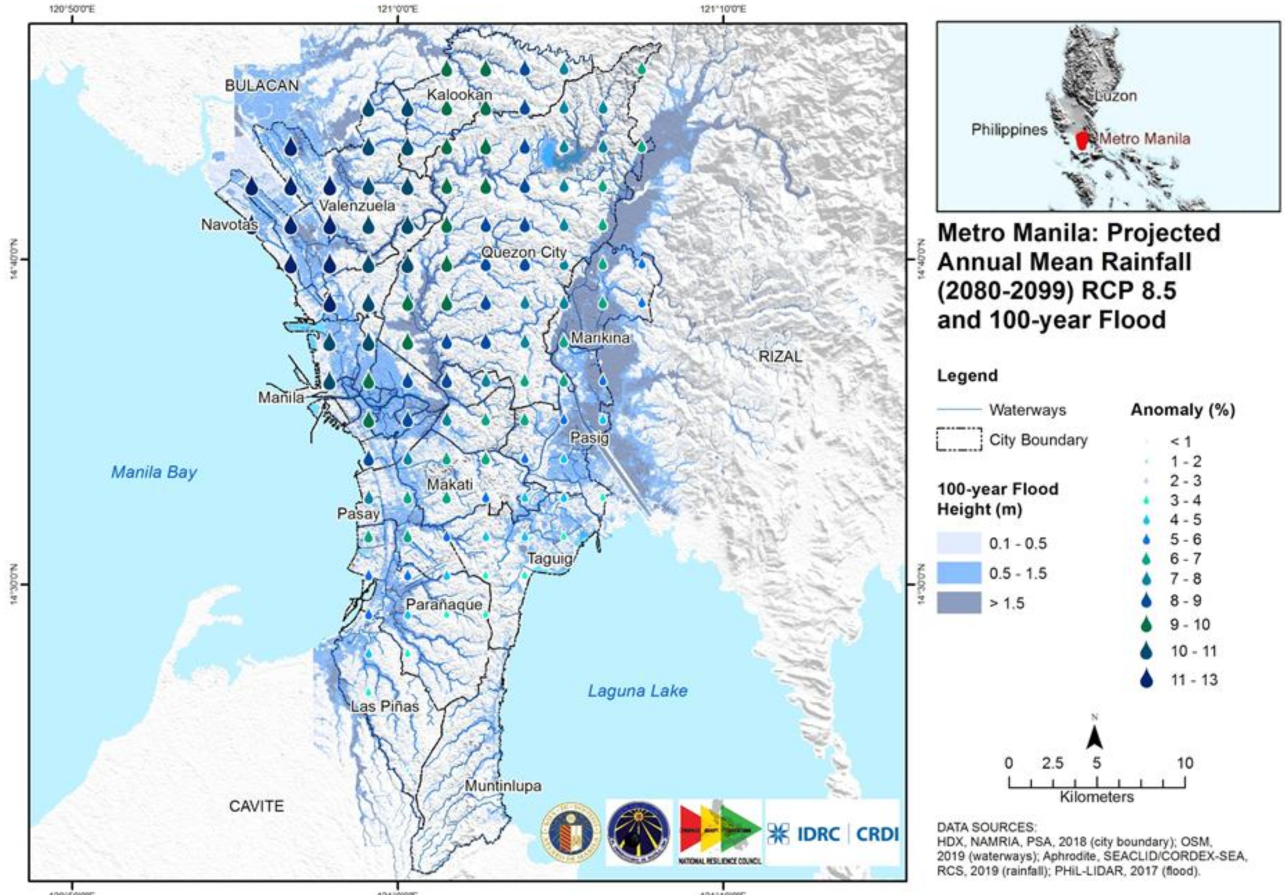

Figure 55. Projected Annual Mean Rainfall (2080-2099) RCP 8.5 and 100-year Flood

Rainfall and Water Resources

Water supply in Metro Manila is entirely reliant on a single source of raw water, the Angat, Reservoir situated approximately 30 kilometers northeast of Manila. It delivers around 98% of the region's water supply which is 4 million cubic meters per day. The remaining 2% is from deep wells. In addition to two private concessionaires regulated by the Metropolitan Waterworks and Sewerage System (MWSS) Regulatory Office, several small private sources supply water to local households (Palacios, n.d.). Common sources of drinking water in the region are the following:

Sources of Drinking Water

1. Shared or Own Use, Faucet, Community Water System - water is obtained from a faucet inside the house/yard or another household directly connected to a water pipeline from the community water system such as the MWSS or the local water network system. Water system with deep well as source is under this category as long as it subscribes to a community water system;
2. Shared or Own Use, Tubed/Piped Well - water is taken from a tubed/piped well which is at least 100 feet (5 pieces of 20 feet pipes) or 30 meters deep, for private or public use
3. Peddler - water is obtained from neither of the above sources. Included in this item are bottled water like mineral water, water bought in drums, pails, etc. (peddler).
4. Bottled water - distilled water, mineral water, or spring water packaged in plastic or glass water bottles.

Apart from providing equitable access to clean, potable and affordable water, MWSS is tasked to protect, secure, optimize and expand our water sources, watersheds and infrastructure. Given Manila's reliance on surface water, protecting the watersheds that feed into the rivers and reservoirs is essential to its operations. Population is linked with demand in water as well as indirectly linked to flooding. Population growth increases both the likelihood and the potential impact of flooding and demand and quality of water because of urbanization and increasing the pressure on sewer systems (Perrow, 2007). Dewan in 2015 stated that rapid population growth is producing an increased pressure in settlements, highways and roads construction and agricultural areas leading to problems in flooding. Because of these, the discharge of domestic and industrial wastewater and runoff has caused extensive pollution of the receiving water-bodies.

According to Dayrit (2016), water is becoming a critical resource in Manila. This is because of the increased pressure on freshwater resources by the rapid growth of population, increasing economic development and improvement of living standards. Although the region is endowed with abundant water resources, usable water is becoming limited due to pollution and contamination. All rivers in Metro Manila are considered biologically dead. The runoff during floods flushes out contaminants like effluents, traffic emissions, street refuse and uncollected garbage that flows into the rivers and groundwater aquifers.

Overlaying the rainfall, population and water sources, results showed that majority of the households in almost the entire cities use faucet as a source of drinking water (Figure 56). More households in **Navotas, Las Piñas City, Muntinlupa City and Paranaque City** uses bottled water than faucet as drinking source. Peddler is also used by fewer households and a lesser amount of households take their water from tubed or piped well. The map also shows that **Barangay 176, Commonwealth, Batasan Hills, Pinagbuhatan and Payatas** are the most populated barangays. Their proximity to rivers increase the chances of rise in water levels during wet season leading to flooding especially as well as contamination of their drinking water from faucets can be a risk. High population densities (Figure 57) observed around the City of Manila can also produce an increase pressure in settlements, highways and roads construction leading to problems in wastewater, flood and sewage problem. Because of these, the discharge of domestic and industrial wastewater and runoff can cause extensive pollution of the receiving water-bodies leading to risk in quality and demand of drinking water.

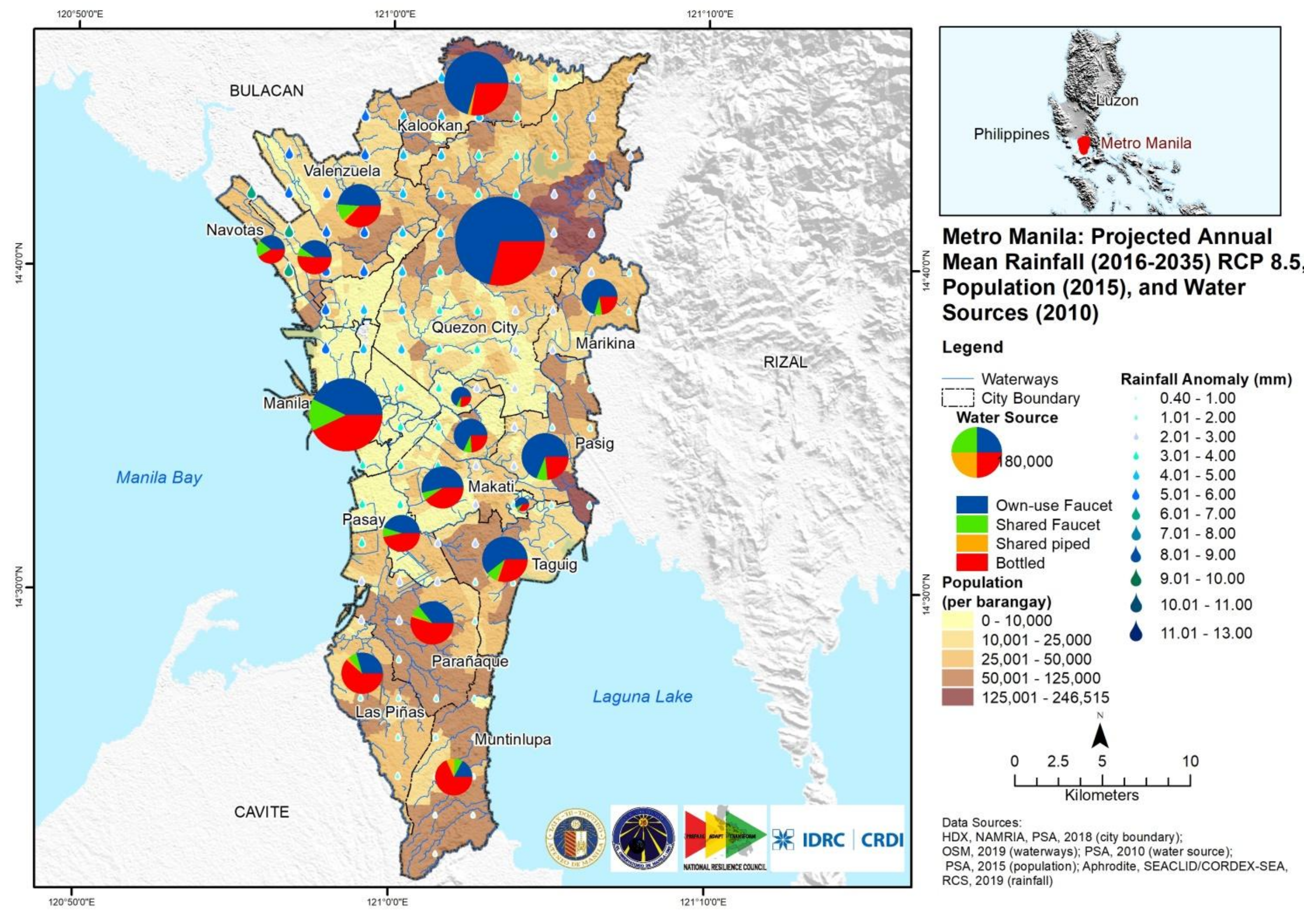

Figure 56. Projected Annual Mean Rainfall (2016-2035) RCP 8.5, Population (2015) and Water Sources (2015)

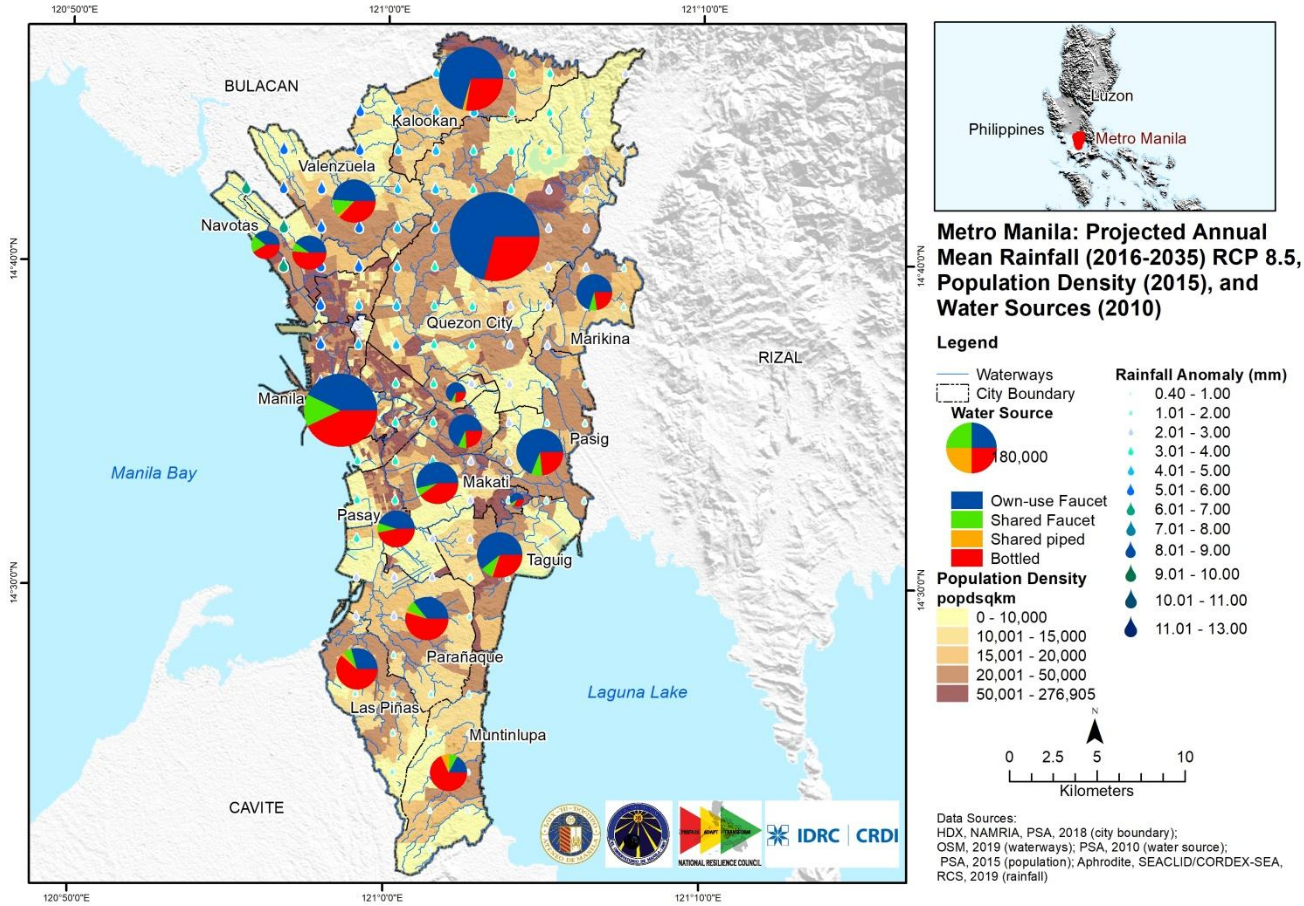

Figure 57. Projected Annual Mean Rainfall (2016-2035) RCP 8.5, Population Density (2015) and Water Sources (2015)

<u>Rainfall and Land Cover</u>

Land cover (the physical characteristics of the land surface, including grain crops, trees, or concrete) change plays an important role in influencing the hydrologic response of watersheds in multiple ways. It is considered directly linked to changes in the hydrologic components in a watershed, such as rainfall, evapotranspiration, surface runoff, groundwater, and stream flow. Land use in Metro Manila is categorized as commercial, bare soil, formal residential, informal settlements, industrial, grass, tree, and water as shown in Figure 58. Land cover change processes may have contradictory impacts on the formation of runoff. Forest expansion mitigates runoff (e.g., due to retention increase) while urbanization increases it (e.g.,due to the increase of impervious areas) (Tellman et al. 2015). It is expected for the region to have a high runoff that is leading to flooding for almost all areas are impervious. Only a small part of Metro Manila are covered with grass (5.4%), tree (11.6%) and water (4.1%). The increase in rainfall can be a hazard to the informal settlements living near the coastal areas of Manila. As rainwater runs off the impervious surfaces of the region, land use determines the pollutants that are carried off. Commercial effluents, domestic and industrial wastewater may pollute nearby bodies of water. A considerable number of observational studies show that urban areas cause changes in rainfall, and affect local or even regional weather and climate (Pielke et al., 2007).

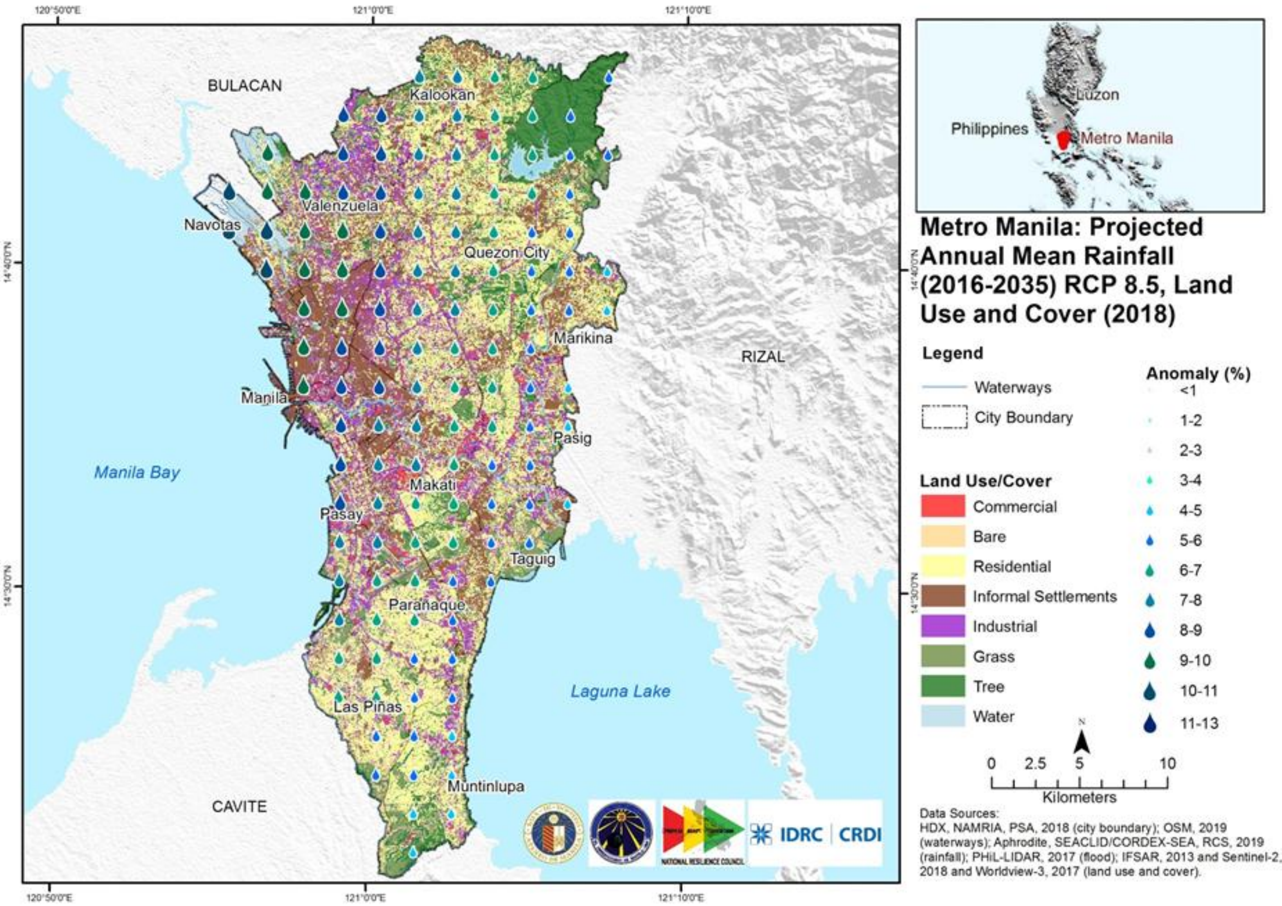

Figure 58. Projected Annual Mean Rainfall (2016-2035) RCP 8.5, land Use and Cover (2018)

Visualizing the Impacts of Flooding

Impact on different age groups

"The lives of people in metropolitan Manila – especially the poor, women and children – are severely affected by exposure to frequent cyclones and flooding induced by heavy rain. The floods disrupt business and commercial activities, causing unnecessary economic costs," said Supee Teravaninthorn, Director General for Investment Operations, AIIB. "Investing in sustainable infrastructure is a key priority for AIIB and we feel this project is a great fit for our first investment in the Philippines." In the series of map below, population and densities on different ages, flood hazard and infrastructures like hospitals and schools are overlaid because of this correlation.

The study of Nguyen and James (2013) documented children as the most vulnerable individuals during flood events. Deaths of children were mostly reported in the highest and moderate flood prone areas, and very few reports in the low flood prone region. Figure 65 shows that children constitutes approximately a third of Manila's population. As mentioned before, most children are located in barangays of Kalookan, Quezon City and Pasig City. On the other hand, high level of hazard in the figures observed in Quezon City where 31% of their submerged areas are >1km. This means that flood-prone areas in Quezon City have high children population. Therefore, places with social health care and related infrastructure facilities (Figure 66) play an important role in quality of life in those areas.

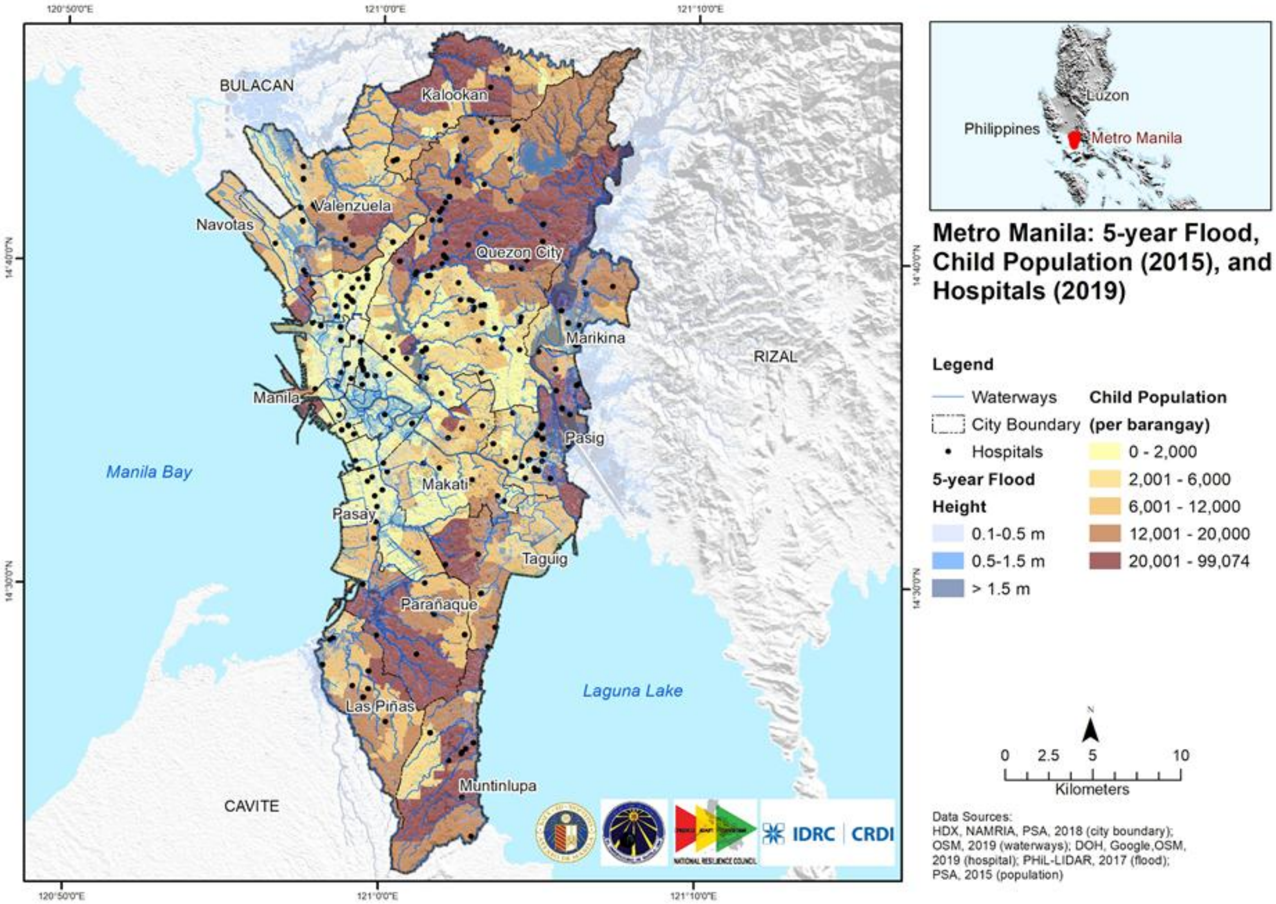

Figure 65. 5-year Flood, Child Population (2015), and Hospitals (2019)

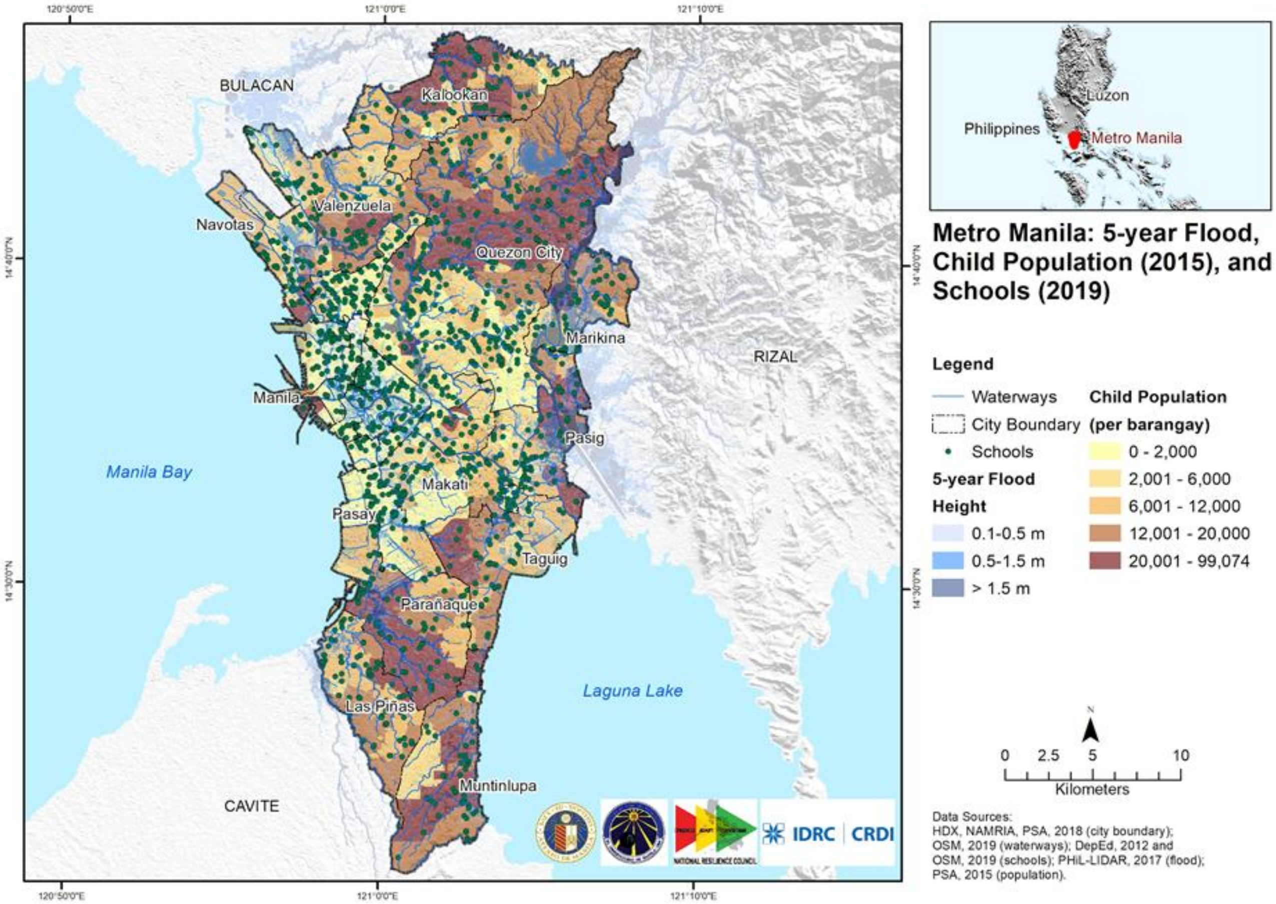

Figure 66. 5-year Flood, Child Population (2015), and Schools (2019)

The deaths of children, though may not be directly caused by flood-related diseases, but are mostly connected to drowning due to lack of supervision by guardians (Pornasdoro, Silva, Munárriz, Estepa, & Capaque, 2014). An increase in area with flood hazard is observed in 25-year flood maps (Figures 67a and 67b) compared to 5-year hazard map. Flood extent in Quezon City increases to 48.63 km^2 followed by Pasig City with 32 km^2 coverage. Quezon City has the widest flood extent with 48km^2 in 100-year flood map (Figure 68a and 68b). It exhibits the highest area coverage among the 5-year and 25-year flood hazard maps. Still, the high population of children and flood-prone areas in Quezon City and Pasig City make it vulnerable for young ones.

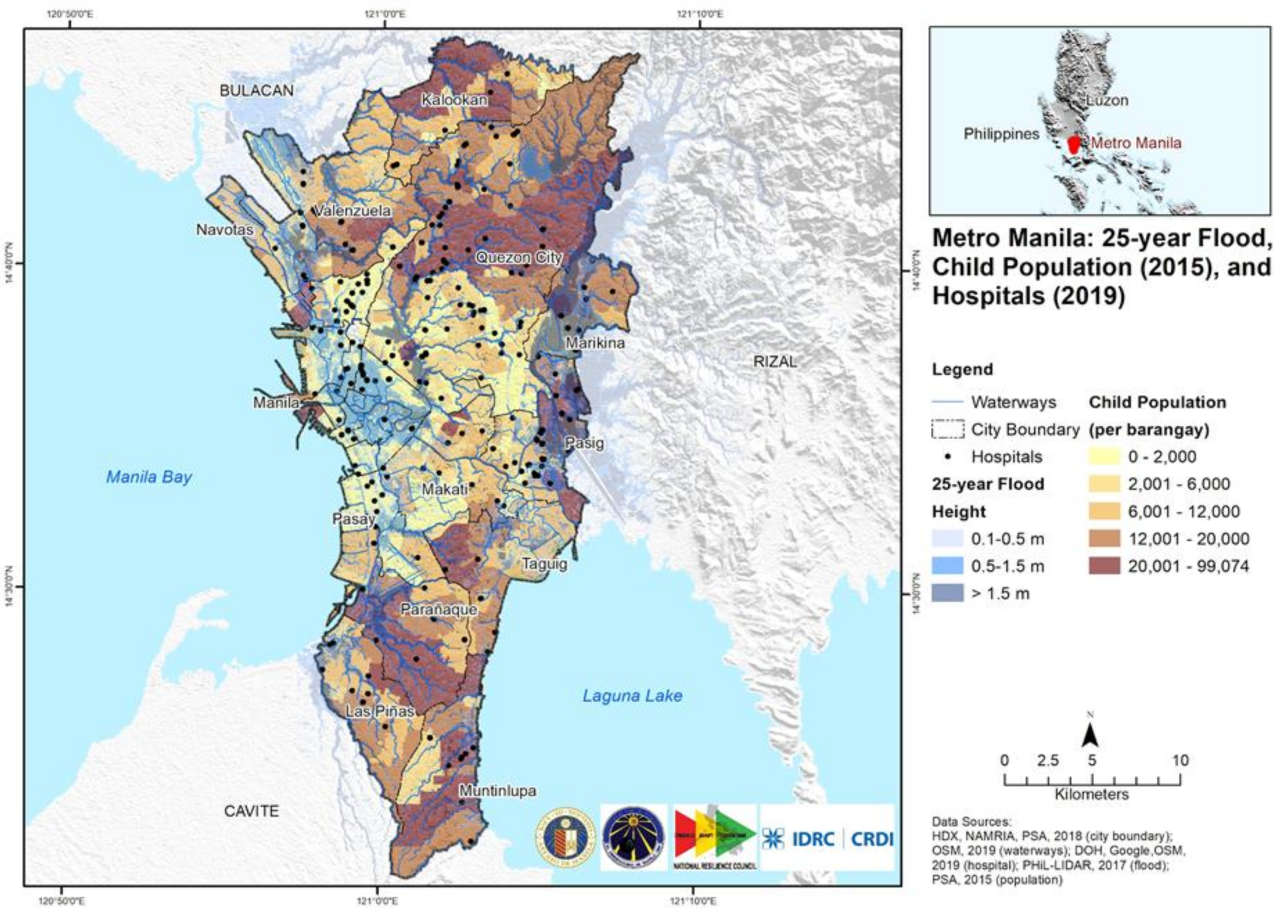

Figure 67a. 25-year Flood, Child Population (2015), and Hospitals (2019)

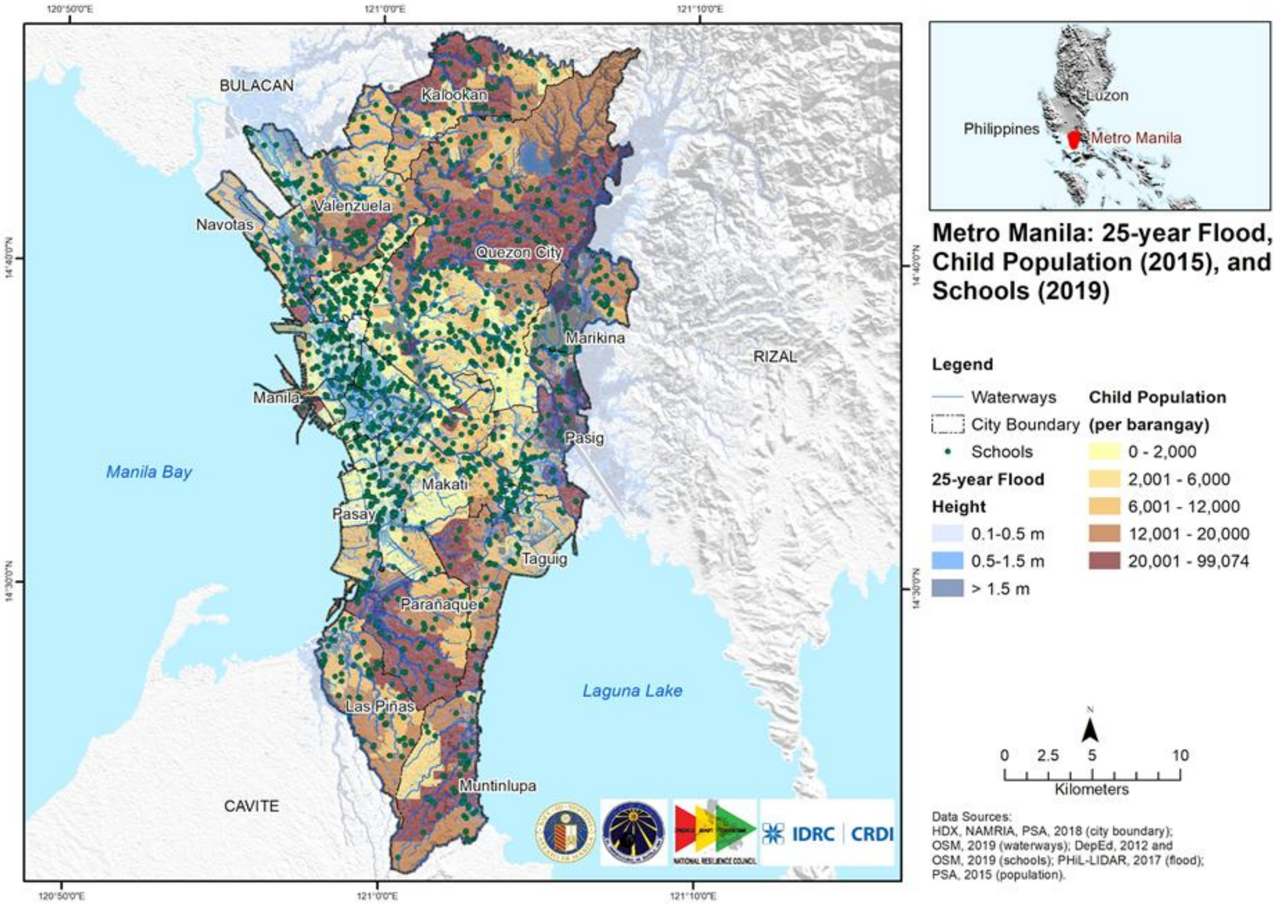

Figure 67b. 25-year Flood, Child Population (2015), and Schools (2019)

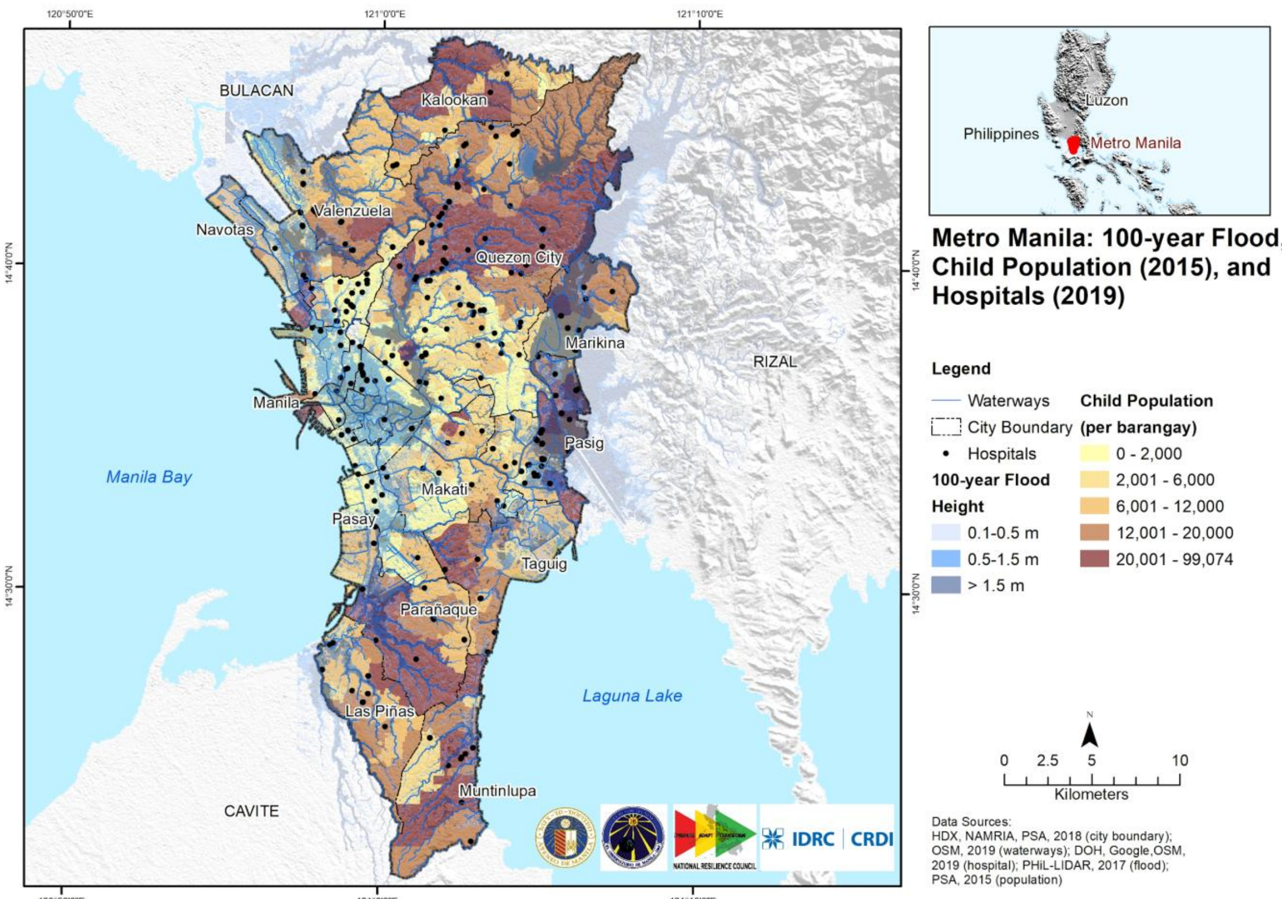

Figure 68a. 100-year Flood, Child Population (2015), and Hospitals (2019)

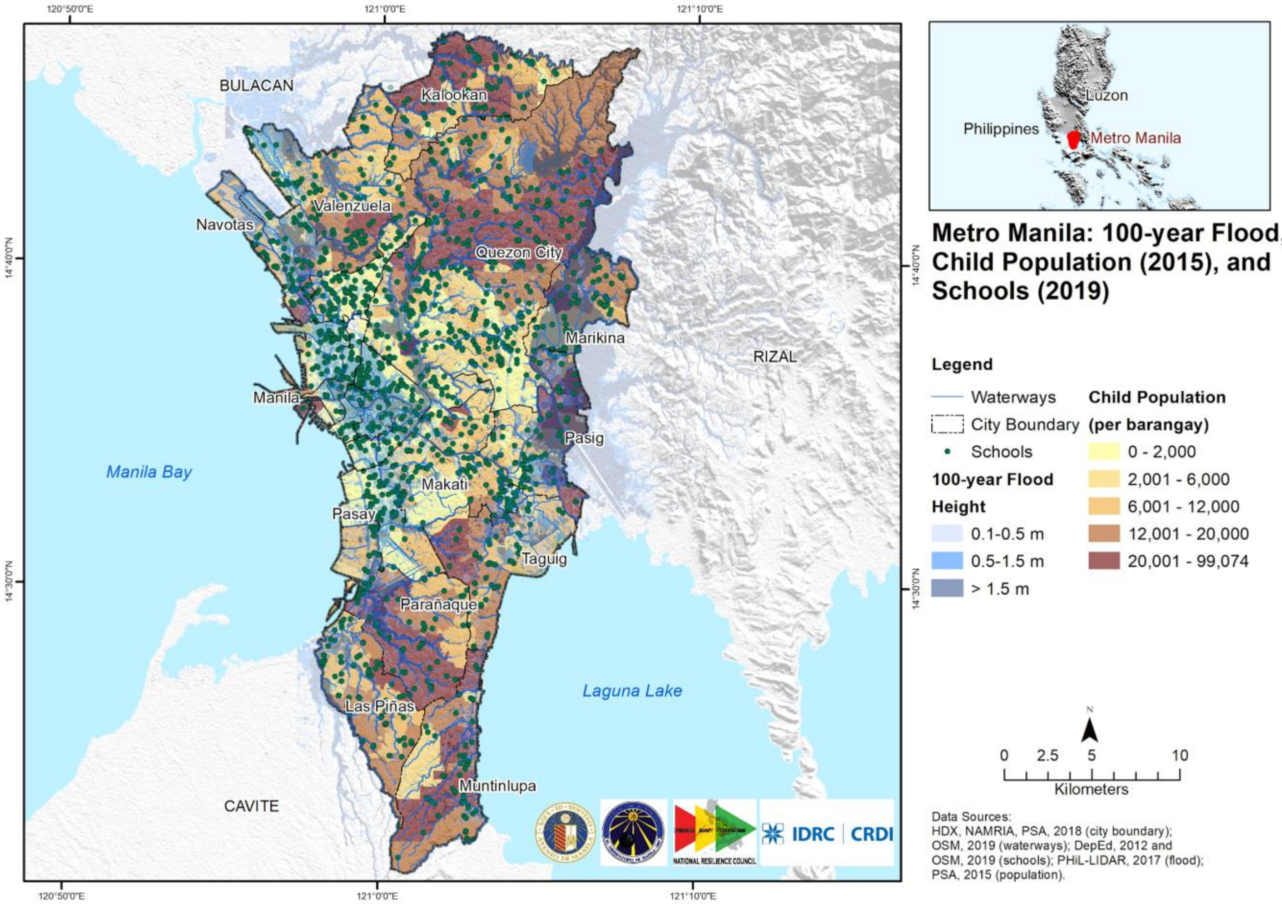

Figure 68b. 100-year Flood, Child Population (2015), and Schools (2019)

Figure 69 shows that majority of flooded areas are near Marikina, Pasig, San Juan and Tullahan rivers indicating rivers exceed their capacity, overflows and inundates urban areas. Also shown in 25yr and 100yr flood hazard maps (Figures 70 and 71), the flood coverage widen with respect to the rivers. It can be also observed that densities are high near Pasig River, esteros in Pasay, San Juan River and Marikina River. High population density also be observed in Quezon City, Pasay City and City of Manila like Malate, Tondo, Pandacan, Santa Ana, Santa Cruz and Paco. The damages caused by flood events can lead to substantial losses of such infrastructure in these areas (Kubai, et. al., 2009). No class advisories during floods and typhoons also indicate income, time and information losses. Flood damage to hospitals, schools and universities also poses unexpected financial worries for parents, relatives and the staff (Cutter et. al., 2003). These infrastructures must have strong foundations and structural materials. Hospitals and other health facilities should be strategically located and have strong structural forms for catering the needs during and after flood events.

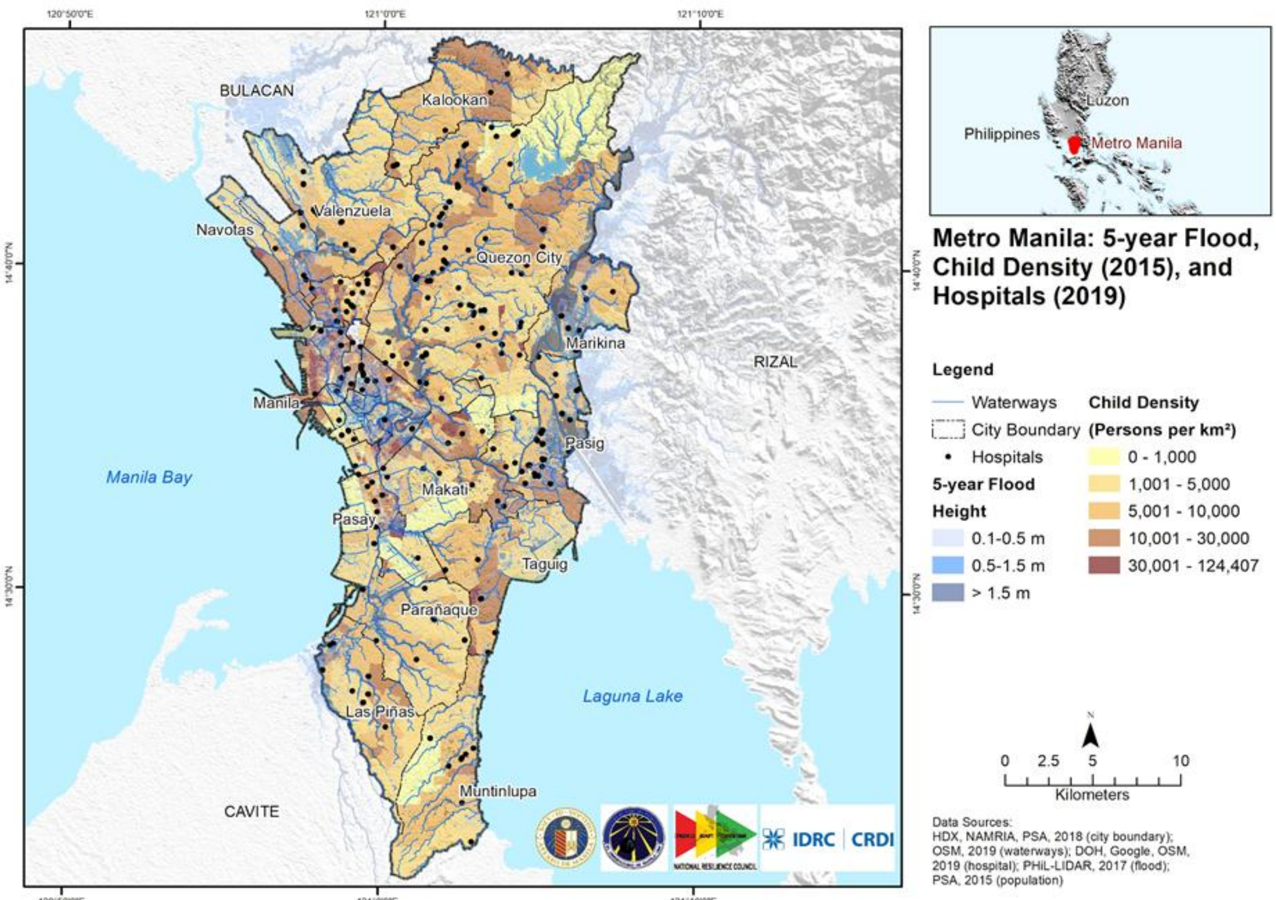

Figure 69a. 5-year Flood, Child Density (2015), and Hospitals (2019)

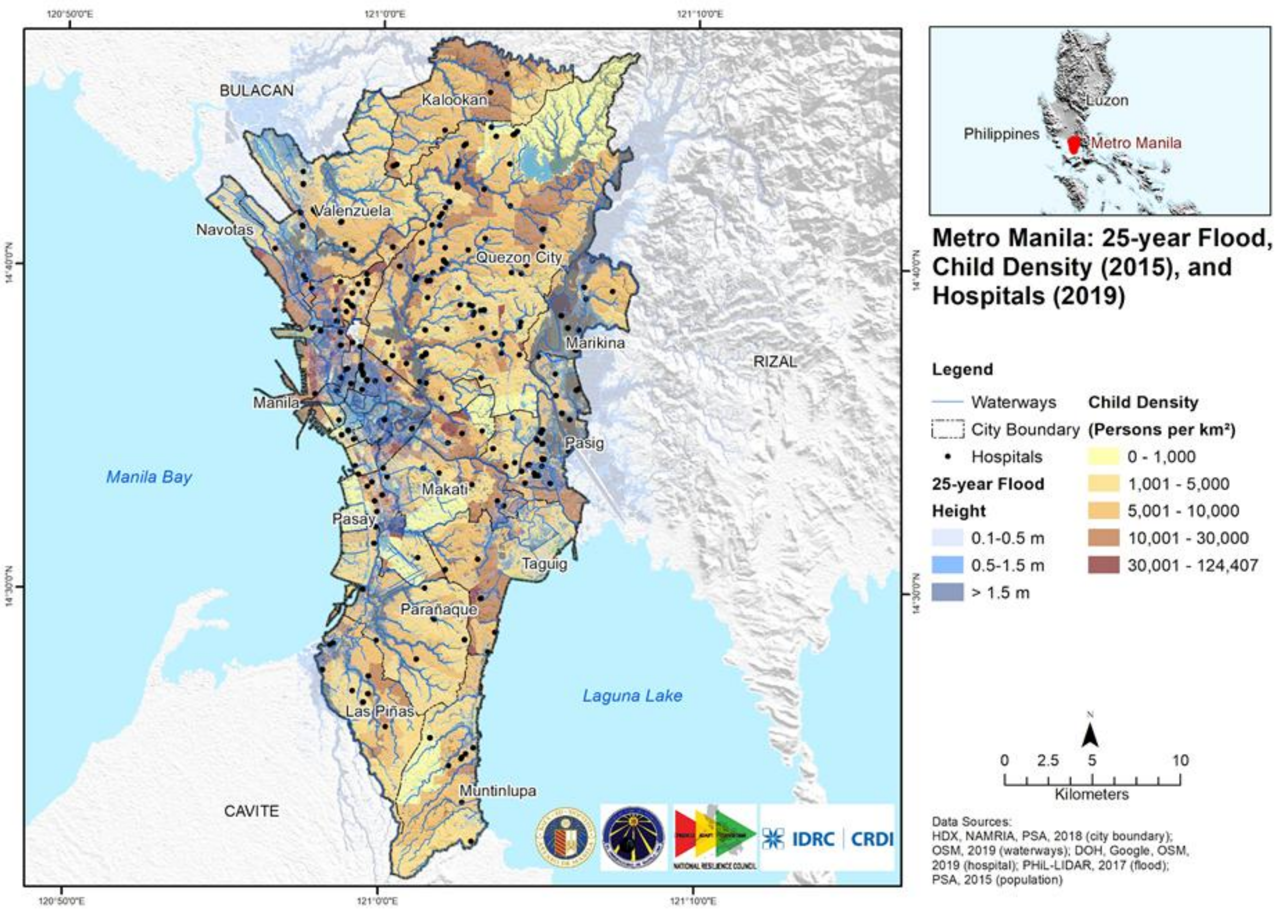

Figure 70. 25-year Flood, Child Density (2015), and Hospitals (2019)

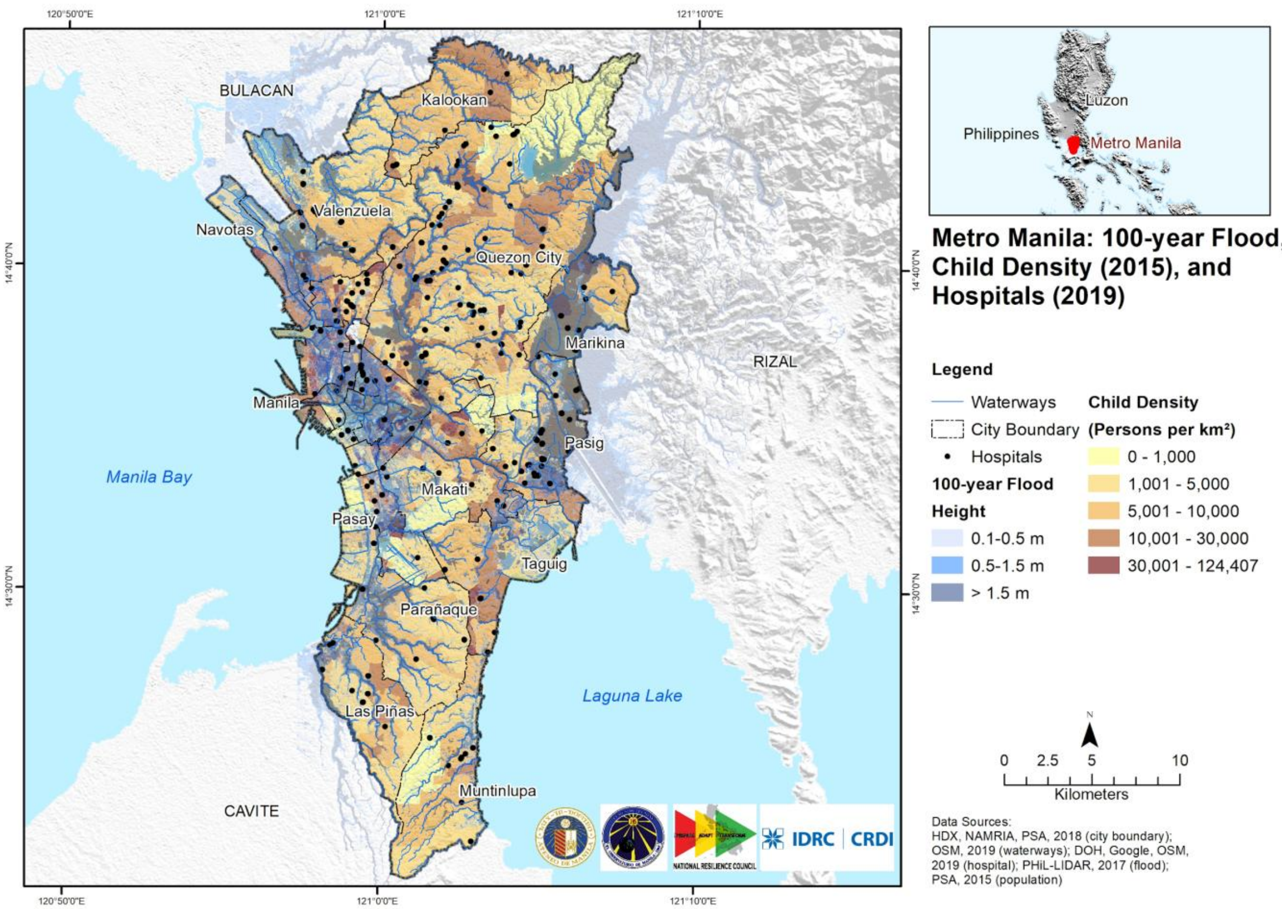

Figure 71. 100-year Flood, Child Density (2015), and Hospitals (2019)

Schools must also be strategically located throughout the region and must have strong structural foundations. Over the past decades, recurrent flooding associated with typhoons, monsoons, and heavy rains, have shown the devastating impacts in the education sector, particularly in Metro Manila. These events have caused damages to school facilities, suspension of classes, destruction of learning materials, and deteriorating learning environments. In undamaged schools, school activities were still interrupted because they are used shelters for evacuees and clean-up efforts after flooding. Figures 72-74 show maps overlaid with flood hazards, child density and schools. It can be observed that schools which are located in flood-prone areas must be given attention.

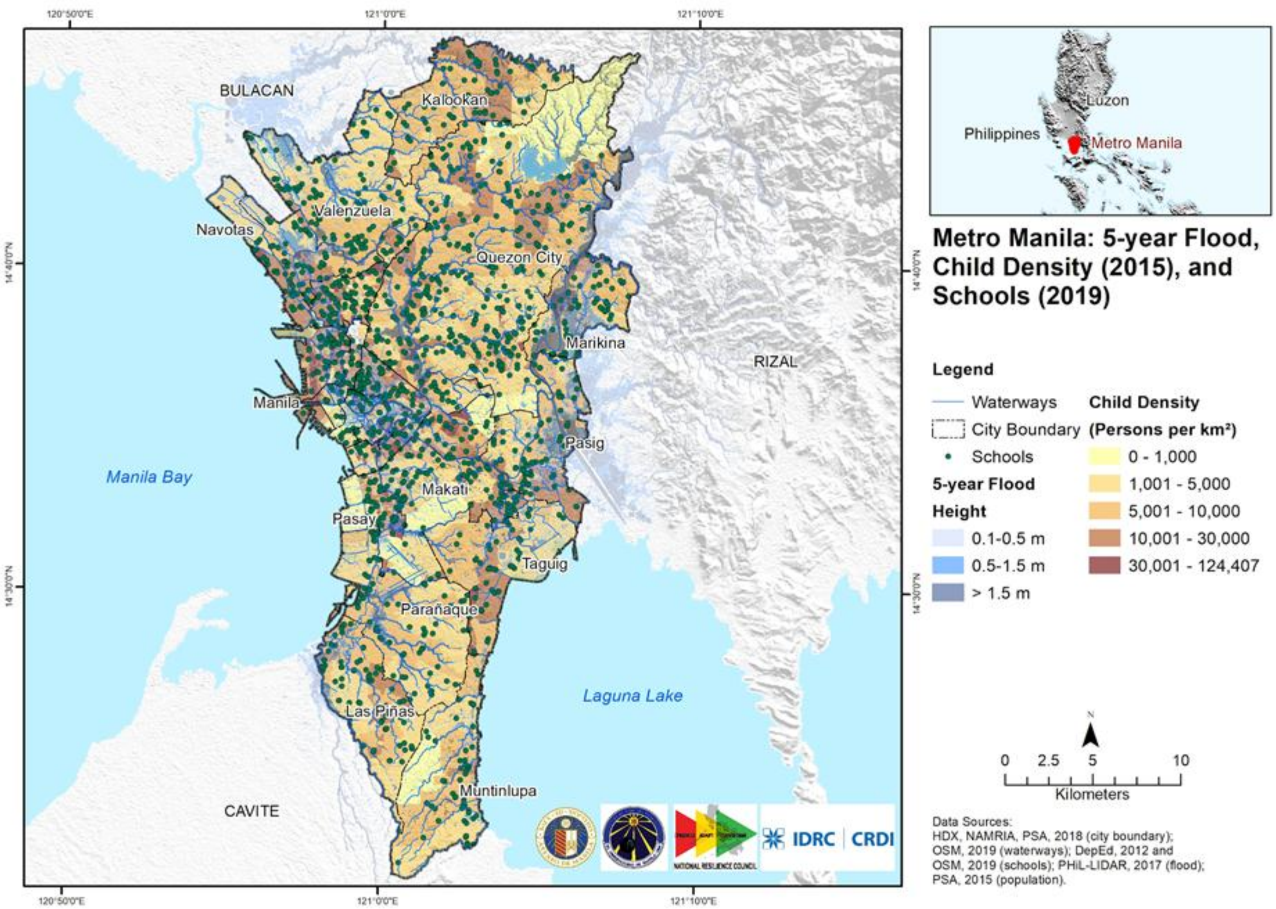

Figure 72. 5-year Flood, Child Density (2015), and Schools (2019)

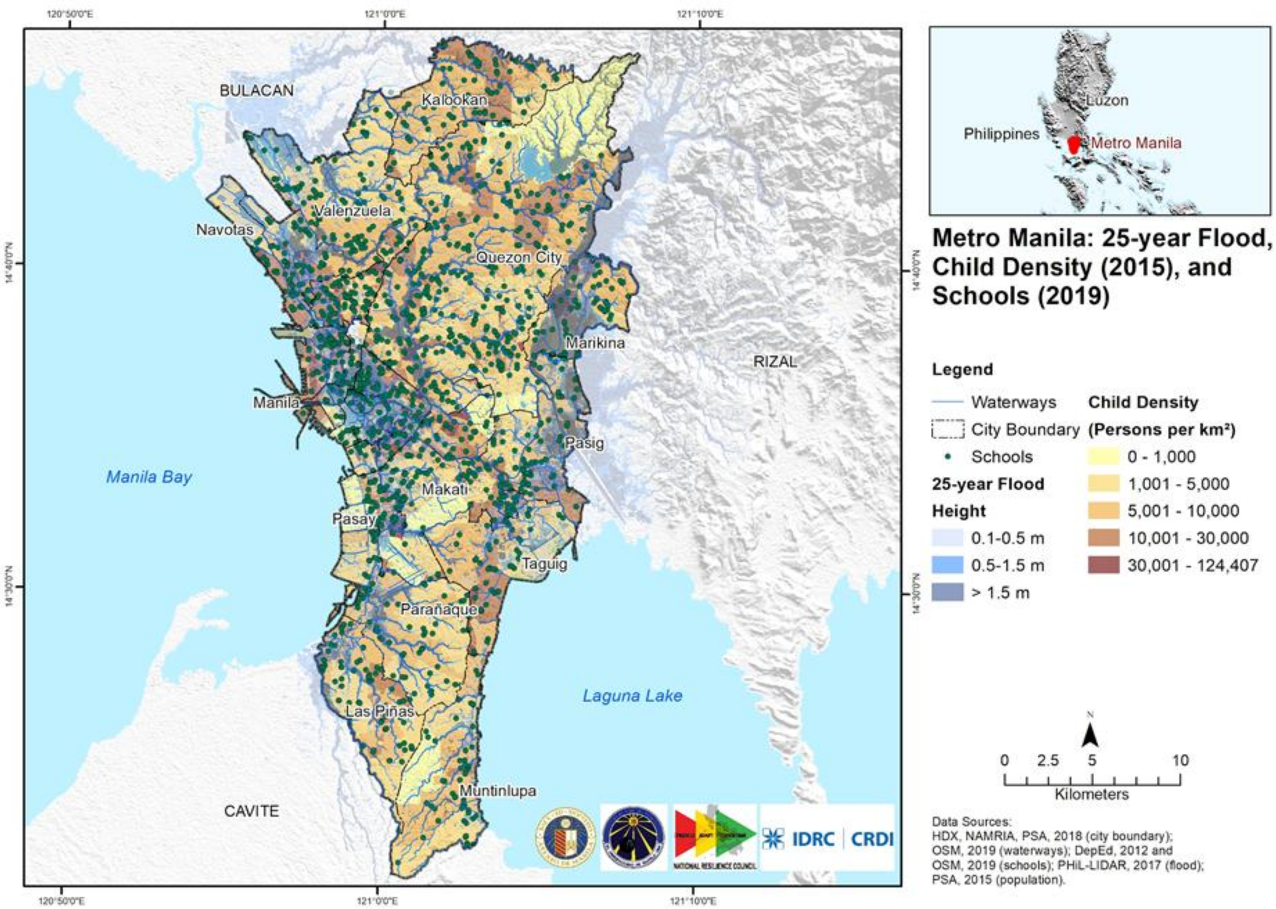

Figure 73. 25-year Flood, Child Density (2015), and Schools (2019)

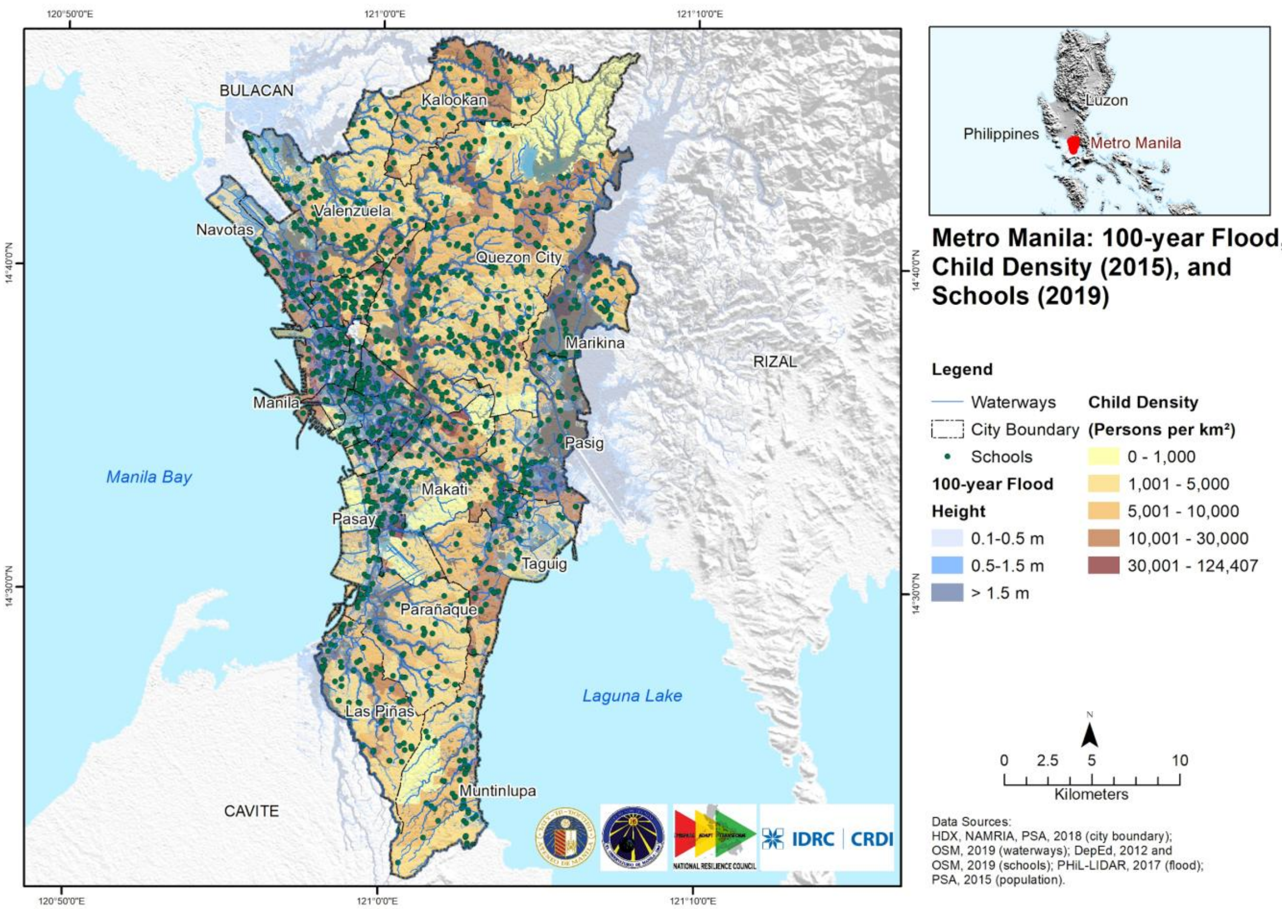

Figure 74. 100-year Flood, Child Density (2015), and Schools (2019)

Youth population per area is highest in Malate, Tondo and Pandacan (Figure 75-77). It can be also observed that densities are high near San Juan River and Marikina River which are areas in Quezon City, Pasay City and City of Manila like Malate, Tondo, Pandacan, Santa Ana, Santa Cruz and Paco. Flood events affect the youth in Manila since these are the same areas where University-Belt is located. Colleges and universities in the city nestle here. Flood damage to hospitals, schools and universities also poses unexpected financial worries for parents, relatives and the staff (Cutter et. al., 2003). These flood events have resulted on damages to school facilities, suspension of classes and destruction of school materials.

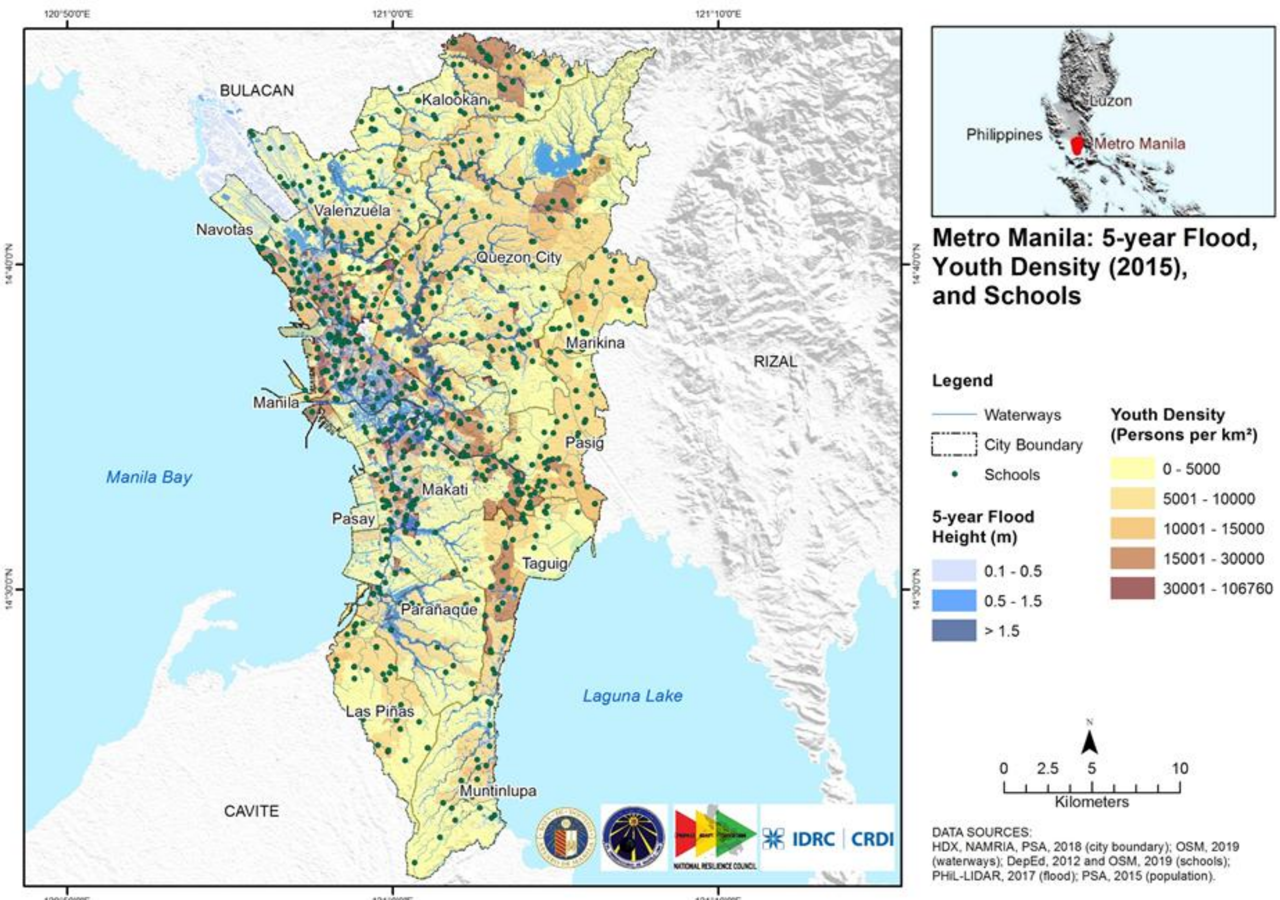

Figure 75. 5-year Flood, Youth Density (2015), and Schools (2019)

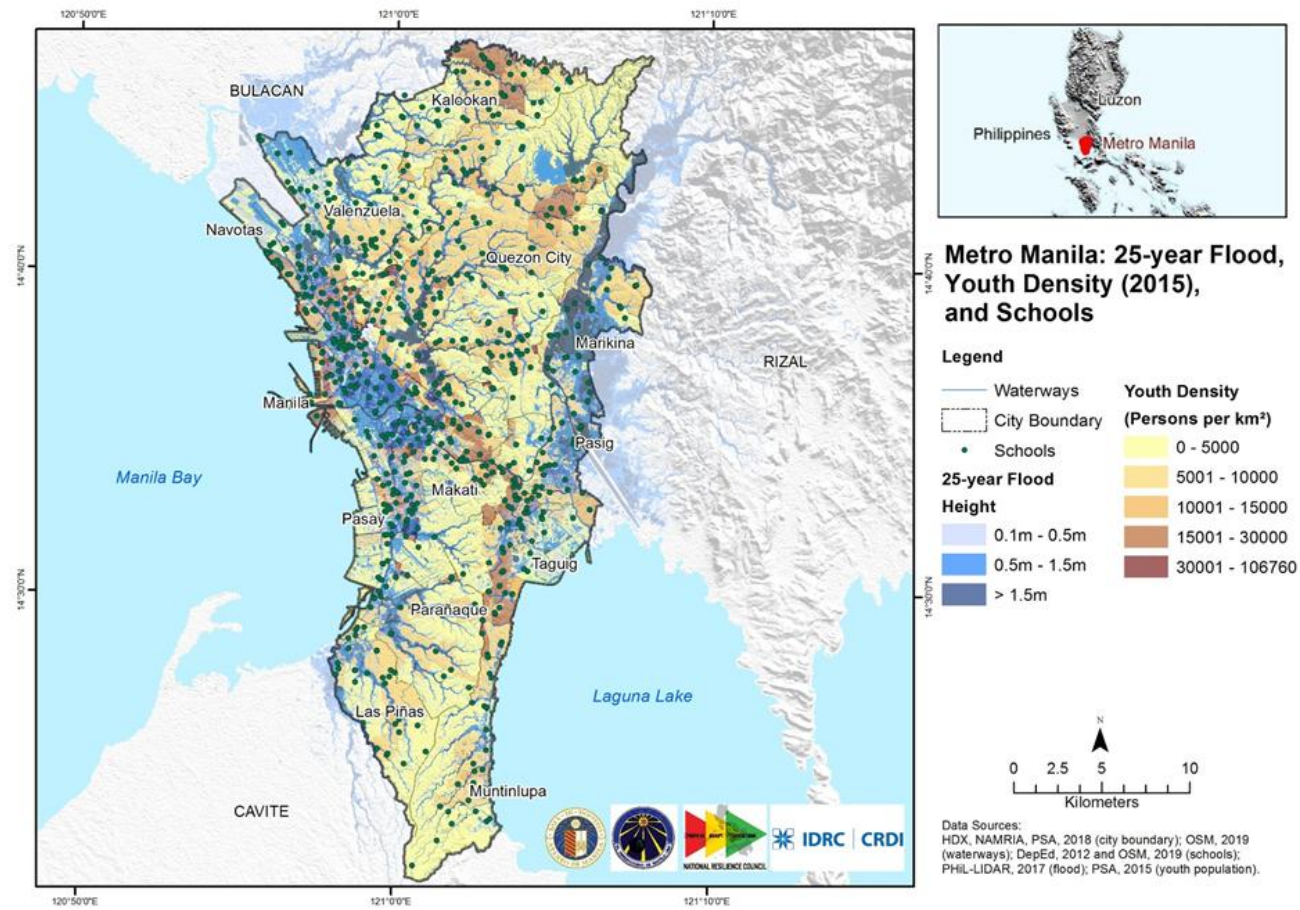

Figure 76. 25-year Flood, Youth Density (2015), and Schools (2019)

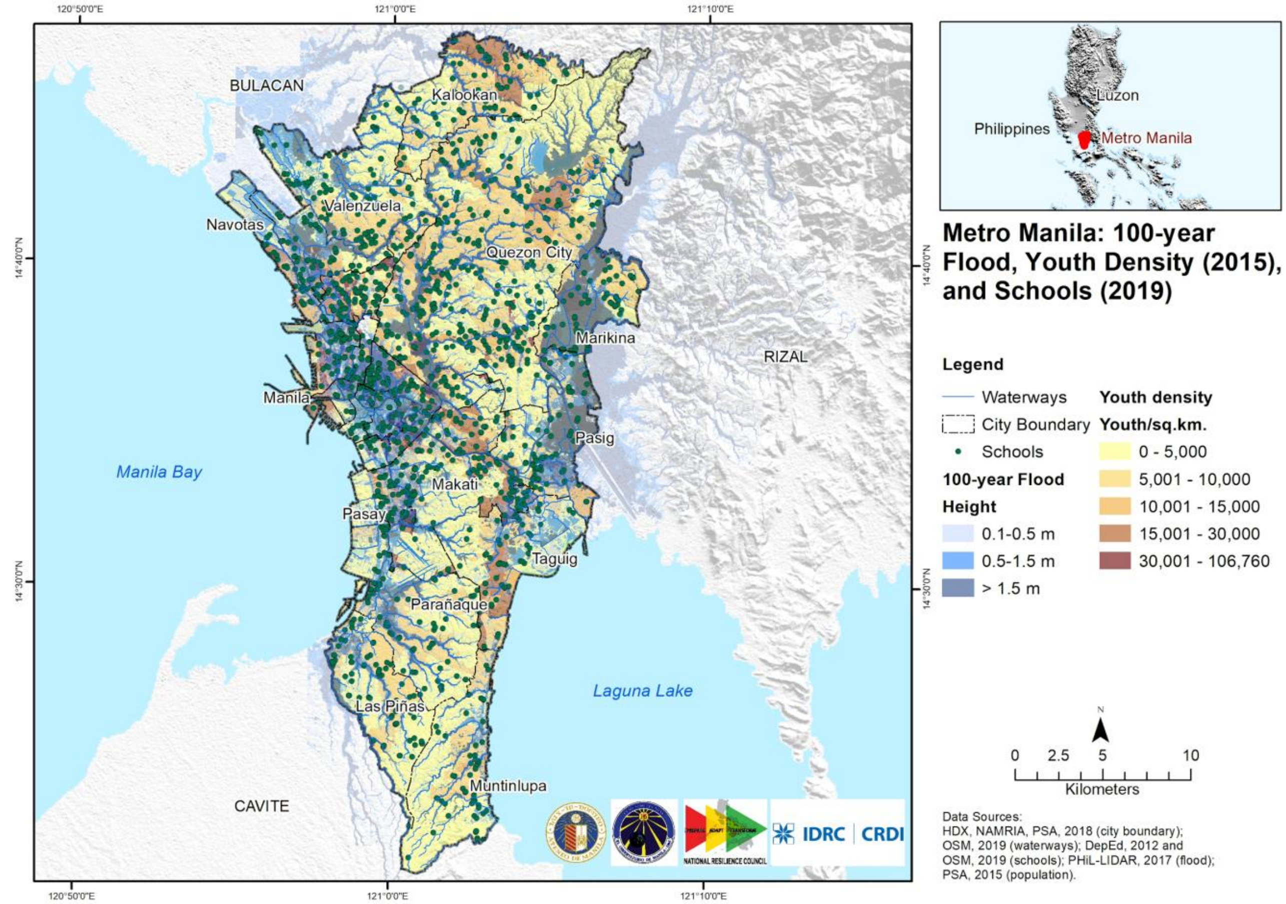

Figure 77. 100-year Flood, Youth Density (2015), and Schools (2019)

The same districts have the highest child and elderly population as shown in the maps Figures 78-80. Children and elderly represent age groups dependent on others for support during flood (Meyer et. al., 2009a in Kubal et. al., 2010). The elderly are vulnerable because of their lack in physical and economic means in responding to a hazard leading to chances of acquiring health problems and in recovering quickly from hazard impacts (Cutter et al., 2003). It can be observed that districts in Manila like Malate, Tondo and Pandacan have the densest elderly population (Figures 81 and 82) and are also flood prone areas. Hospitals and other health facilities should be strategically located and have strong structural forms for catering the needs during and after flood events.

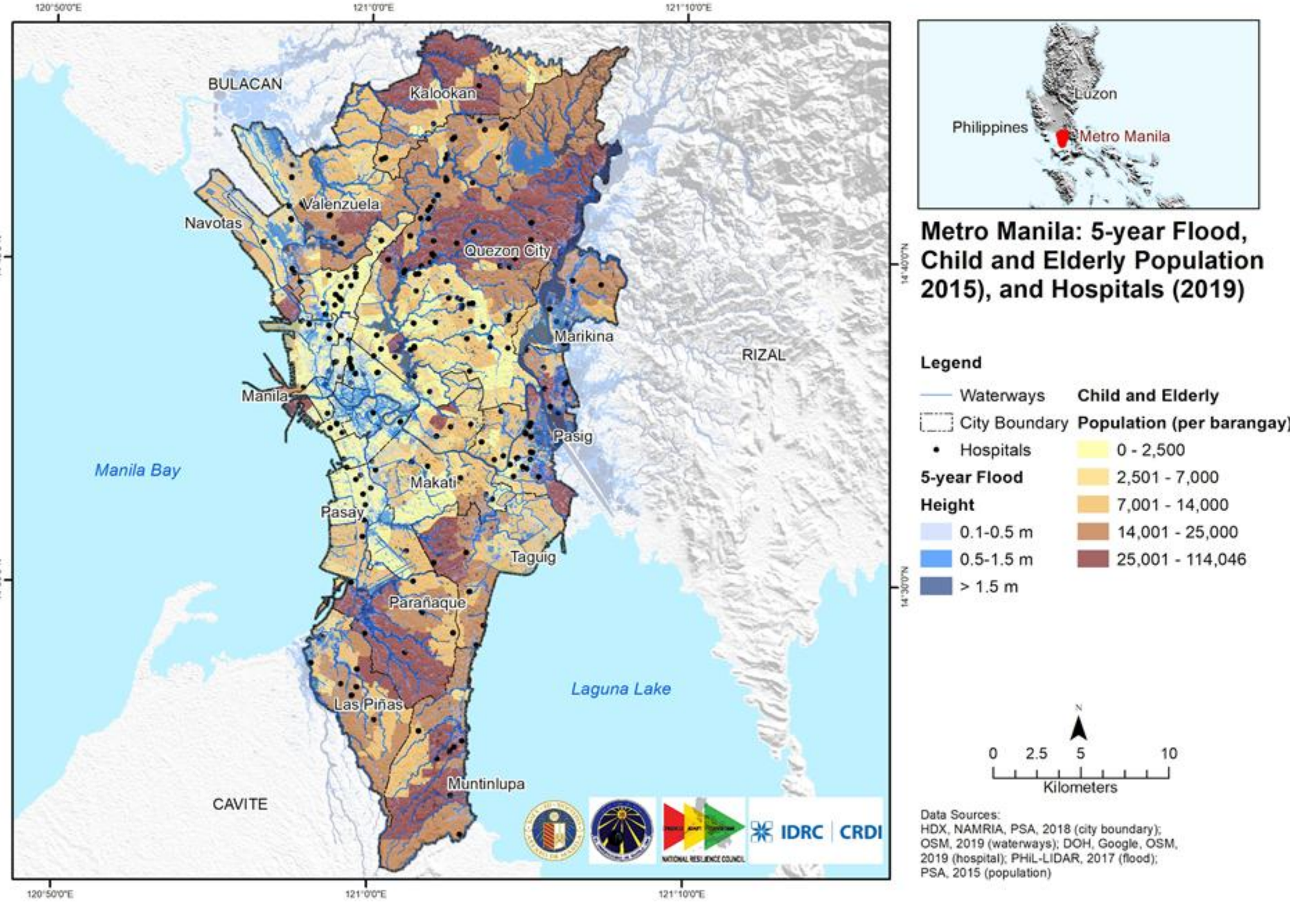

Figure 78. 5-year Flood, Child and Elderly Population (2015), and Hospitals (2019)

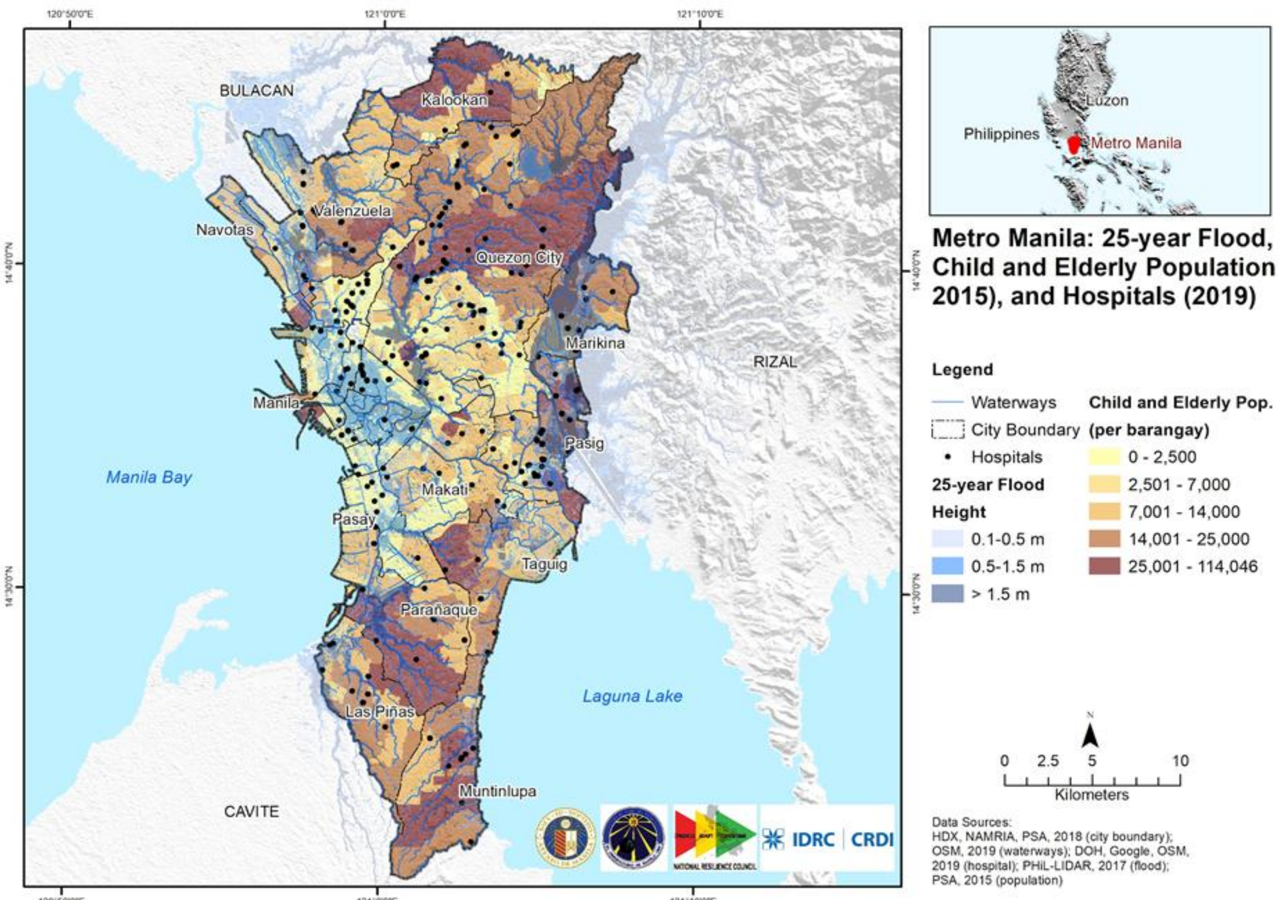

Figure 79. 25-year Flood, Child and Elderly Population (2015), and Hospitals (2019)

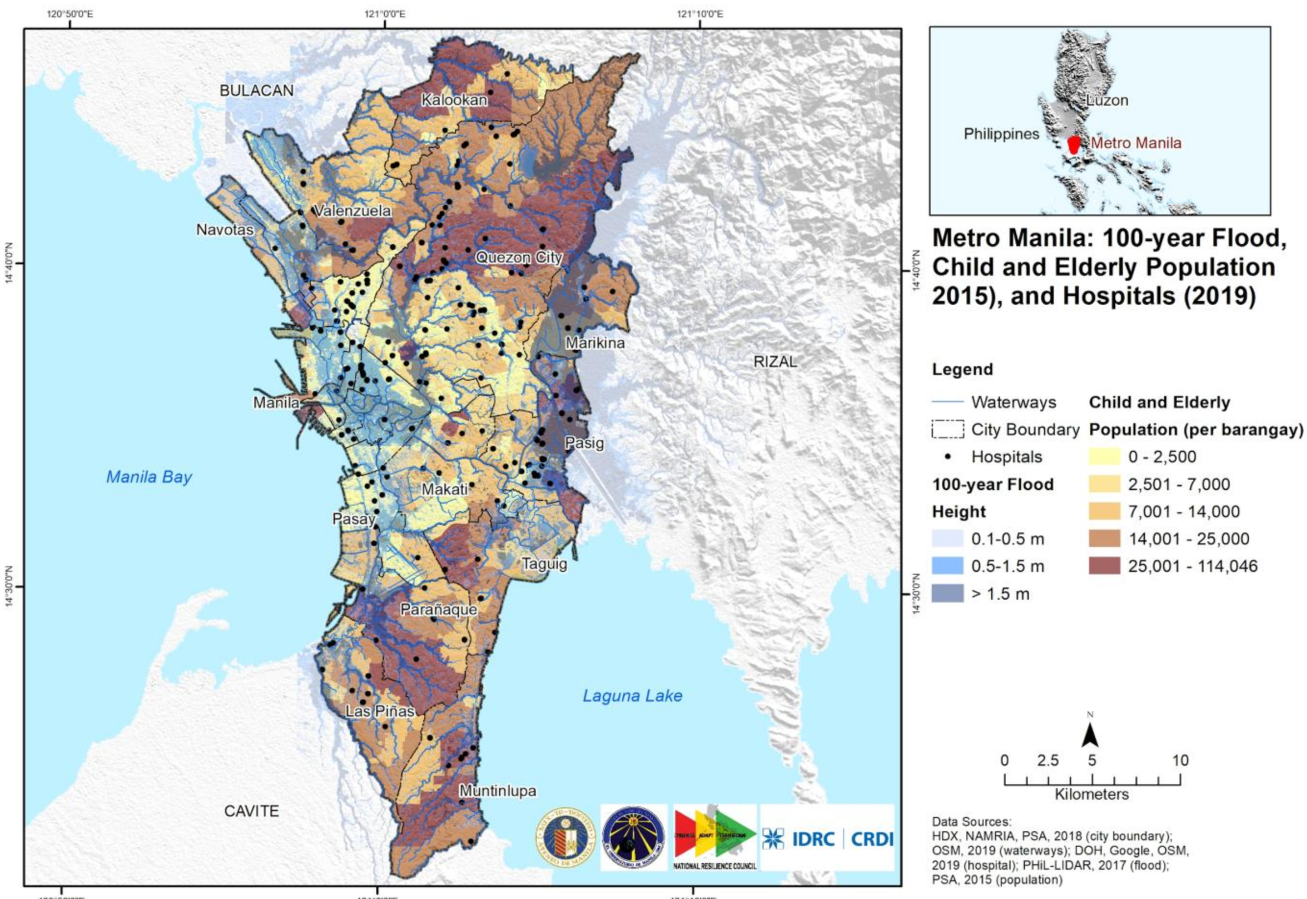

Figure 80. 100-year Flood, Child and Elderly Population (2015), and Hospitals (2019)

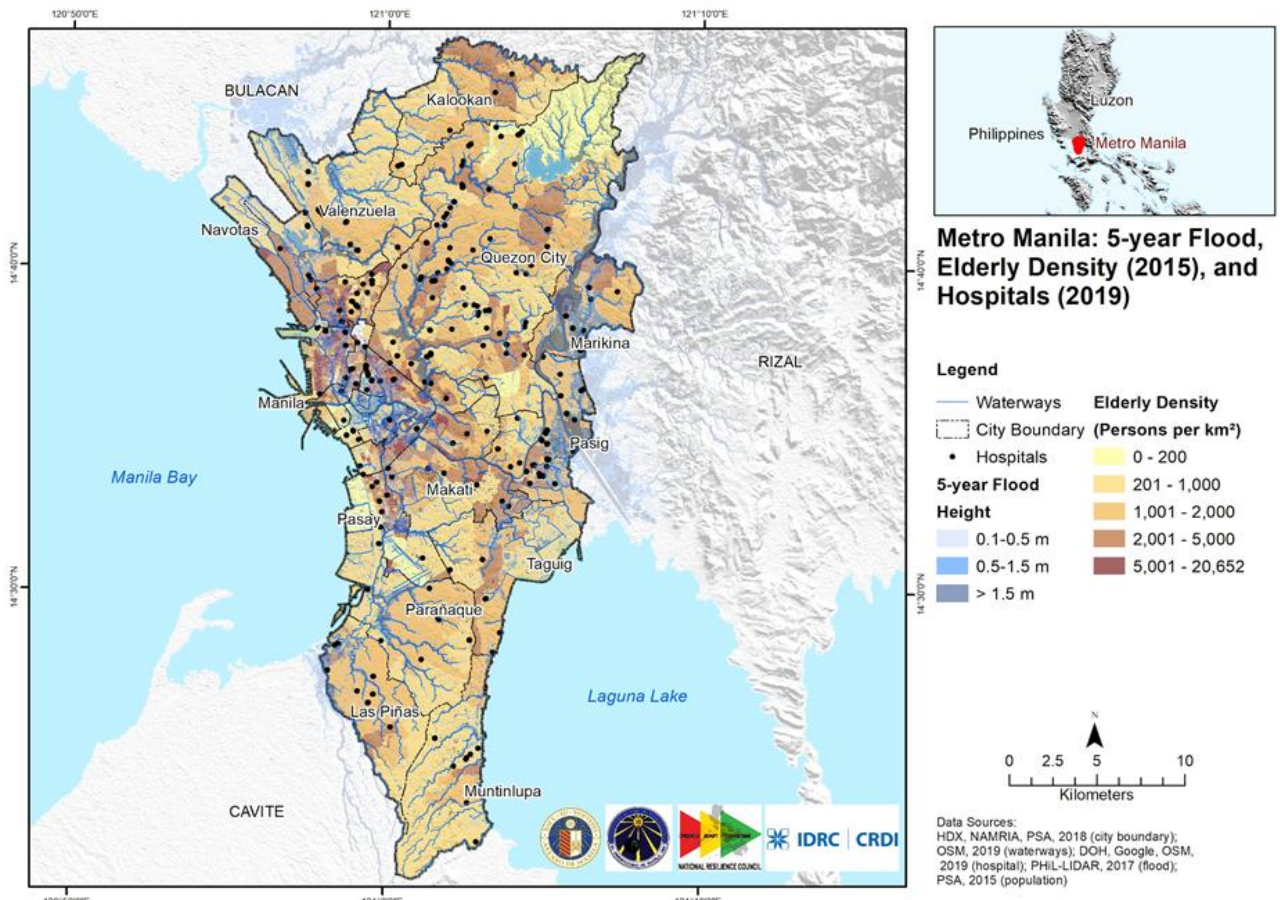

Figure 81. 5-year Flood, Elderly Density (2015), and Hospitals

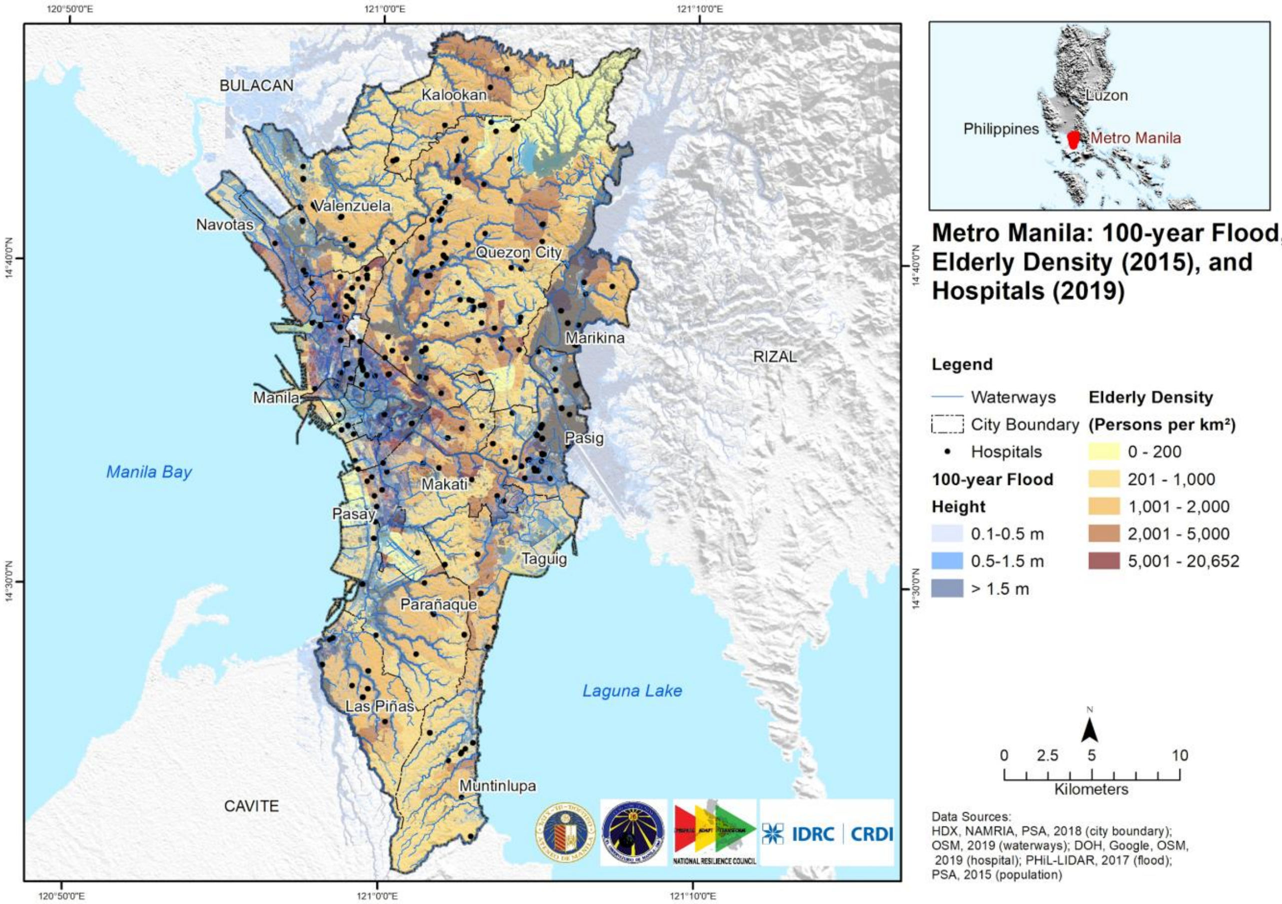

Figure 82. 100-year Flood, Elderly Density (2015), and Hospitals (2019)

<u>Impact on vulnerable population</u>

Vulnerable population including child head of the family, elderly head of the family, persons with disability, single head of the family and single parents were also mapped together with informal settlements and 100-year flood. Maps (Figure 83-87) show that much of the areas prone to 100-year flood are also the informal settlements especially in Manila, Marikina and Pasig. People in extremely difficult conditions like the single head of the family living in those flood-prone informal settlements would have a harder time recovering from the impacts of a flood. The highest single headed families in Metro Manila are in Kalookan City, Manila and Quezon City. These are also the cities with the largest area of informal settlements. The same pattern applies to the number of persons with disability, child-headed families, single parents and elderly-headed families. There are more male single-headed families, male persons with disability and male child-headed families than females. However, for the single parents and elderly-headed families, females outnumber the males.

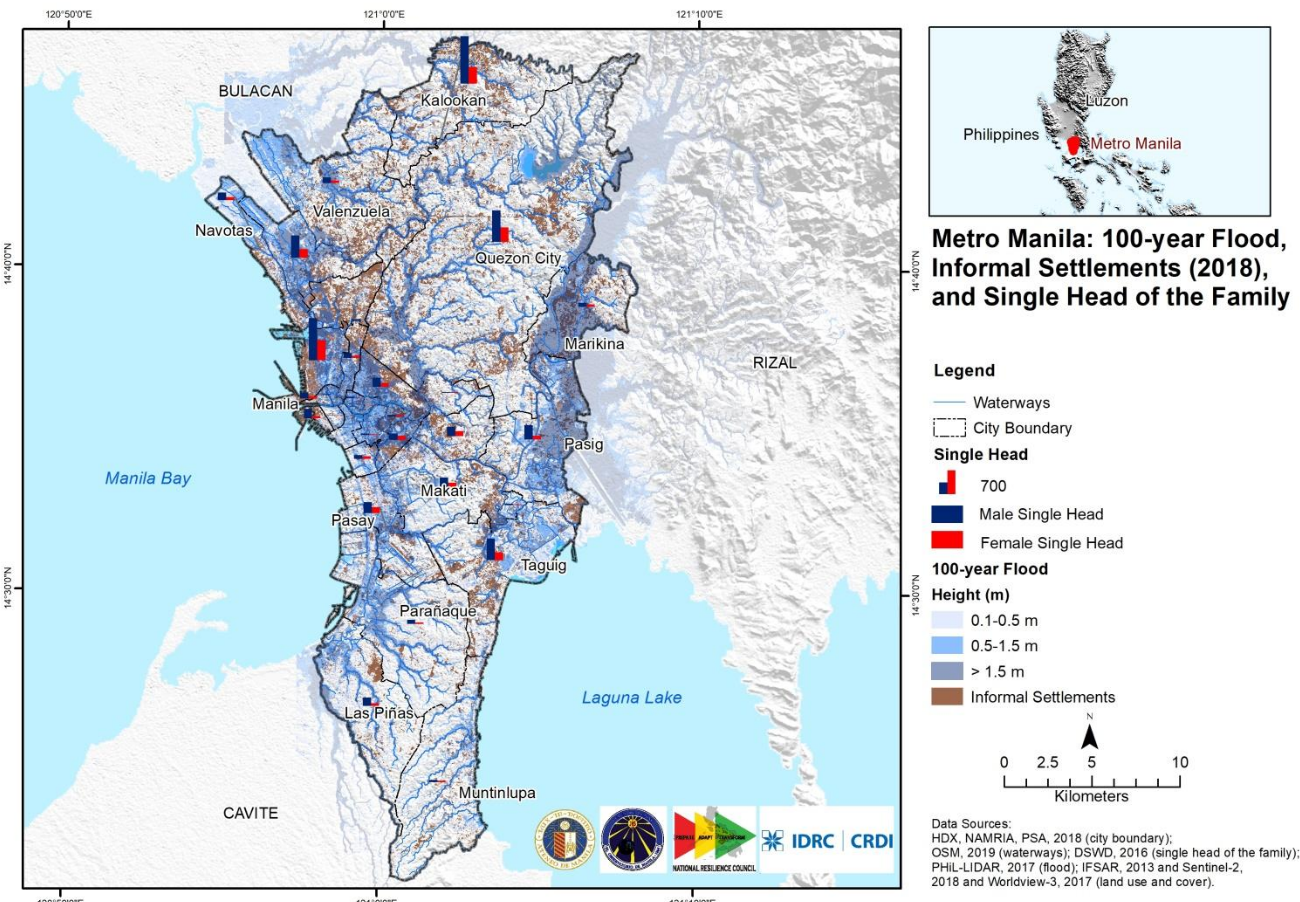

Figure 83. 100-year flood, informal settlements (2018), and single head of the family (2016)

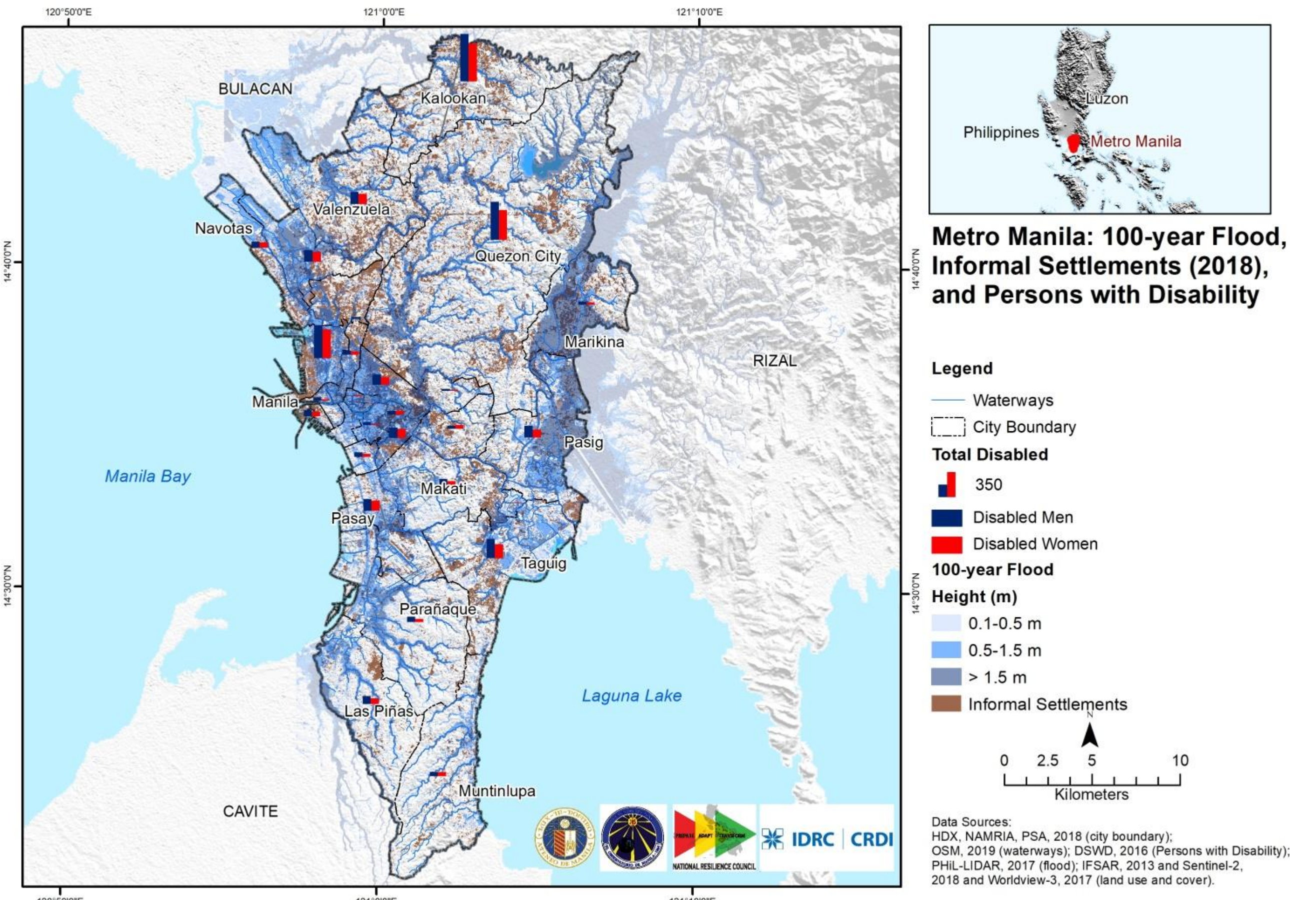

Figure 84. 100-year flood, informal settlements (2018), and persons with disability (2016)

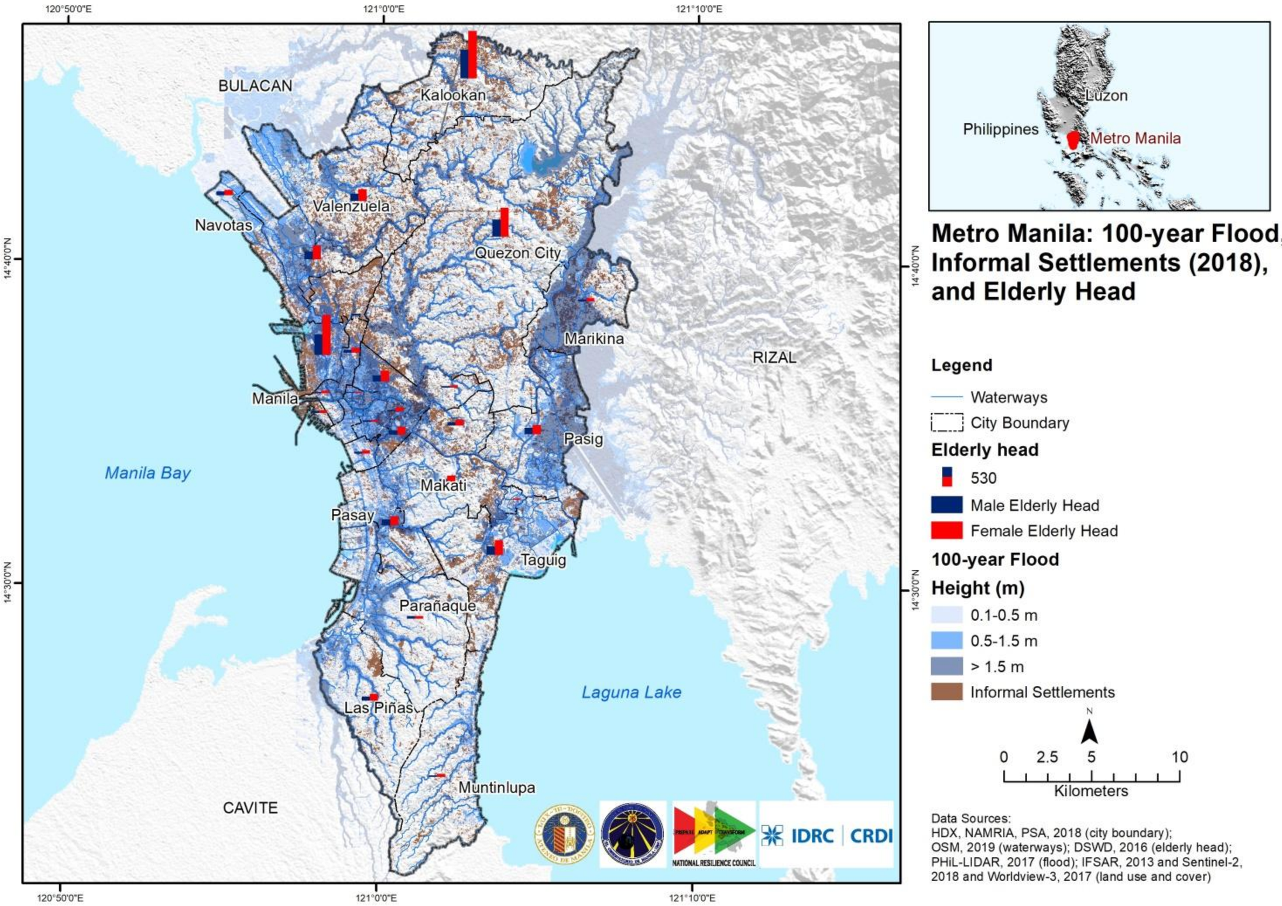

Figure 85. 100-year flood, informal settlements (2018), and elderly head (2016)

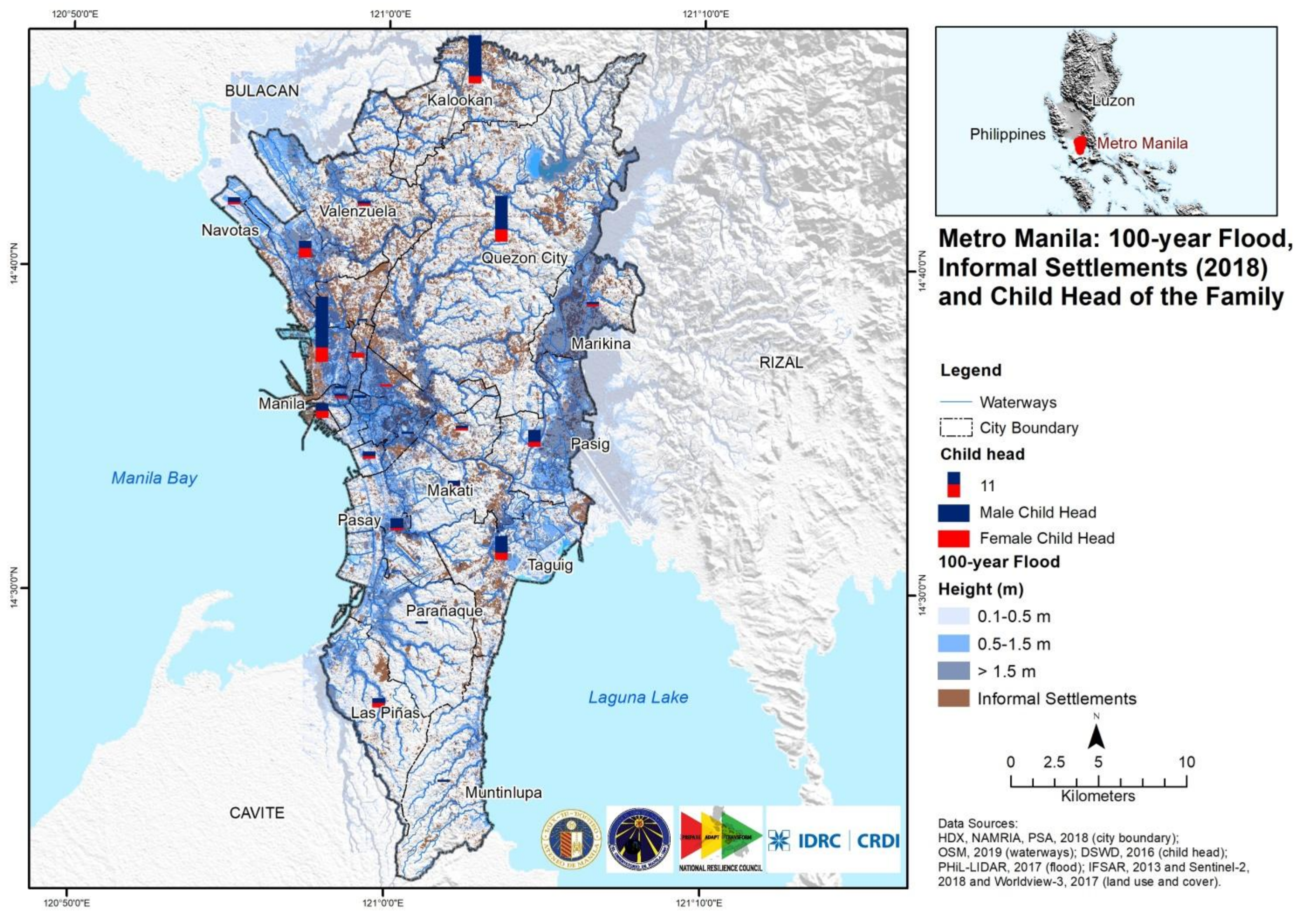

Figure 86. 100-year flood, informal settlements (2018) and child head of the family (2016)

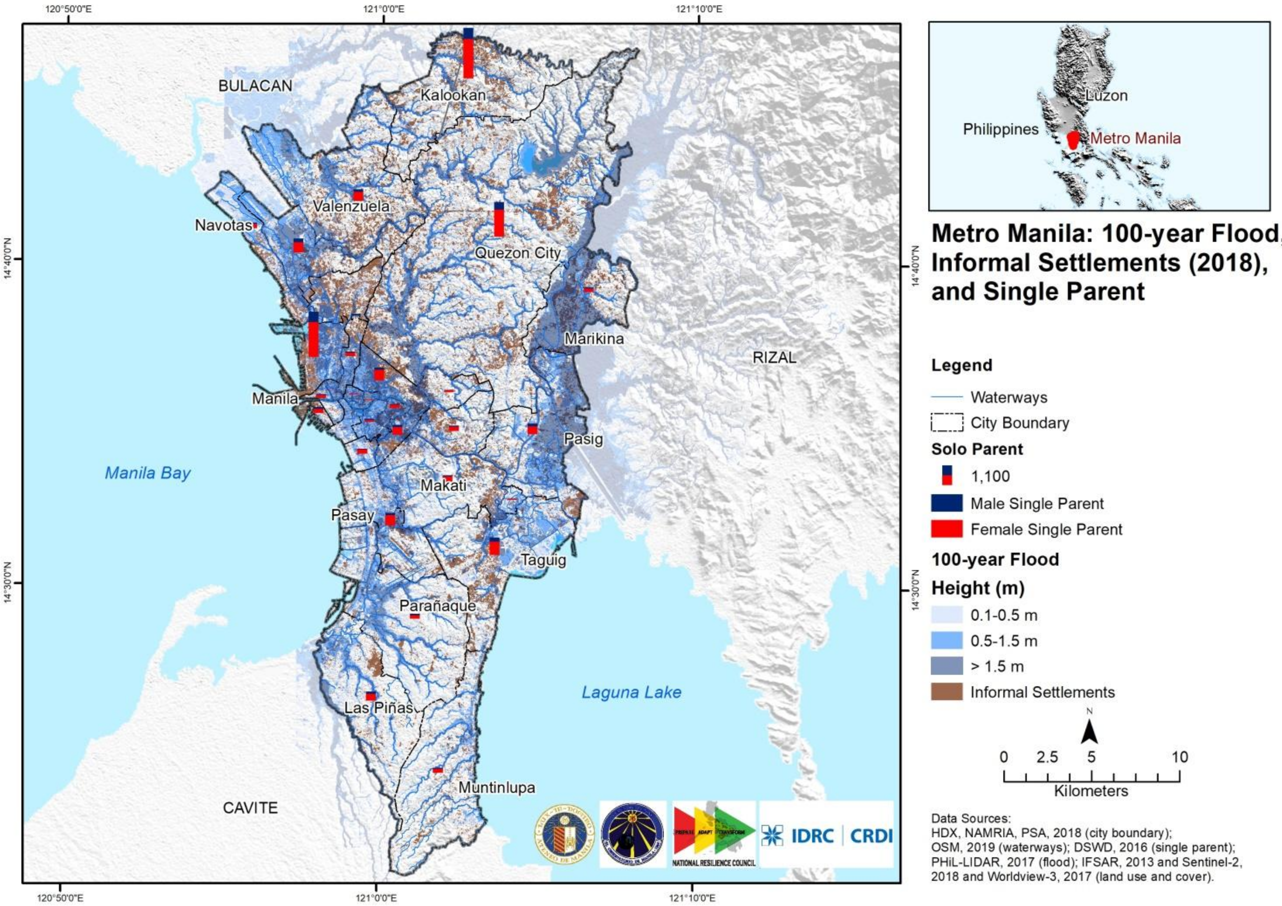

Figure 87. 100-year flood, informal settlements (2018), and single parent (2016)

<u>Impact on health</u>

Globalization, trade, urbanization, travel, demographic change, inadequate domestic water supplies and warming temperatures are associated with the spread of the main vectors of dengue, Aedes aegypti and Aedes albopictus (Murray et al., 2013). According to World Health Organization, floods can possibly increase the spread of the following water-borne diseases: typhoid fever, cholera, leptospirosis and hepatitis. Vector-borne diseases, such as malaria, dengue and dengue hemorrhagic fever are also easily spread during these events.

Water-holding containers in and around homes are used by mosquitoes to complete their growth. On the other hand, blood from humans is required by female mosquitoes for egg development. Eggs are placed on the side of water-holding containers and hatch into larvae after rain or flooding. The larvae change into pupae, and then grow into adult mosquitoes in a week (Ebi & Nealon, 2016). This means that the more people exposed to flooding makes these mosquitoes under favorable environmental conditions. Analyzing these correlations, flood hazard maps, population and dengue cases in Metro Manila are overlaid together for the observance of their relationships. As shown in the maps below, it can be observed that the City of Manila which is flood-prone (Figure 88-90) exhibits the highest dengue cases of 2,234 followed by the 501 cases of Muntinlupa City in 2018.

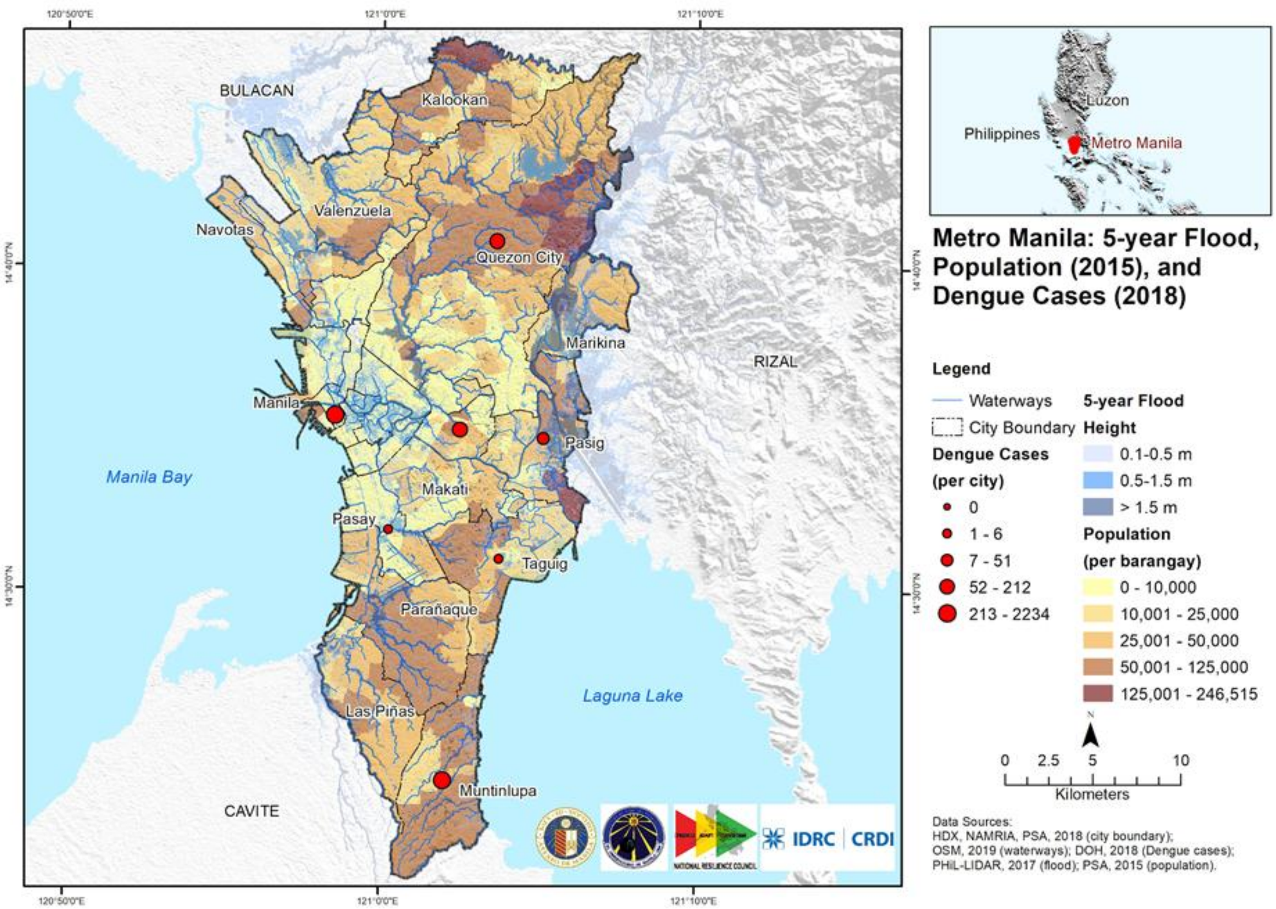

Figure 88. 5-year Flood, Population (2015), and Dengue Cases (2018)

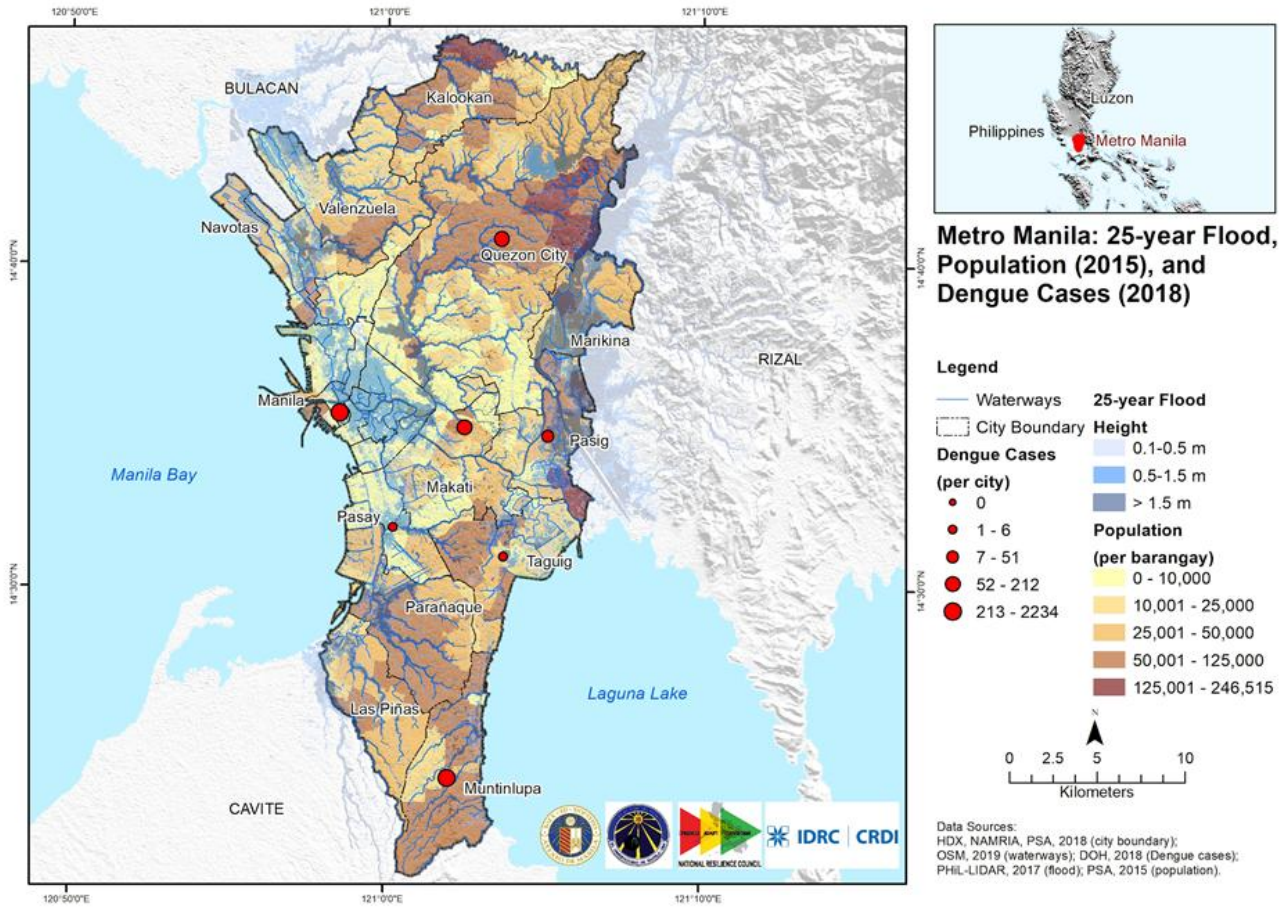

Figure 89. 25-year Flood, Population (2015), and Dengue Cases (2018)

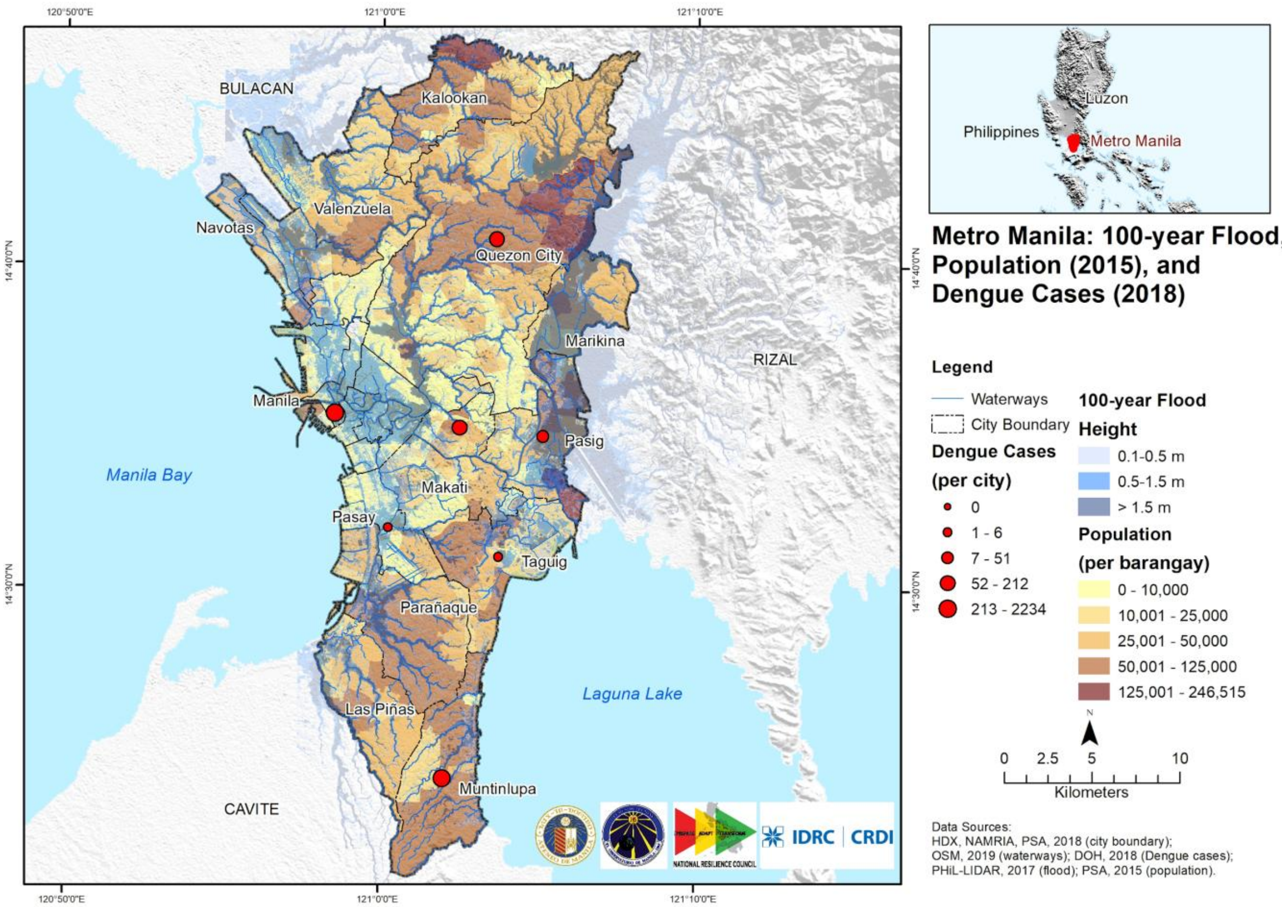

Figure 90. 100-year Flood, Population (2015), and Dengue Cases (2018)

There have also been reports of flood-associated outbreaks of leptospirosis from several cities. Figure 91-93 show that the City of Manila has the highest count of leptospirosis in 2018 with 256 followed by Quezon City with 21. Both areas are flood-prone. Leptospirosis is caused by pathogenic spirochaetes of the genus Leptospira. Humans usually become infected through contact with water or soil contaminated by the urine of infected animals, such as rodents, dogs, cattle, pigs and wild animals. When high population is exposed to wet conditions for a long period of time, it can be epidemic (Levett, 2001). Floods may result in the garbage, debris and food scattering that may contribute to the migration and increase of rodent populations (Ivers & Ryan, 2006). During flood, animals like rats, pigs, cattle and reptiles displacement can happen which can contaminate floodwaters. Spirochaetes can infect humans once directly or indirectly have contact with contaminated water (Ding et al., 2019).

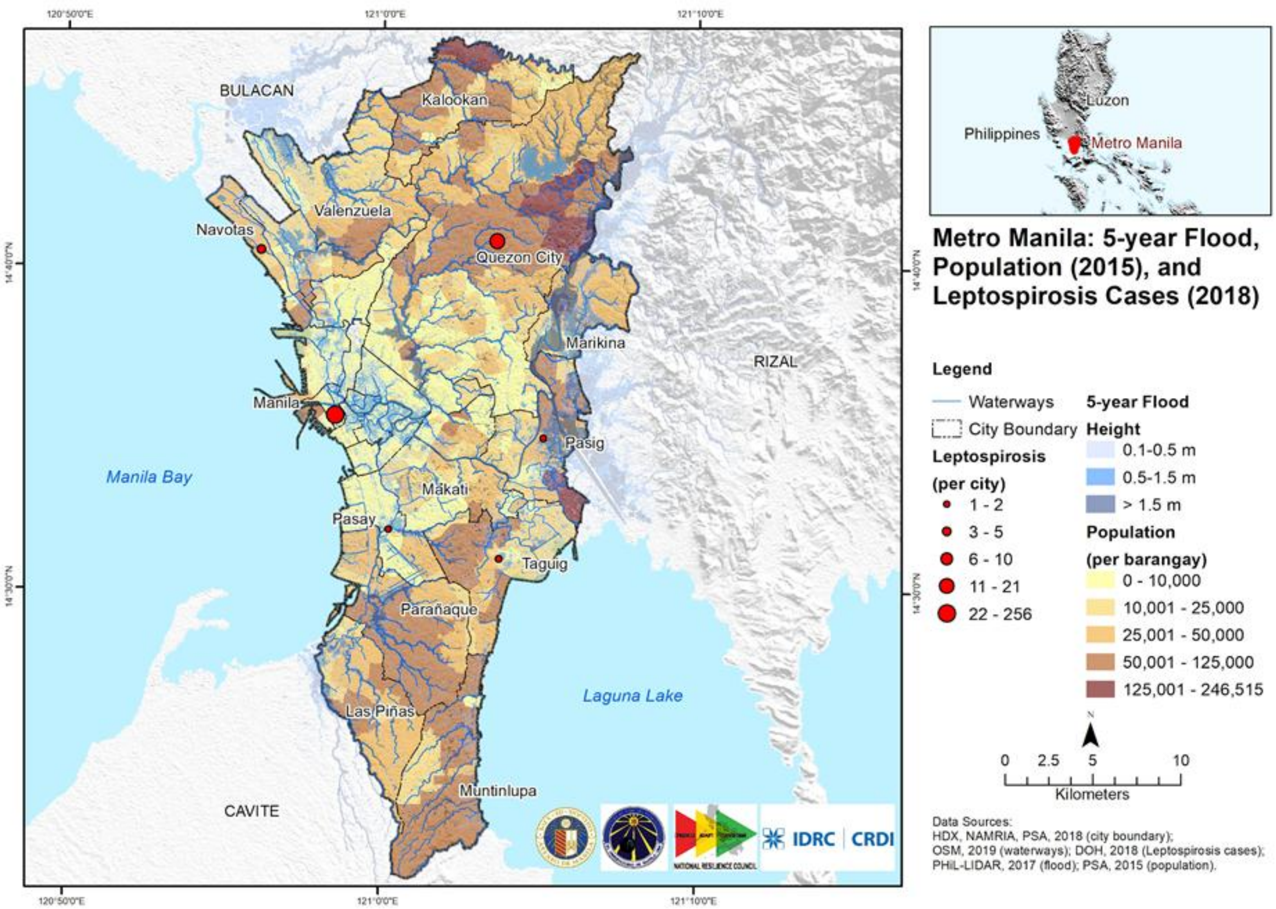

Figure 91. 5-year Flood, Population (2015), and Leptospirosis Cases

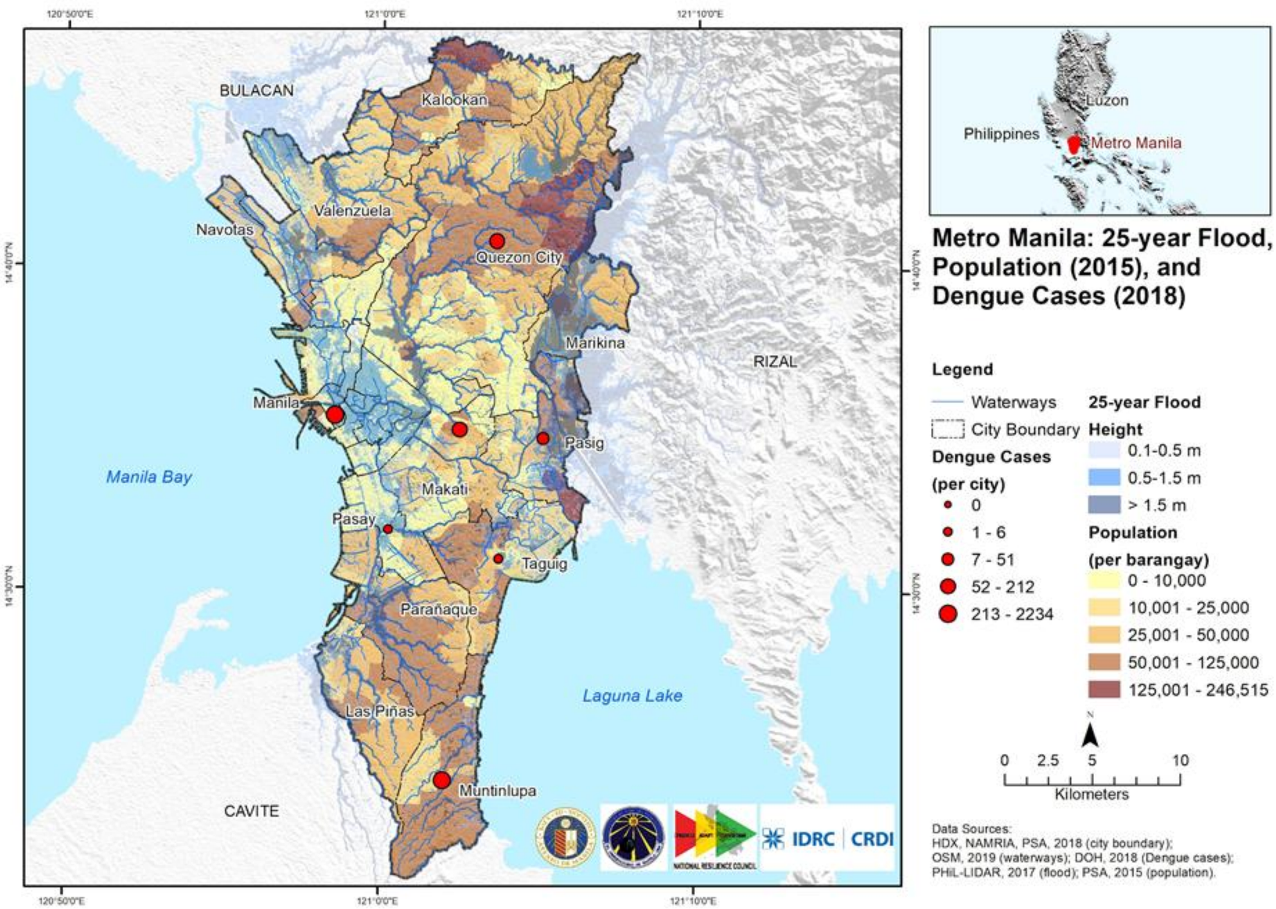

Figure 92. 25-year Flood, Population (2015), and Leptospirosis Cases

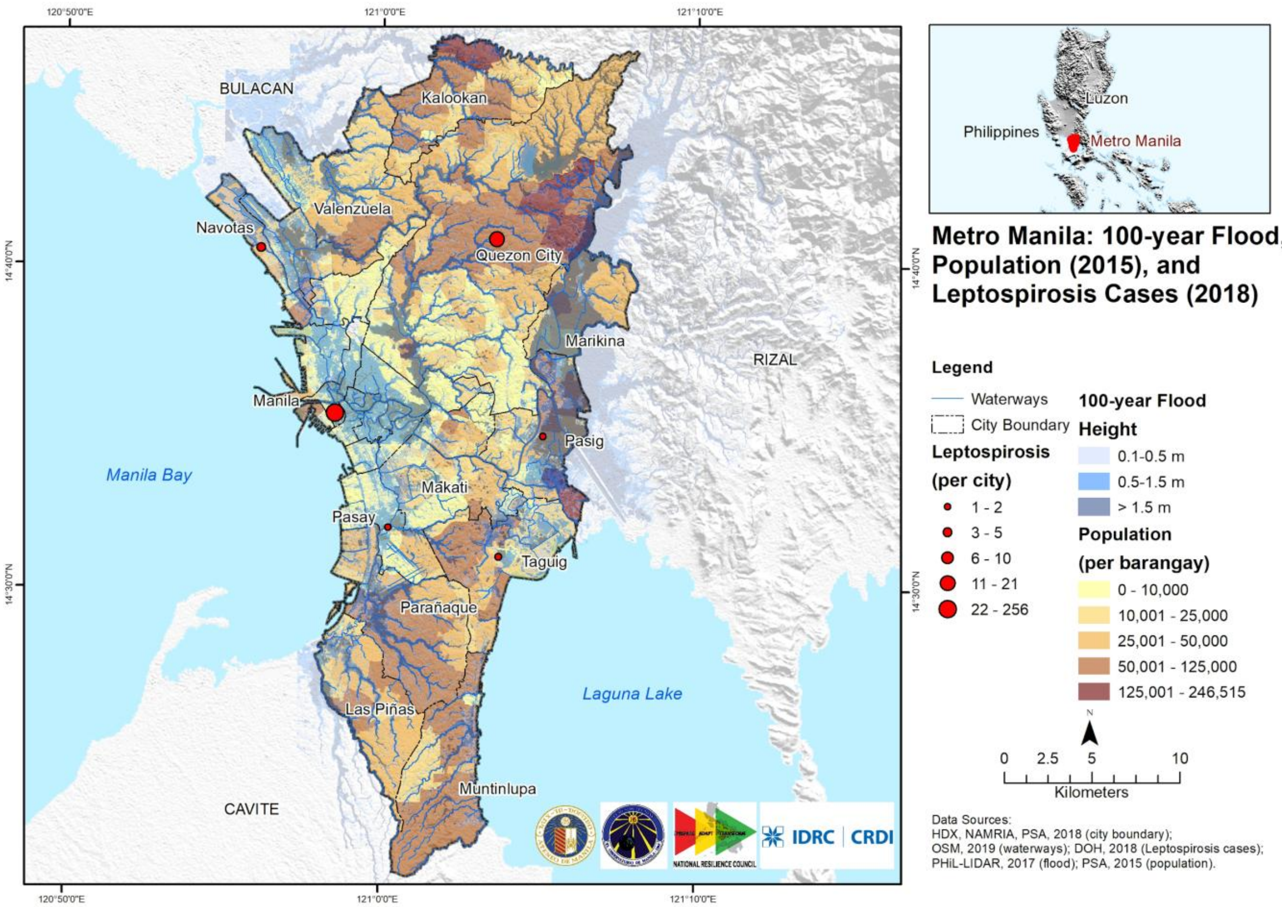

Figure 93. 100-year Flood, Population (2015), and Leptospirosis Cases

Water-borne epidemics of diarrheal diseases after floods result primarily from contamination of water during flooding. In addition to this, secondary effects of flooding, including crowding in evacuation centers and succeeding fecal-oral spread of gastrointestinal pathogens, may also add to outbreak of diarrheal diseases (Khan et al., 2006). Figure 94-96 show overlaid maps on flood and diarrhea cases in Metro Manila. Result showed that City of Manila has the highest outbreak with 4779 cases followed by Quezon City with 2917 cases. It can be observed that these areas are near bodies of water like Marikina, Pasig, San Juan and Tullahan rivers which can be contaminated especially during flooding.

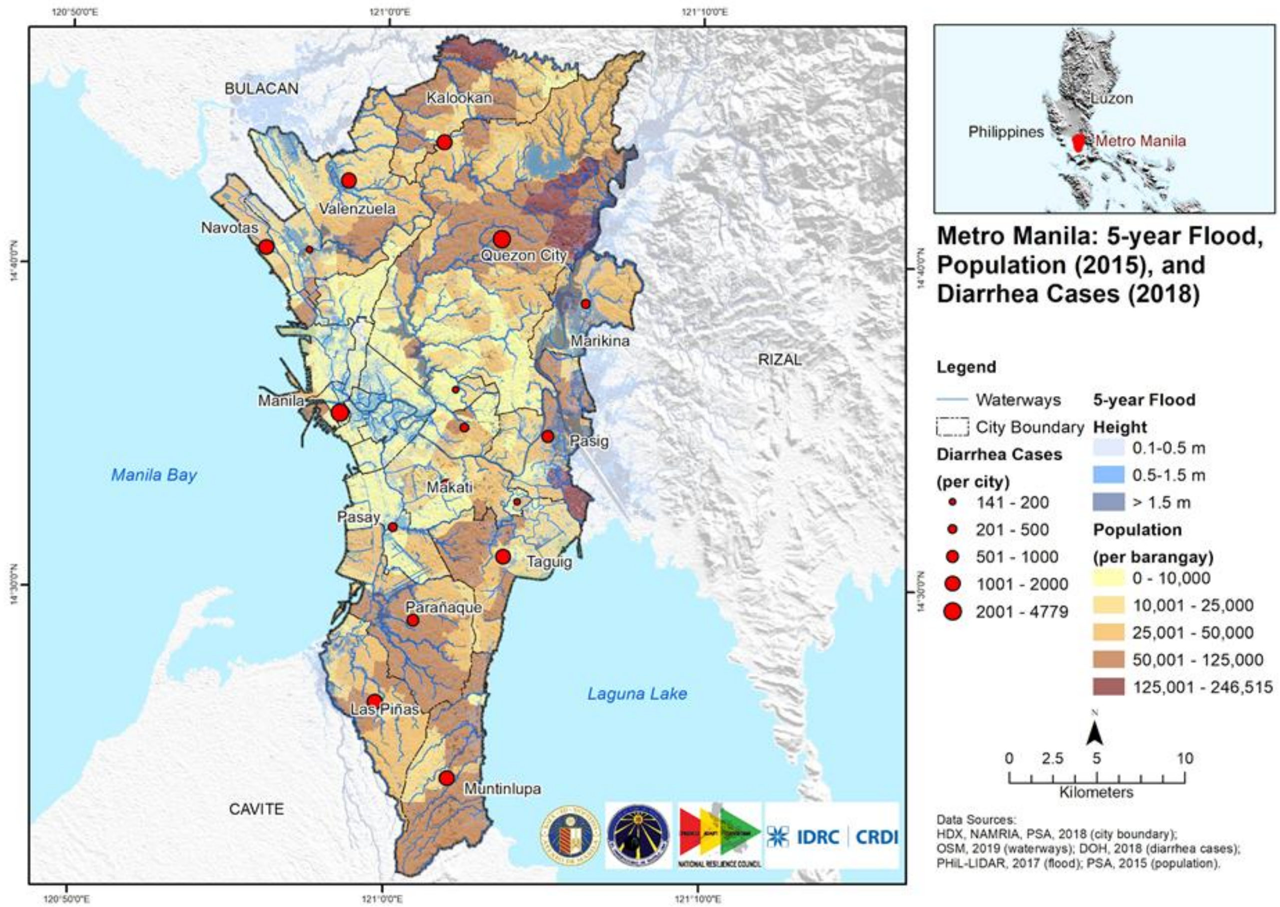

Figure 94. 5-year Flood, Population (2015), and Diarrhea Cases (2018)

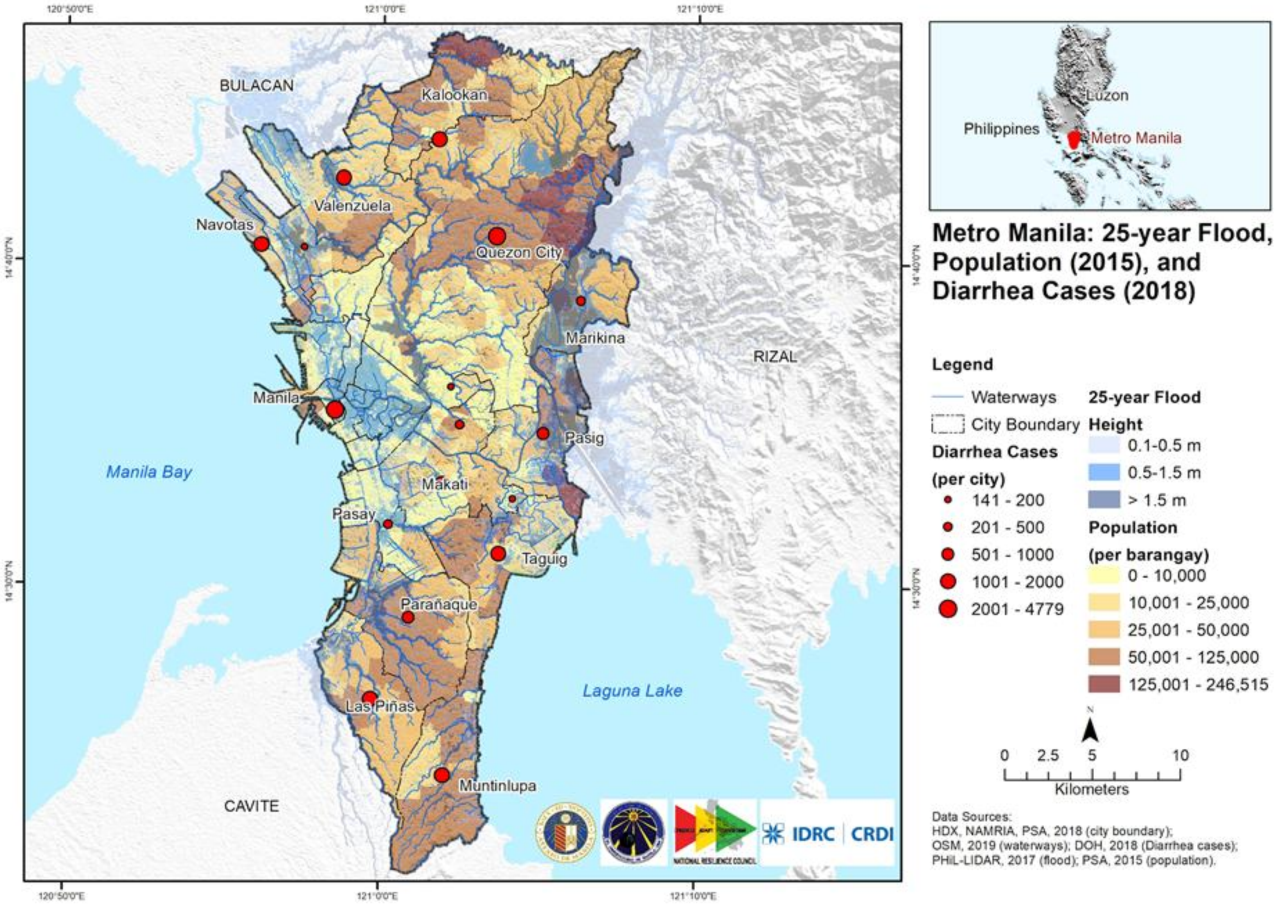

Figure 95. 25-year Flood, Population (2015), and Diarrhea Cases (2018)

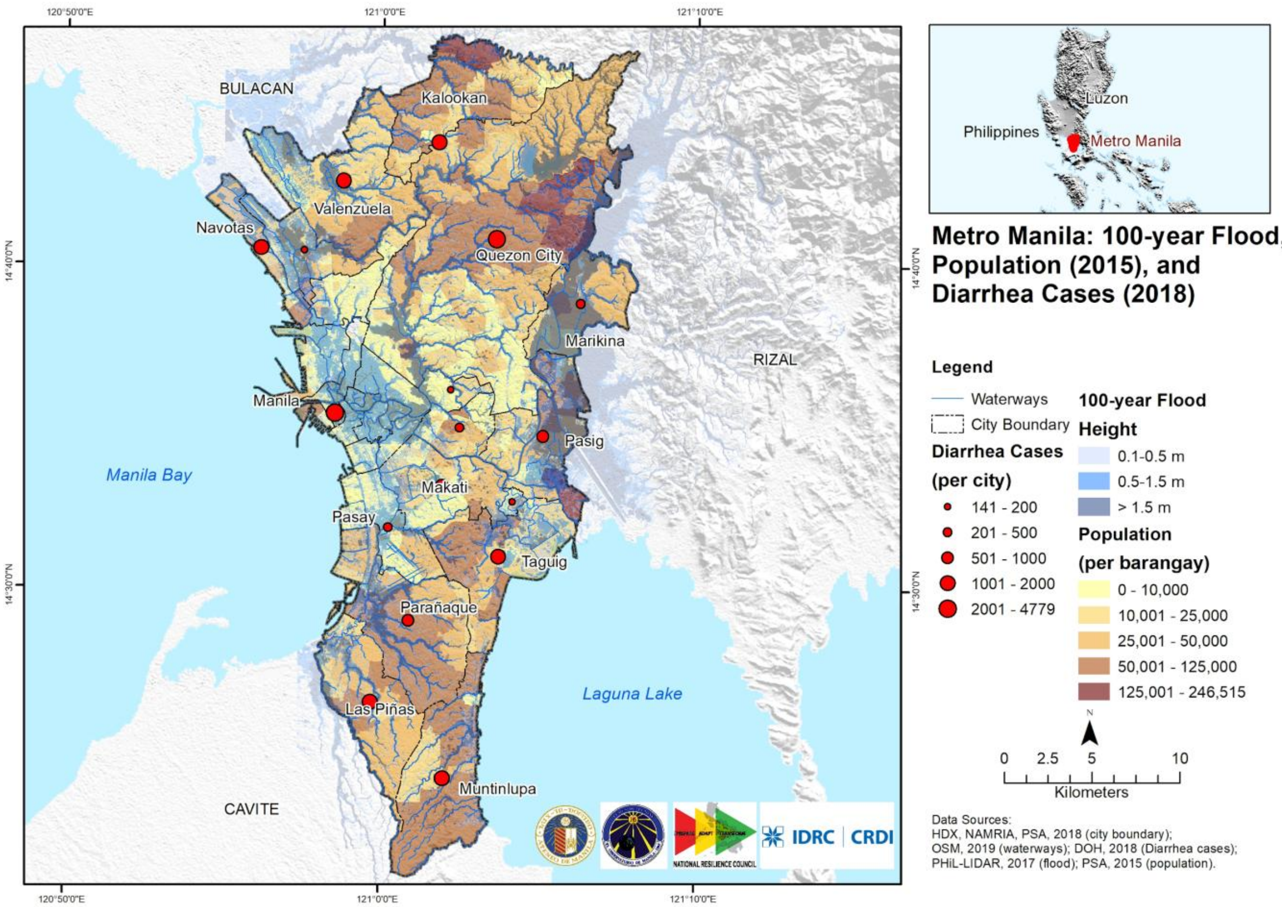

Figure 96. 100-year Flood, Population (2015), and Diarrhea Cases (2018)

Overlaying the flood, population and water sources (Figure 97) showed that majority of the households in almost all cities use faucet as a source of drinking water. More households in Navotas, Las Piñas City, Muntinlupa City and Paranaque City use bottled water than faucet as drinking source. Peddler and tubed or piped water are also used by fewer households. The most populated barangays around Manila is also shown in the map. Most of them are flood-prone leading to flooding contamination of their drinking water from faucets can be a risk. Because of high densities around the area, the runoff of domestic and commercial wastes can cause can pollute nearby water bodies indicating lower quality of drinking water.

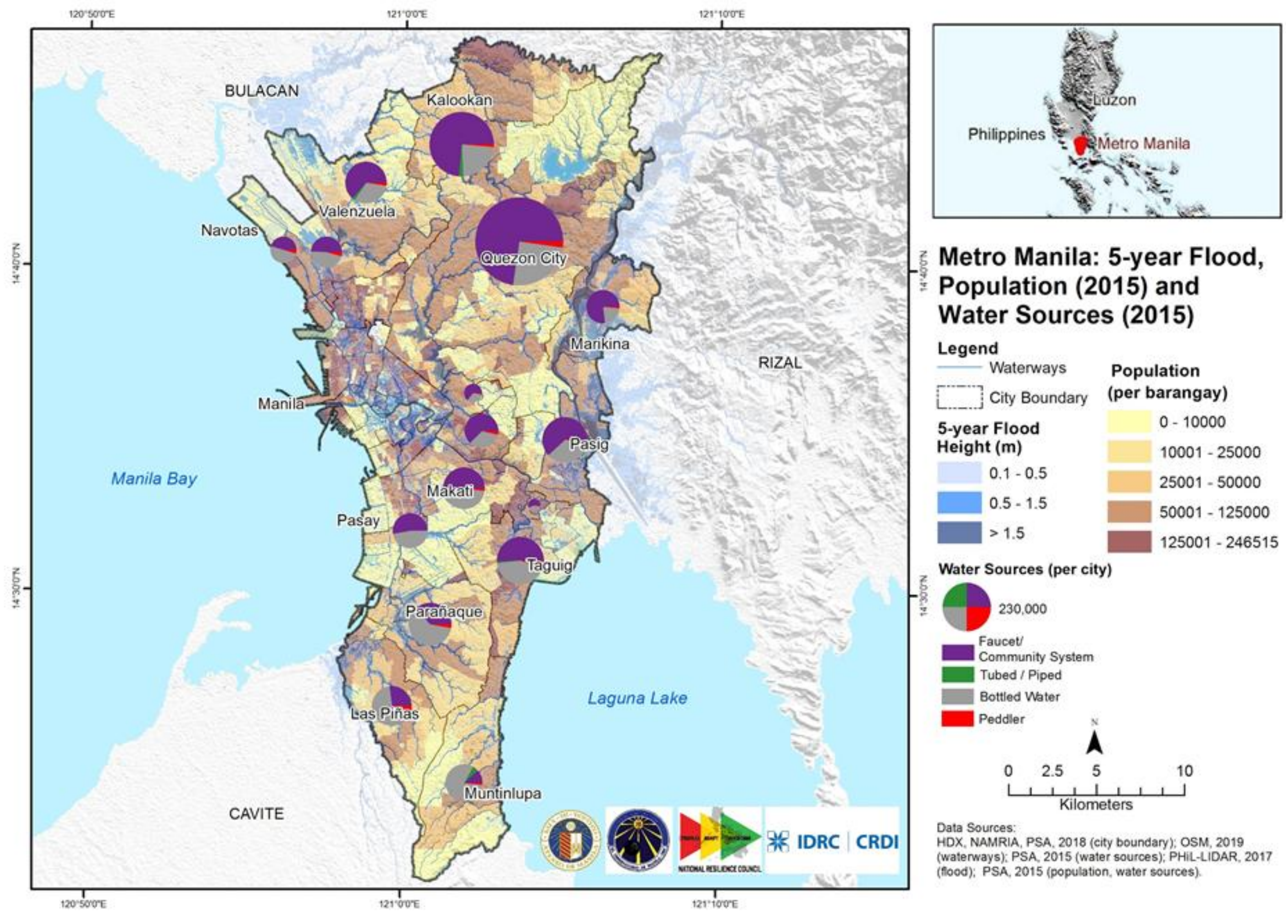

Figure 97. 5-year Flood, Population (2015), and Water Sources (2015)

Visualizing the Impacts of Tropical Cyclones

It is evident that the types of land use that is most often hit by tropical cyclones are the industrial, informal settlements, and the commercial areas. The intersections of the typhoon tracks are mostly in the areas of Manila, Navotas, Mandaluyong, and a bit in Pasig (Figure 59). Other areas often hit by typhoons are mostly residential.

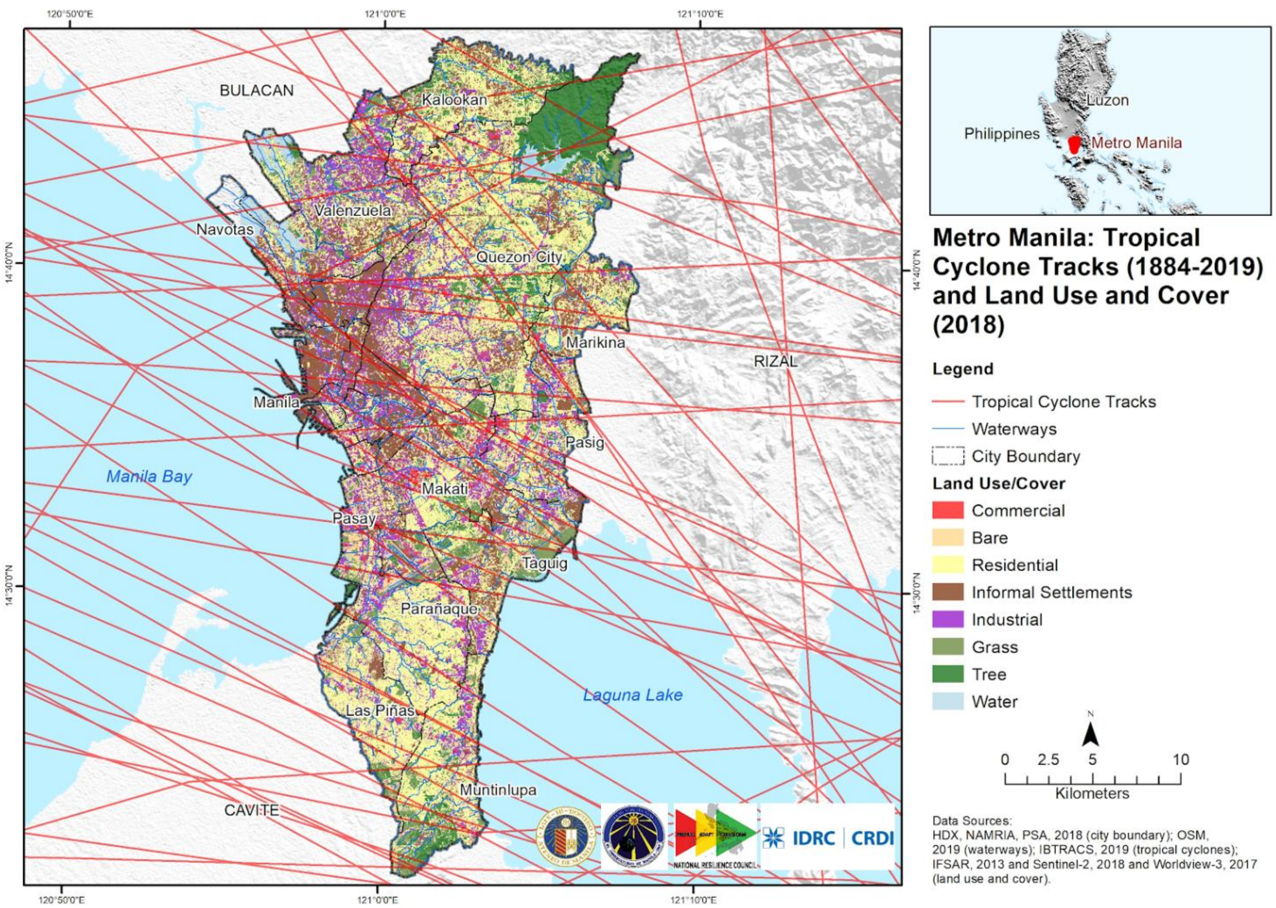

Figure 59. Tropical Cyclone tracks 1884-2019 and Land Use and Cover 2018

Navotas' Industrial area has been hit significantly both by the storm surge and the tropical cyclones (Figure 60). It has medium to high storm surge level. As for the tropical cyclones, there are several intersection points of typhoon tracks as well. Aside from Navotas, Pasay and Manila also have significantly levels of Storm Surge Hazard Level.

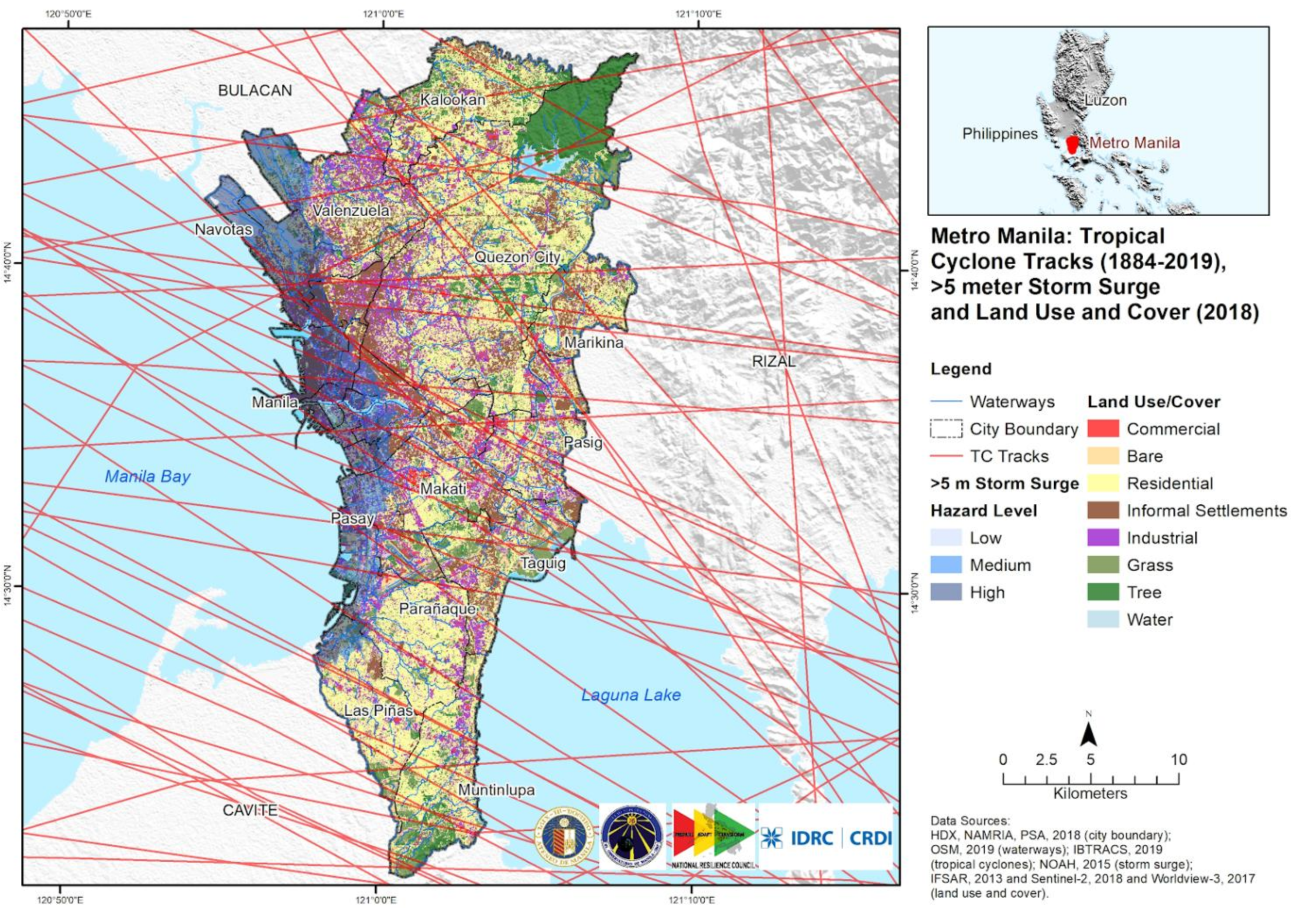

Figure 60. Tropical Cyclone Tracks 1884-2019, > 5 Meter Storm Surge and Land Use and Cover 2018

Figure 61. Tropical Cyclone Tracks 1884 – 2019 and informal settlements 2018

Areas with more than 5,000 4Ps beneficiaries are in close proximity with the typhoon paths (Figure 62). Aside from this, there are significantly less 4Ps beneficiaries in areas with a greater number of informal settlers. But evidently, all these 4Ps beneficiaries have been closely struck by typhoons one way or another.

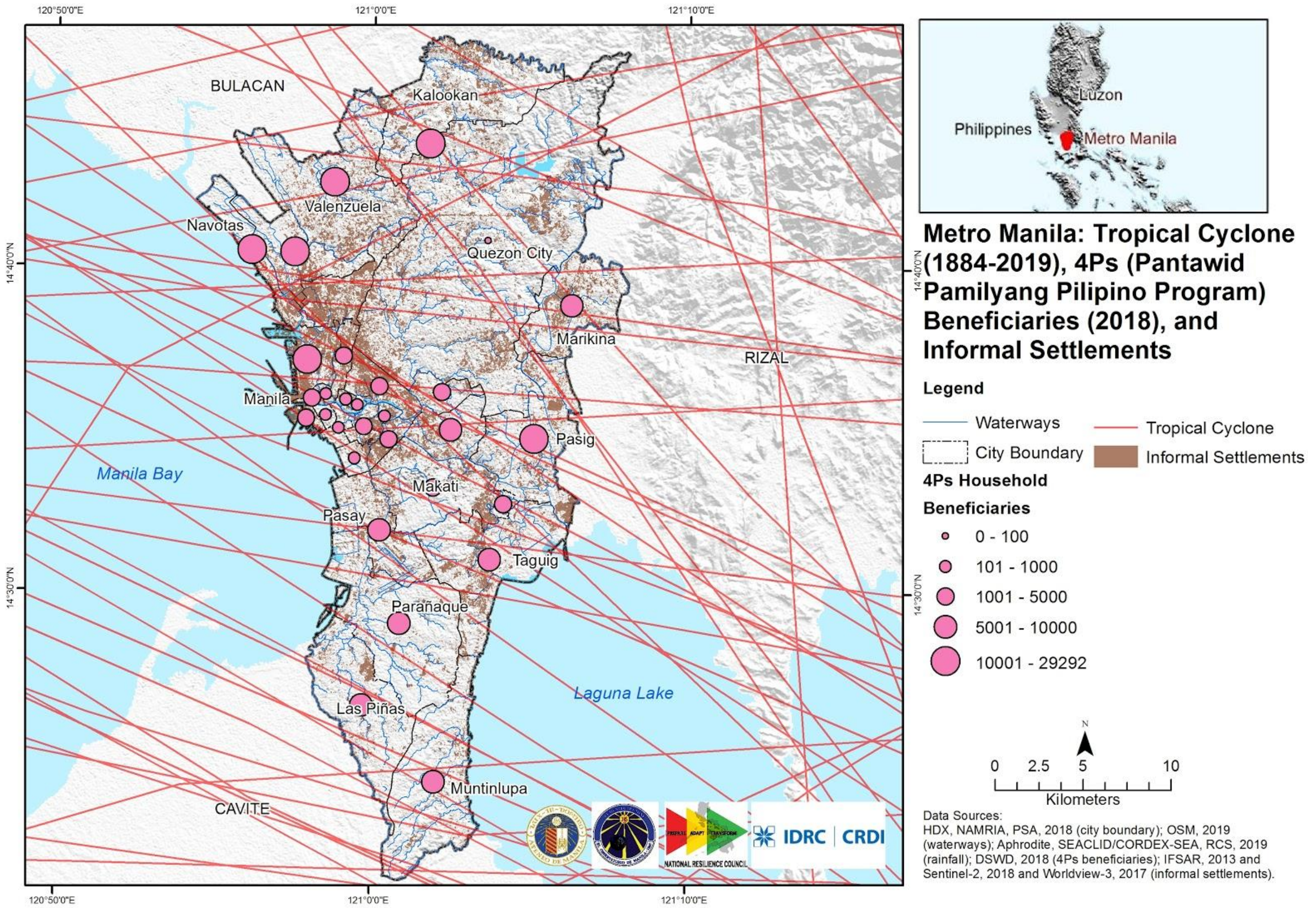

Figure 62. Tropical Cyclone 1884-2019, 4Ps Beneficiaries and Informal Settlements Areas with higher population density are hit by typhoons evidently more times than others (Figure 63). Schools are also hit more times but this is because there are more schools than hospitals. It is also noticeable that the informal settlements have a way higher population density than others. The high density areas are in Manila, Navotas.

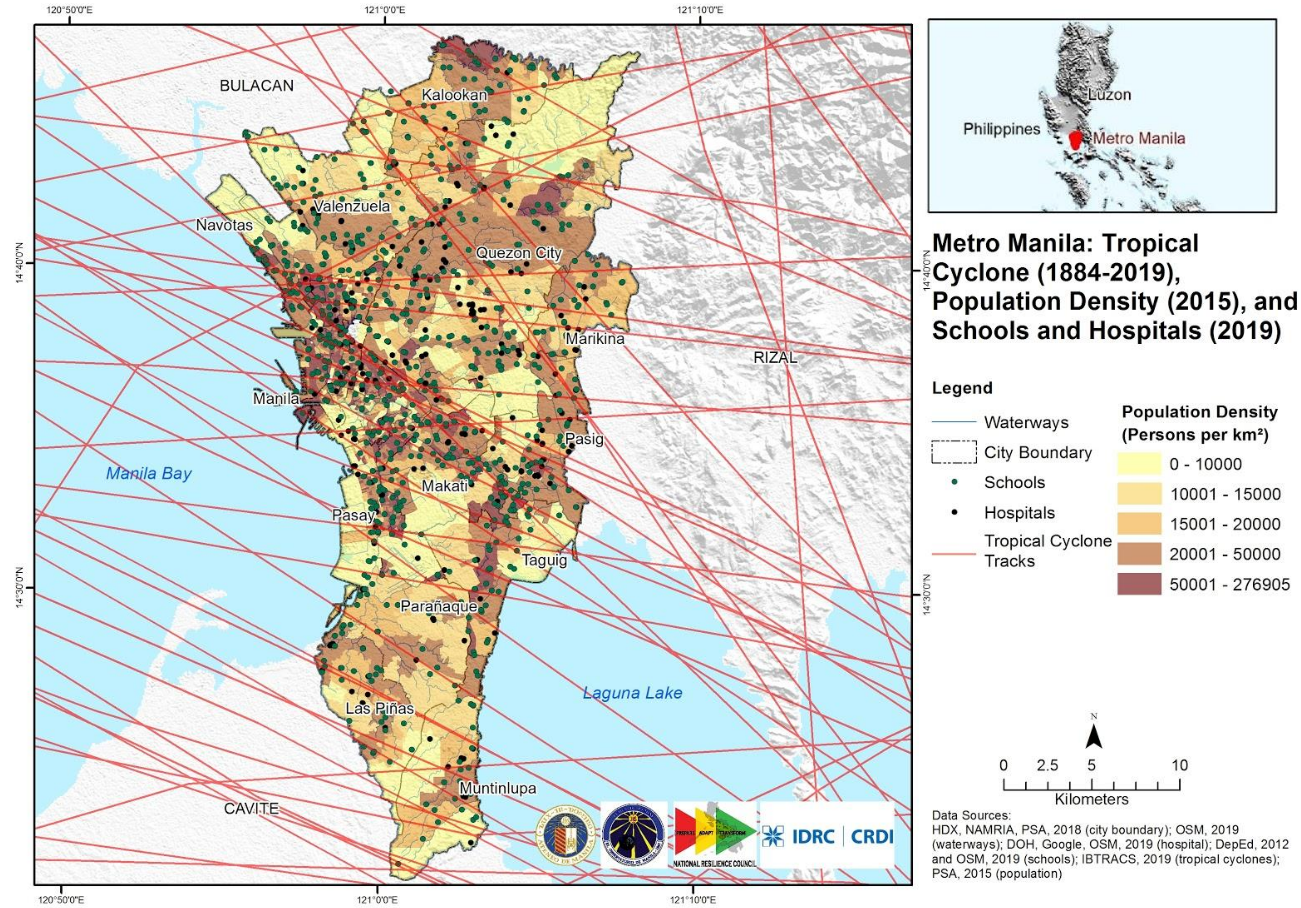

Figure 63. Tropical Cyclone 1884-2019, Population Density 2015, and Schools and Hospitals Areas with more than 125,000 populations are hit by typhoons less often than other areas. These areas are found in Quezon City, Kalookan, and Taguig (Figure 64). They have much less typhoons passing directly over them. On the other hand, the areas of a lot of hospitals and schools are also hit a lot by these typhoons.

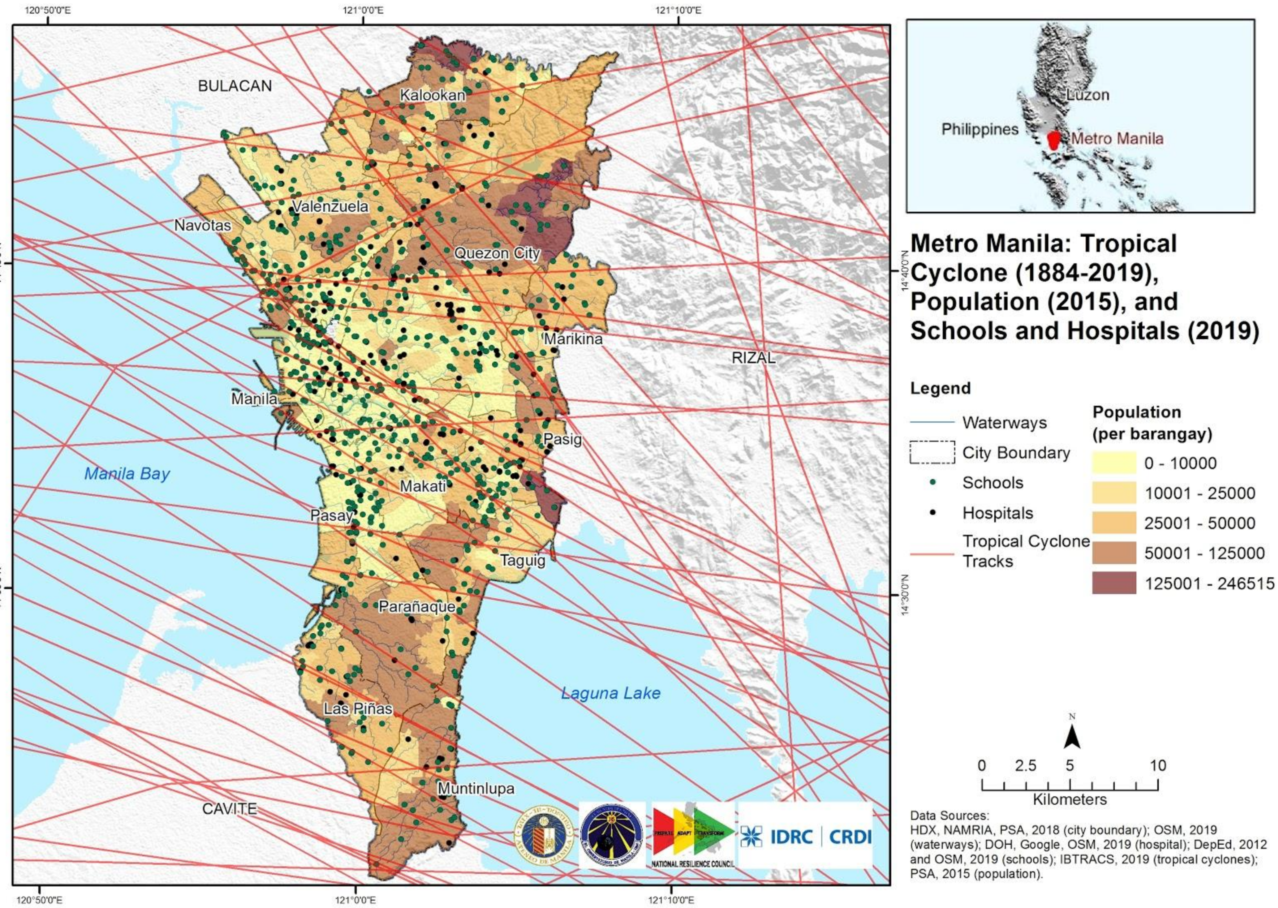

Figure 64. Tropical Cyclone (1884-2019), Population (2015), and Schools and Hospitals (2019)

Visualizing and estimating the impacts of storm surge through maps

<u>Storm surge in coastal cities of Metro Manila</u>

Storm surge is an increase in sea level that inundates low-lying coastal areas during tropical cyclones. This type of coastal inundation is different from the coastal inundation caused by astronomical tides. The astronomical tide, together with storm surge is called storm tide. Storm surge is also different from tsunami that is caused by earthquakes in the oceans.

Storm surge is primarily a product of strong winds associated with tropical cyclones. As the tropical cyclones move towards the land, the atmospheric pressure drops, strong winds push water up causing waves that could move inland. Storm surge severity is influenced by the storm intensity, speed, size, pressure, shape characteristics and slope of bathymetry. Stronger, faster, and larger tropical cyclones carry stronger winds affecting a larger area. Flatter coastal topography tends to have higher storm surges compared with steeper coast as the ocean waves can easily move inland.

Storm surge can be fatal as recorded in historical events. Storm surges have taken thousands of lives in various parts of the world. In the Philippines, the most recent and destructive storm surge event was caused by Typhoon Haiyan in 2013 that killed 6,000 people in the Visayas Region. Metro Manila faces the west coast. Hence, it is prone to less powerful tropical cyclones compared to the eastern regions. Despite of its location, Metro Manila is not spared from storm surges. In a study conducted by Morin, Warnitchai & Weesakul in 2016, they found out that a total of 89 tropical storms (even the weaker storms) passing within 50km north or south of Metro Manila spawned storm surges (1.7 storm surge per year) from 1960-2012. Most of these storm surges have low level and intensity and not as deadly and destructive as Haiyan (Morin, Warnitchai & Weesakul, 2016). The most destructive storm surge in Metro Manila was associated with Typhoon Nesat in 2011. During this storm surge event, maximum storm surge level was 0.78 meters with additional high tide water that made the water level to rise up to 1.28 m.a.s.l. (Morin, Warnitchai & Weesakul, 2016). This storm surge level is relatively low. Nevertheless, it destroyed 2,000 informal settlement housing along the coast of Navotas City and damaged some parts of the sea wall. Their research has pointed out several factors such as ground subsidence due to unregulated groundwater extraction (Rodolfo & Siringan, 2006), sea level rise measuring 15mm/year which is 10 times higher than the average rate of global sea level rise of 1.7mm per year (Church et al., 2013), the storm surge coinciding with the high tide, and the vulnerability of the informal settlements construction leading to this storm surge damage in Navotas.

People living in Navotas have been used to coastal inundation due to tides. The high tide inundation has disrupted the lives of people as they cannot go to school and to work and get sick (Porio, 2011; Morin, et al., 2016). But storm surge carries a greater force than tidal inundation, hence more destructive. Storm surges will happen again and again as tropical cyclones continue to pass over our country. Low-lying coastal cities like Navotas, Manila, Pasay, Las Pinas, Paranaque and Malabon are the most prone to storm surges compared to other cities of Metro Manila (Table 4). Maps show how these cities have varying exposures and vulnerabilities to storm surge hazard. In Metro Manila, the city of Manila has the largest area (31.73 sq.km. corresponding to 75.6% of the city) exposed to a storm surge level exceeding 5-meters, the highest storm surge level data available from Project NOAH. Aside from Manila, coastal cities of Malabon, Navotas and Pasay City have high exposure to >5-meter storm surge. More than 99% of Navotas is exposed to >5-meter storm surge. Overall, 15.6% of Metro Manila is prone to this level of storm surge.

Table 4. Metro Manila cities' exposure to >5-meter storm surge

CITY	Area affected by >5m Storm Surge (sq.km.)	City Area (sq.km.)	%Area affected by storm surge
City of Navotas	10.44	10.54	99.1
City of Malabon	12.49	15.77	79.2
City of Manila	31.73	41.98	75.6
Pasay City	7.68	17.89	42.9
City of Valenzuela	11.70	46.57	25.1
City of Parañaque	9.89	44.84	22.1
City of Las Piñas	5.29	32.75	16.2
City of Makati	1.31	24.97	5.2
Caloocan City	2.60	53.25	4.9

Exposure and vulnerabilities to storm surge

Land use

Our estimation shows (Table 5) that of the land use classes in Metro Manila, the informal settlements have the greatest exposure to the varying levels of storm surge (from the lowest up to the highest hazard level). The substandard housing construction materials and highly populated nature of the urban informal settlements make them at higher risk to storm surge (Brecth, et al., 2012; Morin, et al., 2016).

Table 5. Land use affected by >5-meter storm surge

	Area affected per storm surge height (low-high hazard)			
Land Use	**2-3m**	**3-4m**	**4-5m**	**>5m**
Informal Settlements	5.0	14.2	24.2	27.6
Residential	2.6	7.8	15.8	19.7
Industrial	1.6	6.9	13.7	16.4
Water	7.5	10.3	12.3	12.4
Bare	0.8	1.8	3.8	4.6
Grass	0.3	1.2	3.1	4.0
Tree	0.7	1.7	3.0	3.4
Commercial	0.1	0.7	1.2	1.6
Total	**18.5**	**44.5**	**77.2**	**89.8**

Figure 98 show that a 2-3 meter high storm surge would affect mostly the northern coast of Metro Manila. It covers Navotas and Malabom City and some portions of Manila where a lot of informal settlers dwell (Figure 99-100). A 3-4 meter storm surge would cover Navotas, Malabon and some portions of Manila (Figure 101-104). Higher storm surge height (4-5 meters would affect Navotas, Malabon, most of Manila, some portions of Pasay, Paranaque and Las Pinas (Figure 105). The available worst-case storm surge, greater than 5 meter storm surge (Figure 106), would affect the previously mentioned cities but in a greater extent.

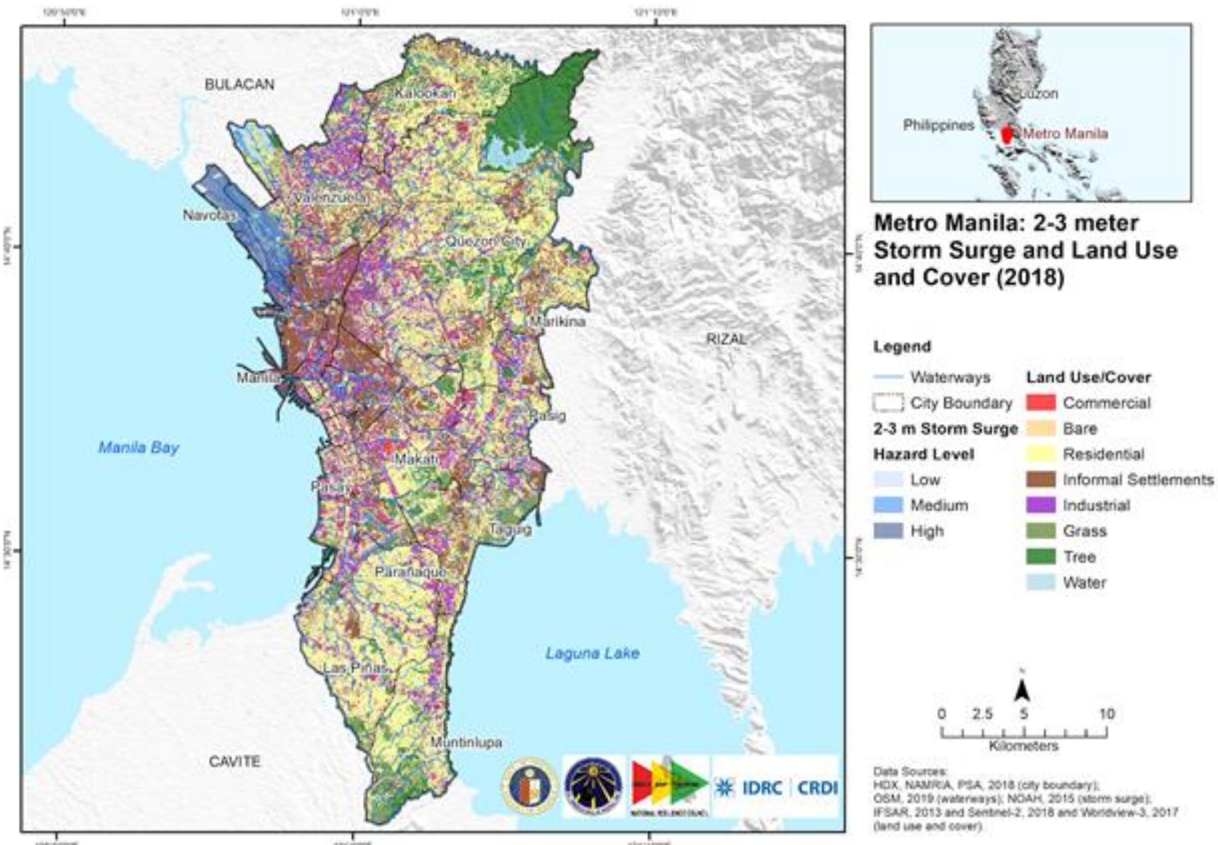

Figure 98. 2-3m Storm Surge and Land Use

Figure 99. Some of the housing units made of substandard materials barely standing near the outlet of Tullahan River in Navotas City that are prone to 2-3 meter storm surge

Figure 100. More houses, composing a dense coastal community in Navotas City

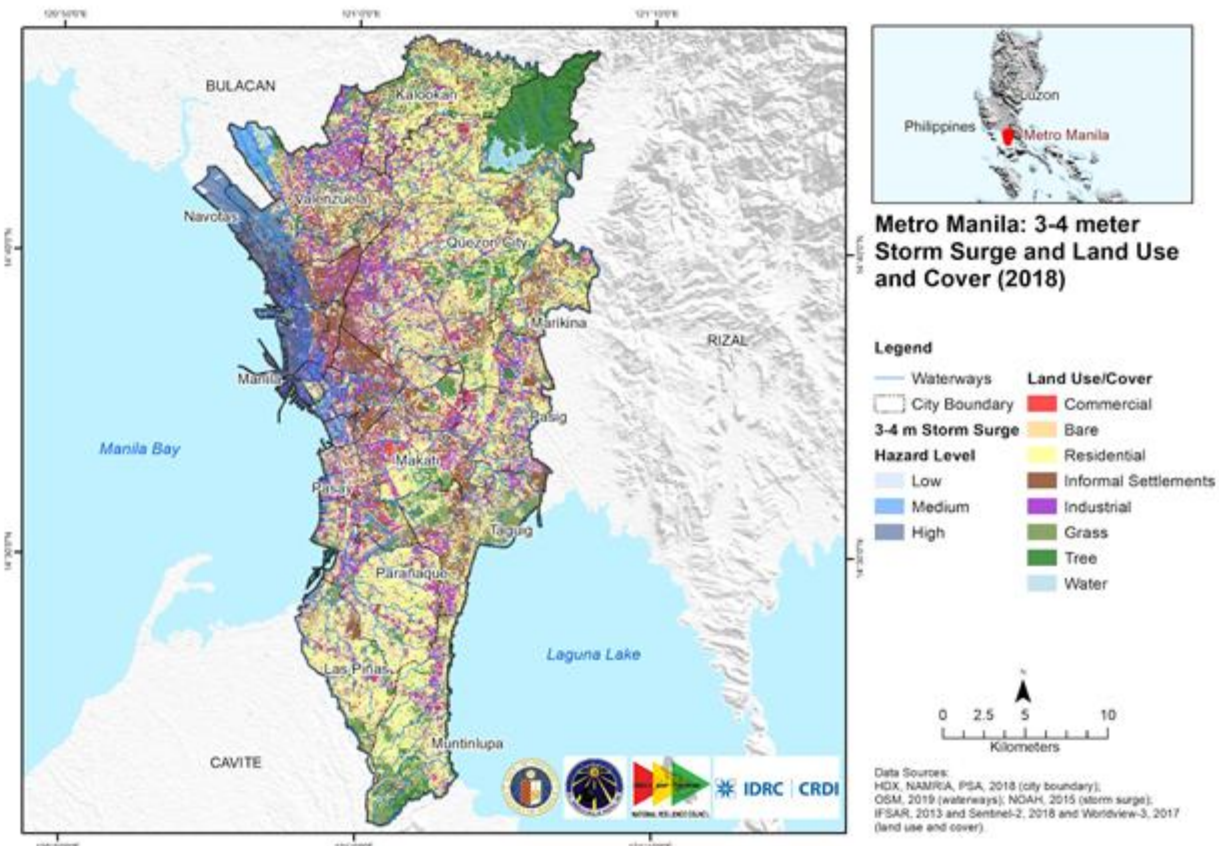

Figure 101. 3-4m Storm Surge and Land Use

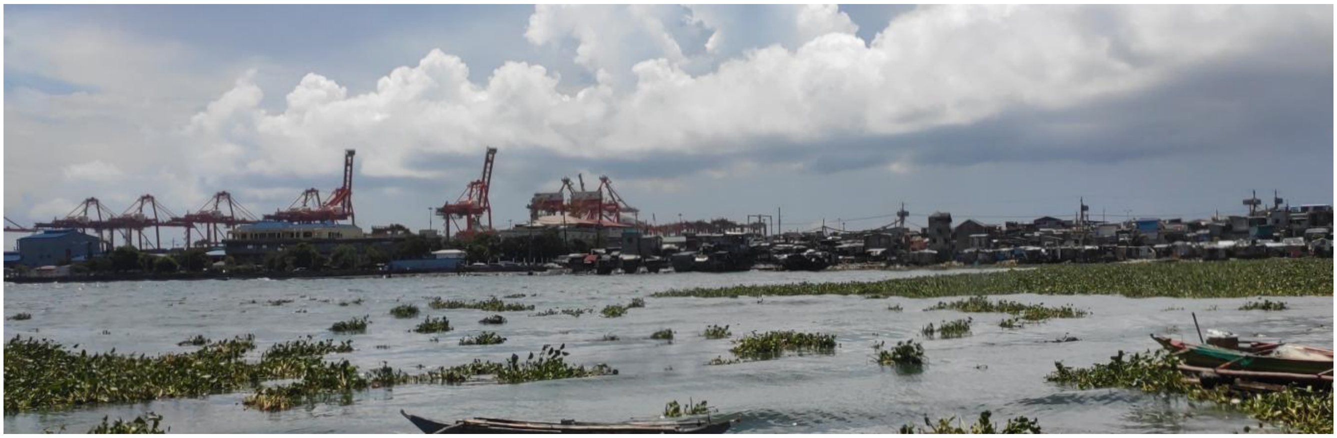

Figure 102. Informal settlements prone to at least 3 meter storm surge line the outlet of Pasig River towards Manila Bay

Figure 103. Informal housing structures beside Radial Road 10 exposed and vulnerable to at least 3-meter storm surge

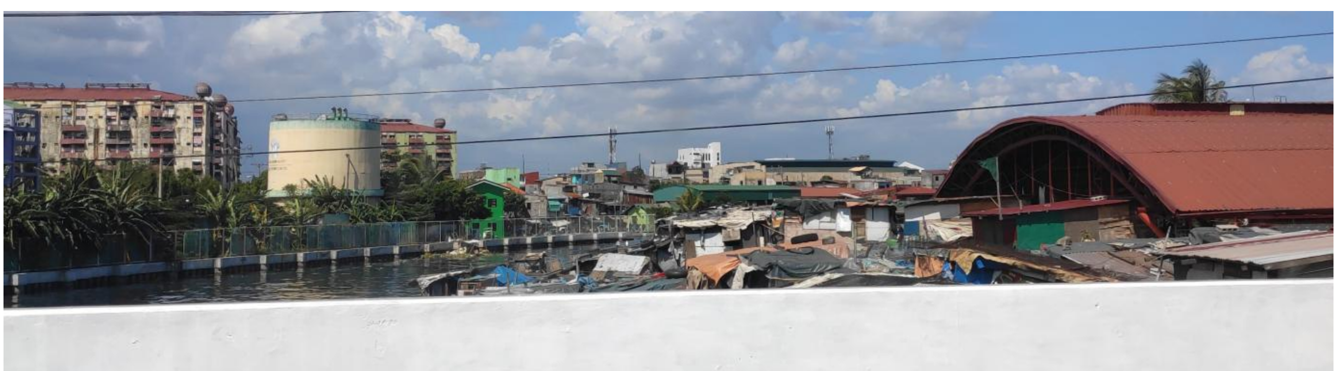

Figure 104. Formal and informal structures are exposed to storm surge inundation as both located near the outlet of Estero de Vitas in Manila but informal structures are more vulnerable to hazards

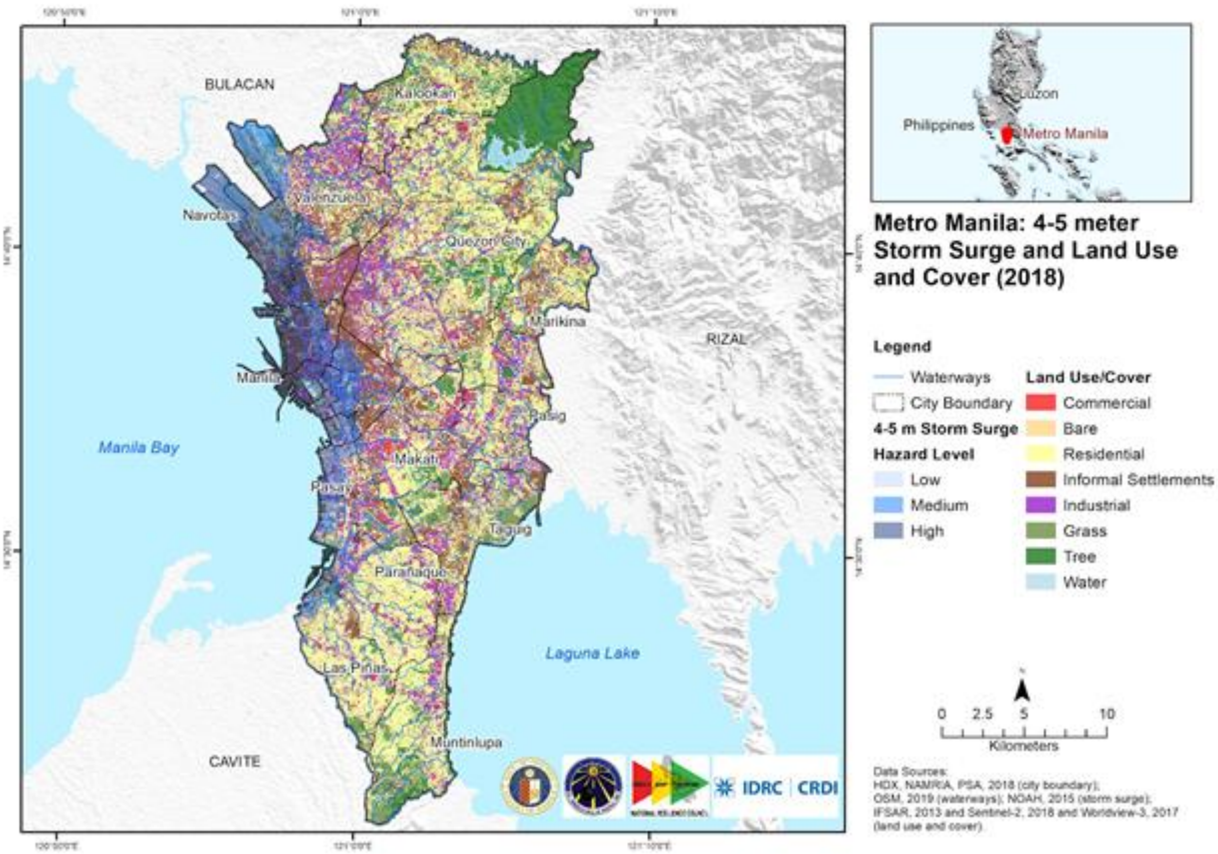

Figure 105. 4-5m Storm Surge and Land Use

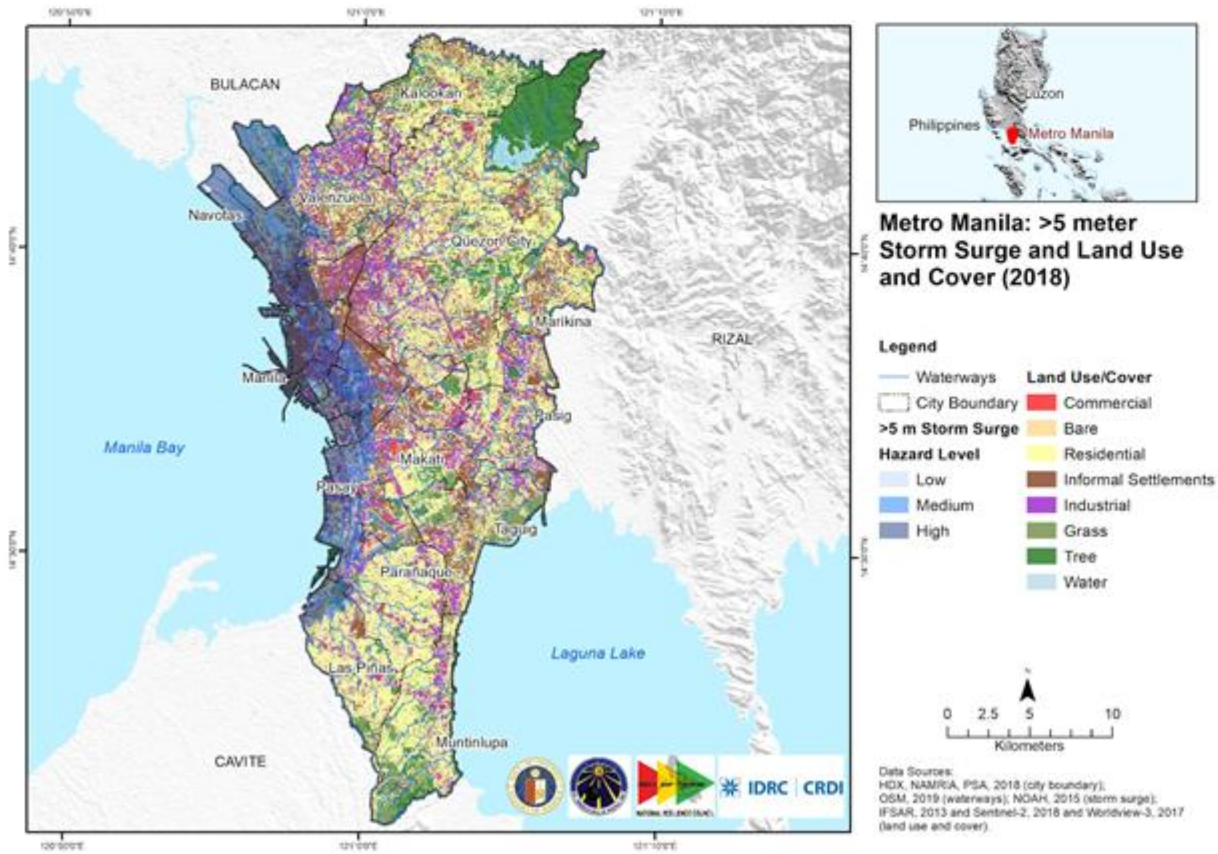

Figure 106. >5m Storm Surge and Land Use

Population demographics and Critical Infrastructures

A total of 515,200 people reside in the areas affected by a 2-3 meter storm surge. An estimated number of 222,000 storm surge-exposed people live in Navotas City. This makes up 26.8% of Navotas' City population. Malabon, Manila, Valenzuela, Paranque, and some parts of Las Pinas, Caloocan and Pasay City are also exposed to a 2-3 storm surge hazard (Table 6).

Table 6. Estimated population in 2-3 meter storm surge per city

CITY	**2-3 m Storm Surge Affected area (sq.km.)**	**Estimated population living in 2-3m Storm surge-affected area**	**% of City Population**
CITY OF NAVOTAS	9.41	222,000	26.8
CITY OF MALABON	7.80	184,000	19.9
MANILA	2.36	80,000	4.5
CITY OF VALENZUELA	0.88	10,000	3.8
CITY OF PARAÑAQUE	0.62	10,000	1.6
CITY OF LAS PIÑAS	0.23	5,000	2.8
CALOOCAN CITY	0.06	4,000	1.4
PASAY CITY	0.16	200	1.1
TOTAL	**21.52**	**510,000**	

A worst-case scenario of more than 5 meter storm surge would affect roughly 2.6 million people in Metro Manila. A third of this population are children. Tondo would have the greatest number of affected people (more than 600,000 people or roughly 99% of its population). Malabon and Navotas would follow Tondo. Table 7 show the other cities and districted that would be affected by a more than 5-meter storm surge inundation.

Table 7. Computed >5 meter storm surge-affected population per city/city district

City/City District	Affected population	Affected children	Affected elderly	% of City Population	% of Child Population	% of Elderly Population
TONDO I / II	625,981	242,508	40,080	99.1	38.4	6.3
CITY OF MALABON	303,338	111,629	21,409	83.0	30.5	5.9
CITY OF NAVOTAS	248,873	95,569	16,006	99.8	38.3	6.4
CALOOCAN CITY	193,886	70,082	12,104	12.2	4.4	0.8
PASAY CITY	161,453	50,565	10,229	38.8	12.1	2.5
CITY OF VALENZUELA	125,508	44,578	9,109	20.2	7.2	1.5
CITY OF PARAÑAQUE	122,497	41,294	7,049	18.4	6.2	1.1
SAMPALOC	120,619	39,060	7,941	32.2	10.4	2.1
CITY OF LAS PIÑAS	120,370	45,251	7,771	20.4	7.7	1.3
SANTA CRUZ	102,315	31,654	6,132	77.4	23.9	4.6
MALATE	84,831	29,679	6,039	98.4	34.4	7.0
PACO	80,328	27,458	5,984	97.4	33.3	7.3
PORT AREA	66,588	29,795	1,745	99.8	44.6	2.6
SANTA ANA	64,644	21,742	5,151	33.1	11.1	2.6
PANDACAN	61,402	22,261	4,040	70.3	25.5	4.6
SAN NICOLAS	42,971	16,955	2,479	99.8	39.4	5.8
QUIAPO	28,393	10,122	1,344	99.7	35.5	4.7
CITY OF MAKATI	27,063	7,381	2,350	4.6	1.3	0.4
BINONDO	18,040	5,003	1,647	100.0	27.7	9.1
SAN MIGUEL	17,430	6,366	989	99.8	36.5	5.7
ERMITA	10,518	3,157	997	100.0	30.0	9.5
INTRAMUROS	5,805	2,209	232	97.8	37.2	3.9
TOTAL	2,627,047	952,110	170,595			

A concentration of schools (Figure 102) and hospitals (Figure 103 and 104) along the coastal cities of Navotas, Malabon, Caloocan, Manila, Pasay, Paranaque, and Las Pinas would be affected by a storm surge inundation of more than 5 meters high. With a huge child population in these cities, classes in these schools would be suspended. This would affect children’s education. Aside from schools, hospitals in the affected cities would be inundated.

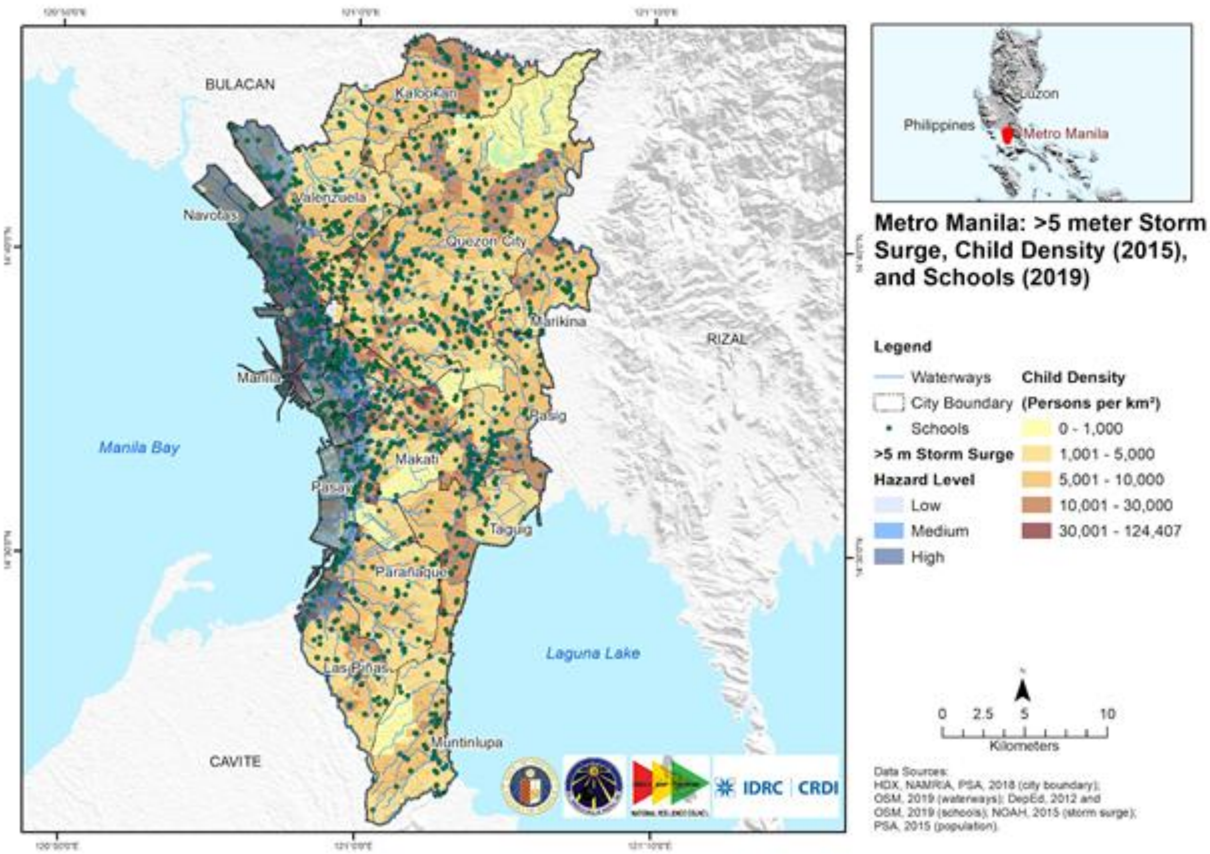

Figure 107. >5-meter storm surge, child density (2015), and schools (2019)

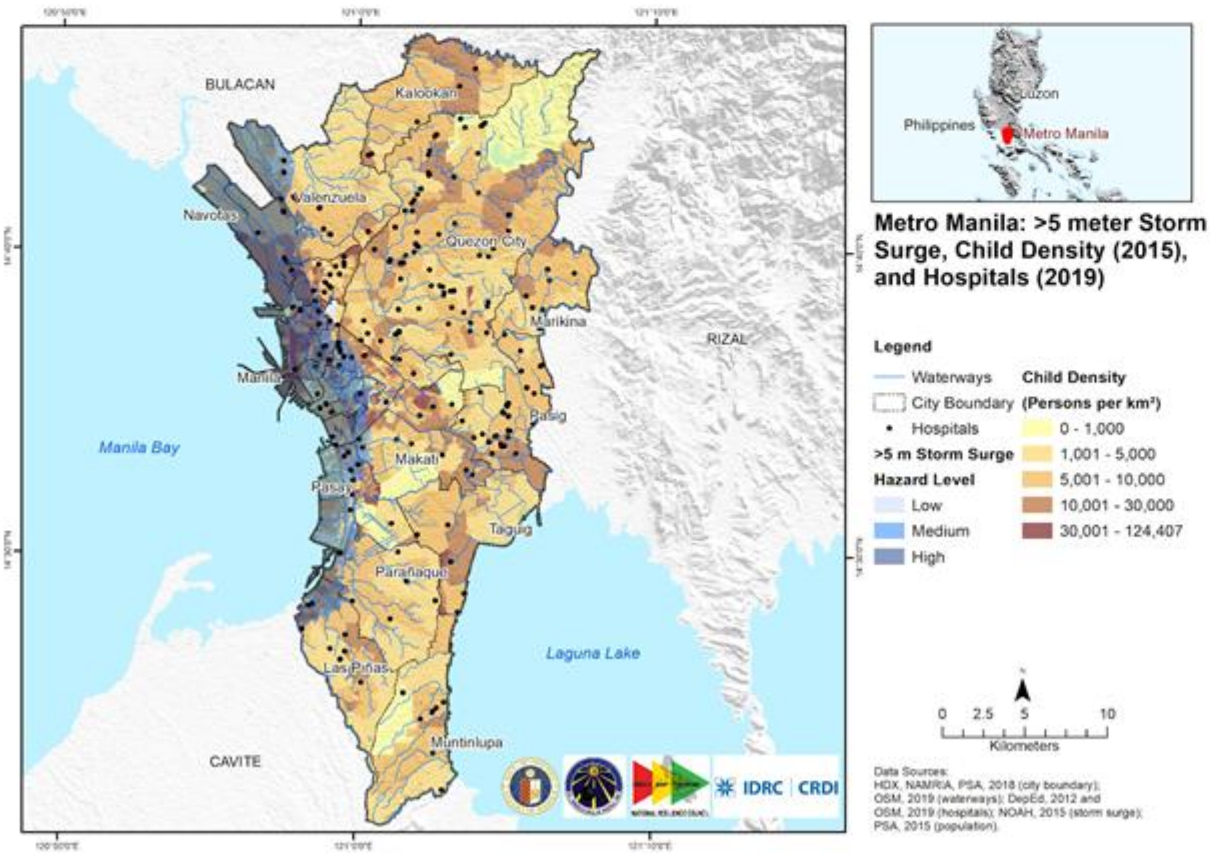

Figure 108. >5-meter storm surge, child density (2015), and hospitals (2019)

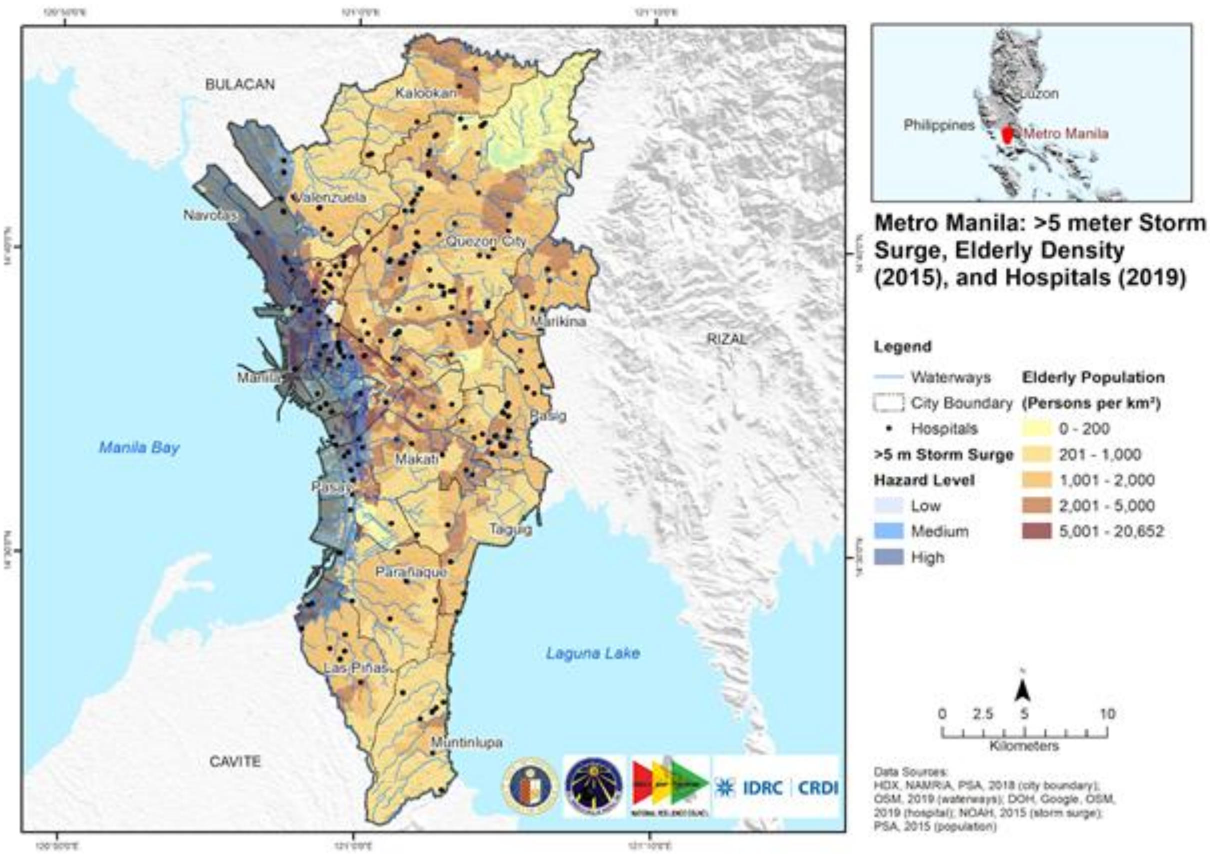

Figure 109. >5 meter storm surge, elderly density (2015) and hospitals (2019)

Informal Settlements

Secondary data and visual observation on the ground undeniably shows that the poor are the main vulnerable population to storm surge especially those that are living at the coastlines. Table 8 show the estimate of informal settler population in the cities of Metro Manila. Manila has the most number of people that would be affected by a 5-meter and more high storm surge. Metro Manila has an estimated number of 4.3 million people living in informal settlements which here refers to the physically vulnerable settlements. Manila had the most number of people living in physically vulnerable settlements and also has the highest number of people exposed to a storm surge at least 5 meters high.

Table 8. Estimated informal settler population per city in Metro Manila

City	Estimated Population in physically vulnerable settlements
Manila*	1,205,000
Quezon City	684,000
Caloocan*	680,000
Taguig	252,000
Makati	212,000
Pasig	195,000
Pasay*	172,000
Valenzuela	152,000

Malabon*	146,000
Mandaluyong	135,000
Marikina	127,000
Navotas*	121,000
Las Pinas*	76,000
Paranaque*	60,000
Muntinlupa	46,000
San Juan	30,000
Pateros	10,000
Total	**4,303,000**

*Cities that are most prone to storm surge

Vulnerable population

Manila has the most number of people exposed to >5 meter storm surge. has the most number of informal settlers. Of the cities exposed to storm surge, Manila also has the highest number of people living in extremely difficult condition including child head of the family, elderly head of the family, single head of the family, single parent and persons with disability. Great exposure to storm surge and the vulnerable condition of its huge population means would make the exposed and vulnerable population suffer greatly to this hazard. Hence, Manila and other coastal cities exposed to storm surge should mitigate the hazard and have preparation and recovery measures for the exposed population, especially for the vulnerable ones.

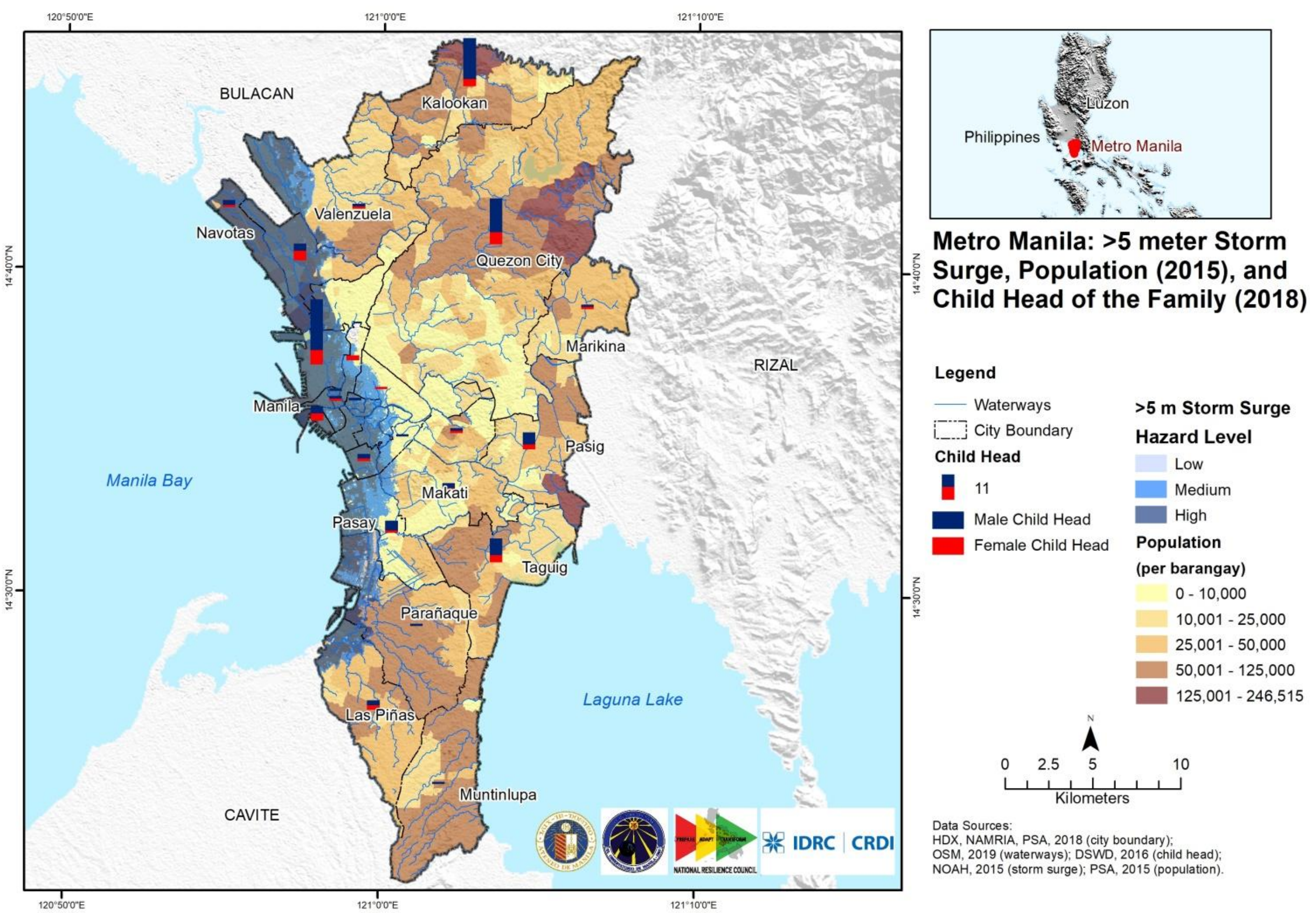

Figure 110. >5 meter storm surge, population (2015), and child head of the family (2018)

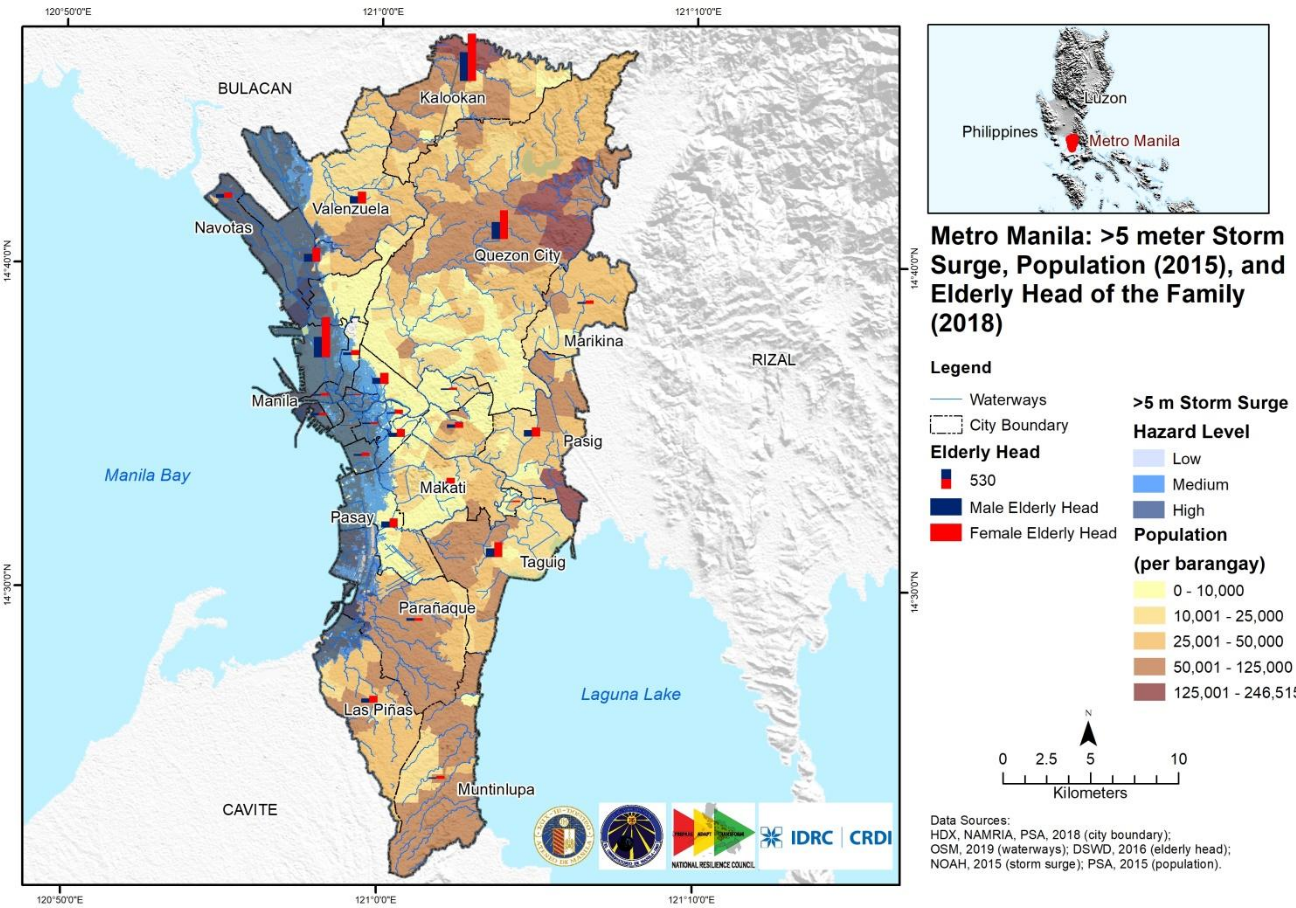

Figure 111. >5 meter storm surge, population (2015), and elderly head of the family (2018)

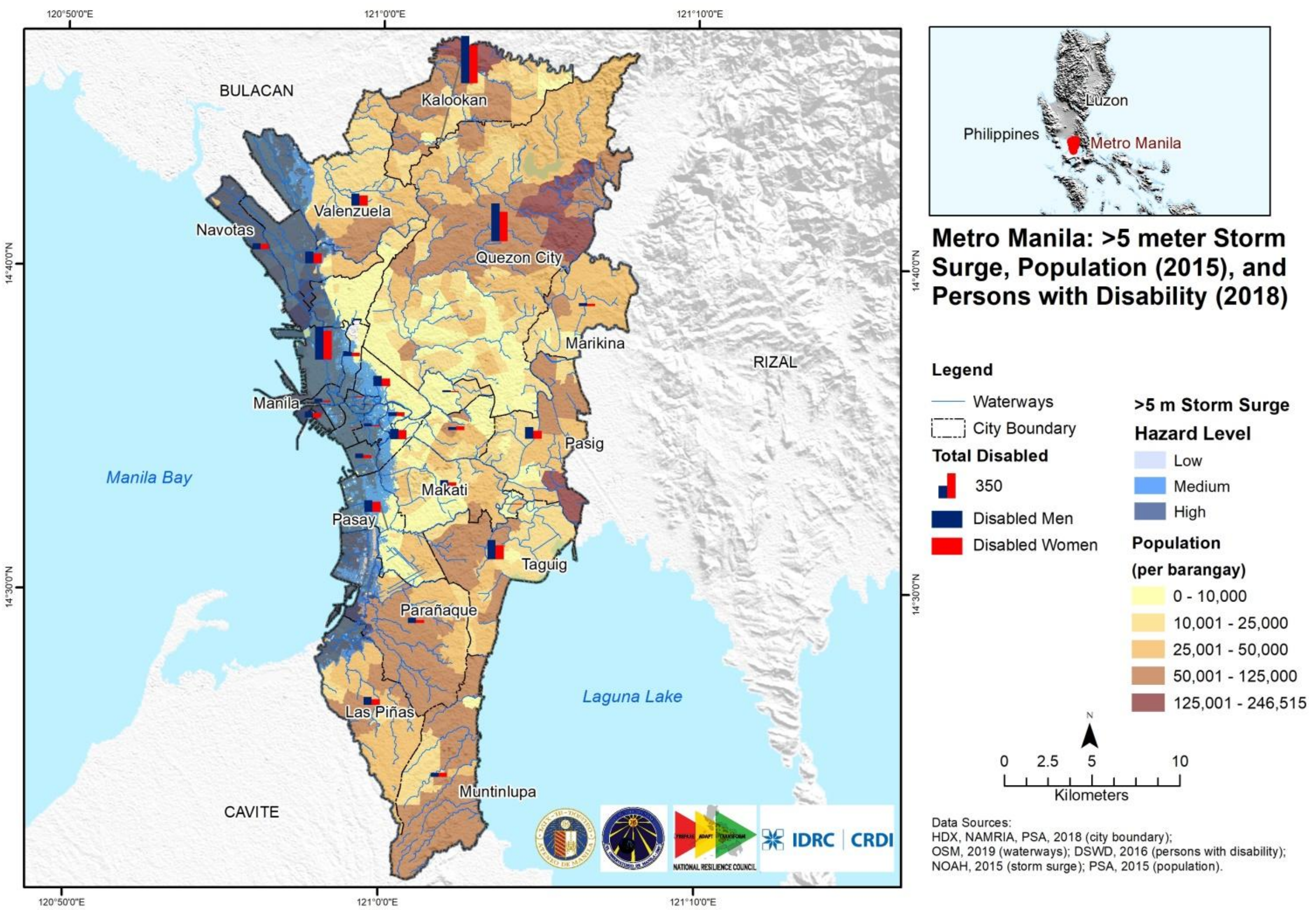

Figure 112. >5 meter storm surge, population (2015), and persons with disability (2018)

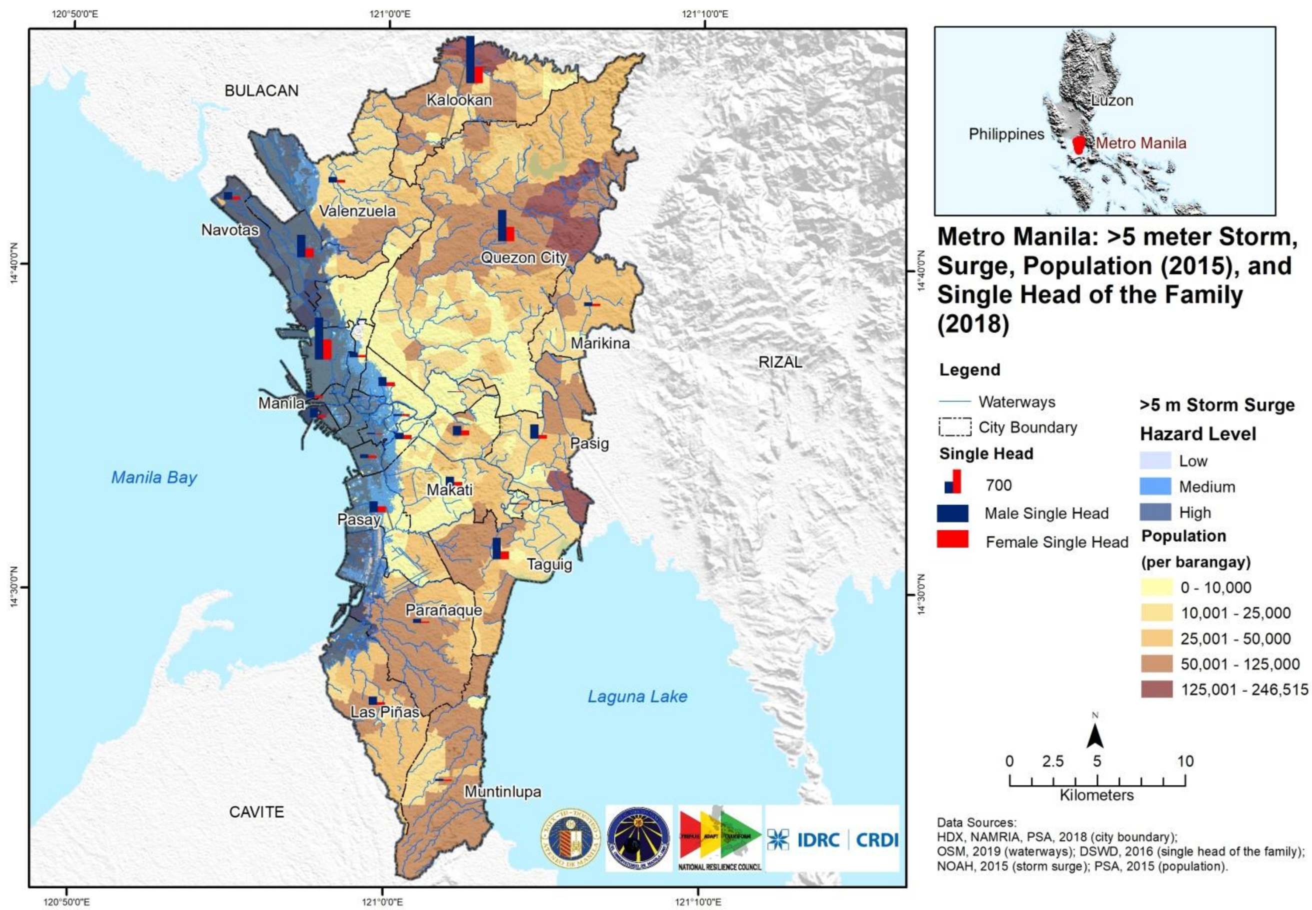

Figure 113. >5 meter storm surge, population (2015), and single head of the family (2018)

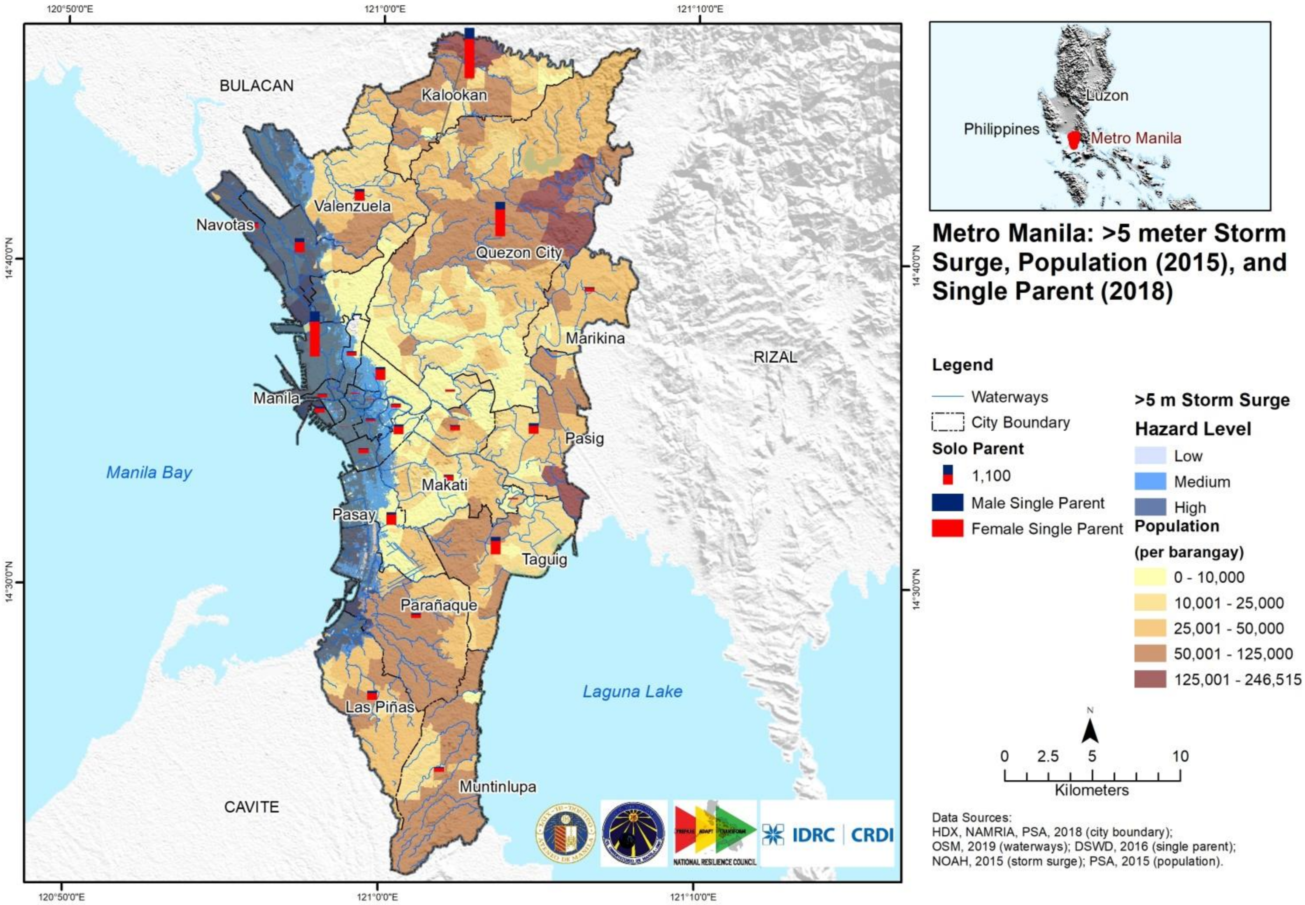

Figure 114. >5 meter storm surge, population (2015), and single parent (2018)

The impact chain showed in Figure 115 summarizes the interactions of the variables a storm surge affects. Storm surges are associated with stronger typhoons. Sea level rise, high rides, and land subsidence can raise storm surge height. A worst-case scenario of storm surge could affect 20% of Metro Manila's population. The most vulnerable to this hazard are the elderly, children, informal settlers and people under extremely difficult condition. Exposed population might suffer from health problem like leptospirosis. They may also incur injuries. Structures and houses especially those structurally weak housing units could also get damaged. Identified critical infrastructures are hospitals and schools.

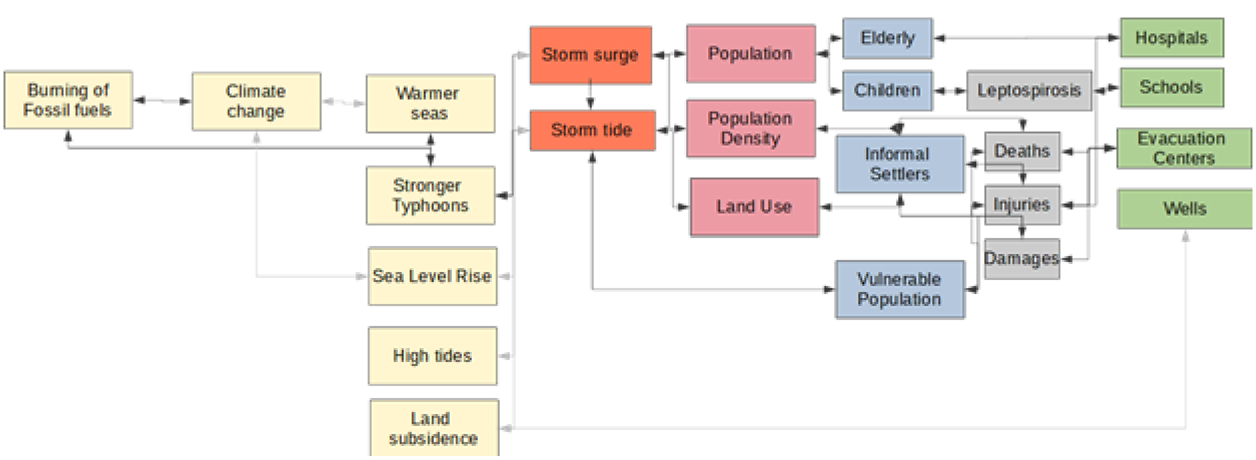

Figure 115. Impact chain of storm surge

III. CONCLUSIONS

Visualizing risk can be a helpful exercise for analyzing, understanding and communicating risk and its variables. One way of visualizing risk is through GIS mapping. For this visualization technique, two things are important: the location and the nominal value. Geographic location is important for mapping critical infrastructures. On the other hand, the nominal value of exposure and vulnerability variables like population, population density, number of vulnerable population, demographics and others help in estimating the exposed and vulnerable entities to a specific hazard. In addition, both the location and the intensity of the hazard two of the most important information in visualizing risk. There are a variety of techniques that can be used for integrating the hazard, exposure and vulnerability variables. For this study, we choose risk overlays because of its simplicity. Risk overlays simply put the risk variables one on top of the other. While the idea of risk overlays is simple, the execution can also be tedious because the risk components have to be mapped in a meaningful manner. Hence, it would be important to have a background of the local situation of the study site. It also helps if one has an understanding of the interactions of the risk components as they happen on the ground. One exercise that can help understand these interactions is the impact chain. In addition, integrating multiple data in a single map and representing them in symbols that preserve the wealth of information while simplifying the interpretation and extracting meaningful insights can be tedious and confusing. This method requires adjustment of sizes, colors and great attention to detail. This method also requires a set of artful eyes to make decisions for better risk information communication. Finally, the simplicity of the idea can result in a multitude of maps that need to be interpreted to be communicated. Sometimes, great number hinders proper communication and comprehension. Hence, not only is it important to present the information in an artful form but more importantly the map maker has to be critical in choosing the layers to integrate in a map and interpret the intersections meaningfully. While risk overlay can be helpful in analysis, the recommendations it can yield with regards to policies can be general and limited to the spatial distribution, and estimates. For more in depth and definitive analysis, other methods may be employed.

Different cities in Metro Manila experience different types of hazard affecting the varying members of society and types of land uses. These exposed entities have varying levels of susceptibility, adaptation and coping capacities. Cities should be aware of their exposure and vulnerabilities to the hazards so that they can craft adaptation and mitigation measures to resist the harmful impacts of hazards.

IV. RECOMMENDATIONS

General recommendations that surfaced out of this risk overlay exercise are as follows

Rising temperature

1. Preserving the vegetation to reduce surface temperature.
2. Live healthier lifestyles especially for elderlies and nearing old age to resist diseases related to extremely warm temperatures.
3. Improvement of health services especially in cities that are going to experience warmer climate to better address the diseases related to warmer temperature.

4. Improve sanitation especially in cities that have dengue cases.
5. Reduce water wastage to have enough water supply.
6. Reduce causes of fire hazards. Indiscriminate throwing of cigarette butts should be prohibited. Fix the electric connections especially in informal settlements to avoid fire incidents. Trainings and seminars on fire prevention should be given to those vulnerable communities. More fire hydrants should be installed in dense communities. Clear roads from obstructions so that responders can quickly and easily mobilize.
7. A map of power lines would help in identifying fire-prone areas.

Rainfall, flooding, tropical cyclones and storm surge

1. Flood damage to hospitals, schools and universities also poses unexpected financial worries for parents, relatives and the staff (Cutter et. al., 2003). These infrastructures must have strong foundations and structural materials. Hospitals and other health facilities should be strategically located and have strong structural forms for catering the needs during and after flood events.
2. Evacuation sites and routes should also be mapped and plotted for risk overlays.
3. Other critical infrastructures such as drainage lines, water distribution lines and power lines should also be mapped out.

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VI. APPENDICES

A. Data Sources List

Table x. List of datasets used, their corresponding sources and year of data acquisition or update

Data	Source	Year

Base map		
Water ways	OSM	2019
City Boundaries	HDX, NAMRIA, PSA	2018
Hazard		
Flood	PhiL-LIDAR	2017
Baseline rainfall	Aphrodite, SEACLID/CORDEX-SEA, RCS	2019
Rainfall projection (early 21st century)	Aphrodite, SEACLID/CORDEX-SEA, RCS	2019
Rainfall projection (mid-21st century)	Aphrodite, SEACLID/CORDEX-SEA, RCS	2019
Rainfall projection (late 21st century)	Aphrodite, SEACLID/CORDEX-SEA, RCS	2019
Rainfall	Aphrodite, SEACLID/CORDEX-SEA, RCS	2019
Storm Surge (2-3 m)	NOAH	2015
Storm Surge (3-4 m)	NOAH	2015
Storm Surge (4-5 m)	NOAH	2015
Storm Surge (>5 m)	NOAH	2015
Baseline temperature	Aphrodite, SEACLID/CORDEX-SEA, RCS	2019
Temperature projection (early 21st century)	Aphrodite, SEACLID/CORDEX-SEA, RCS	2019
Temperature projection (mid-21st century)	Aphrodite, SEACLID/CORDEX-SEA, RCS	2019
Temperature projection (late 21st century)	Aphrodite, SEACLID/CORDEX-SEA, RCS	2019
Tropical Cyclone	IBTRACS	2019
Exposure		
Child Population	PSA	2015

Elderly Population	PSA	2015
Informal Settlements	IFSAR, Worldview-3, Sentinel-2	2013, 2017, 2018
Land Use	PSA	2015
Population	PSA	2015
Working Age Population	PSA	2015
Youth Population	PSA	2015
Vulnerability		
4Ps Beneficiaries	DSWD	2018
Child Head of the Family	DSWD	2018
Dengue	DOH	2018
Diarrhea	DOH	2018
Elderly Head of the Family	DSWD	2018
Fire Hydrant	OSM	2019
Fire Station	OSM	2019
Heart Disease	DOH	2016
Hospital	DOH, Google, OSM	2019
Leptospirosis	DOH	2018
Persons with Disability	DSWD	2018
Schools	DepEd, OSM	2012, 2019
Single Head of the Family	DSWD	2018
Single Parent	DSWD	2018
Water Facilities	OSM	2019
Water Sources	PSA	2015
Wells	NWRB	2016

B. Method

1. Data preparation

To visualize risk, we needed to dissect risk into its hazard, exposure and vulnerability components for the local units. The components have to be represented as points, polylines, polygons or rasters depending on its nature for spatial visualization. Some of these datasets are attributed to a local unit while others are represented by geographic points and others are represented using polygons.

Population data were collected from Philippine Statistics Authority and mapped to the barangay boundaries from National Mapping and Resources Information Authority. The barangay boundaries were updated by Human Data Exchange.

DOH website listed 16 hospitals in Metro Manila with the address, contact person and contact information. DOH also published a partial list of hospitals with license level 2 and 3 and with ambulance as of December 31, 2018. This list includes 66 hospitals in NCR. For the mapping of hospitals, we cross-validated the lists of hospitals from DOH, Google maps and Openstreemap.org.

Barangay population data of 2015 was collected from PSA and was joined with the barangay boundary map from NAMRIA, updated by Human Data Exchange. The barangay area was calculated. We divided the population by the total area of the barangay in (sq.km.) to compute for the population density. PSA data was disaggregated to age from 0 to 100 years old and male versus female population. We computed for the population of children, youth, working age and elderly based on the NSCB definitions. The population of children, youth, working age, and elderly were also divided by the barangay area to compute for child density, youth density, working age density and elderly density.

Land use and cover map was generated through RS and GIS techniques on Worldview-3, Sentinel-2 and IFSAR datasets from NAMRIA. The informal settlements map was derived from the land use and cover map.

3. HEVRI matching

The “HEV banig” helped us plan the HEV variable combinations to map. The HEV banig contains the dataset layers for H, E, and V. The appropriate symbology and mapping visualization technique for each dataset type was identified.

4. HEVR GIS overlay

The available datasets were plotted on top of other relevant HEV variables.

- overlay analysis - what’s on top of what?

C. Risk Information Interpretation and Analysis

1. Visual Interpretation

Visual interpretation of the risk overlay maps was initially done to see spatial correlation among the variables. We looked for overlaps in the hazards, exposures and vulnerabilities.

2. GIS processing

Another method for risk information analysis was the intersect function in GIS. This could extract the variables a polygonal hazard affects. The affected population can be computed by computing for the hazard-prone area per barangay and multiplying that area by the barangay population density. This will give the number of affected population.

Estimation of informal settlement population

$$IS_{brgy} = Pop_{brgy}/Area_{brgy} \text{ x } Area_{IS}$$

Where:

IS_{brgy} = Informal settlement population
Pop_{brgy} = barangay population,
$Area_{brgy}$ = barangay area
$Area_{IS}$ = informal settlement area per barangay

Estimation of exposed population

$$Pop_e = Pop_{brgy} / Area_{brgy} \text{ x } Area_H$$

Where:

Pop_e = Exposed population
Pop_{brgy} = Brangay population
$Area_{brgy}$ = barangay area
$Area_H$ = area exposed to the hazard