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ACHIEVING ECOLOGICAL SUSTAINABILITY THROUGH A GEOSPATIAL ASSESSMENT OF URBAN LANDSCAPES: A CASE STUDY OF METRO MANILA

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This Special Project titled: “**ACHIEVING ECOLOGICAL SUSTAINABILITY THROUGH A GEOSPATIAL ASSESSMENT OF URBAN LANDSCAPES: A CASE STUDY OF METRO MANILA”** is hereby accepted by the Faculty of Management and Development Studies, U.P. Open University, in partial fulfillment of the requirements for the degree Course.

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This is to certify that:

I. The special problem comprises only my original work towards the MENRM except where indicated in the Preface;

II. Due acknowledgment has been made in the text to all other material used;

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Ulysses Nolan C. Paredes
25 January 2023

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TABLE OF CONTENTS

List of Figures

LIST OF TABLES

List of Appendices

ABSTRACT

The compact city model has been an accepted alternative to urban sprawl. However, the densification of cities has led to a loss of urban green spaces, which provide important ecosystem services such as health benefits, climate regulation, and recreation opportunities. This study focuses on the dynamics of landscape change in Metro Manila from 1992 to 2022, using spatiotemporal analysis and remote sensing technology. The study found that there is an overall loss of urban green spaces in Metro Manila, with 77.69% of the city being composed of impervious land cover and 16.15% being pervious cover with urban greens and vegetation, and 4.27% is water. Much of the undisturbed vegetation are within the region's protected landscapes and private parks and golf courses. Environmental variables such as NDVI show a decrease (-0.03) in the average vegetation health and an increase in the average land surface temperature (+1.60°C) highlighting the urban heat island. The study presents how a low-cost rapid assessment of urban green spaces in Metro Manila can be achieved to identify and map changes in the landscape, understand the drivers of change, and introduce appropriate interventions and management paradigms to enhance the city's resilience in the face of climate change. It is essential to have objective environmental assessment and territorial planning and decision-making stages to consider the needs of the landscape and improve the quality and quantity of urban green spaces.

Keywords: urban ecology, sustainability, smart cities, management, geospatial technology, GIS

I. Introduction

Considered as one of the most ecologically destructive forms of global change (Lin & Fuller, 2013), rapid urbanization or the expansion in built-up areas leads to encroachment onto the Earth's natural landscape, promoting the loss of natural ecosystems and biodiversity. Though this change in land use have enabled humans to expropriate a huge portion of the planet's natural resources, it also has diminished the ecosystem's capacity for food production, regulate climate, air quality, replenish both freshwater and forest resources and ameliorate infectious diseases (Foley et al., 2005).

According to (Brody, 2013), urban sprawl is a development pattern that negatively impacts the natural ecological systems with consequences like air pollution and water pollution, loss or disruption of environmentally sensitive areas, and an overall reduction in quality of life. To combat sprawl and the further loss of ecological services, urban areas need to be efficiently managed and sustainably planned. This led to the deliberate increase of the capacity of cities instead of just its size to accommodate growth as a method of ensuring sustainable development (Pelczynski & Tomkowicz, 2019).

Our urban centers are growing immensely. From a survey conducted in 2020 by the Philippine Statistics Authority (PSA), 58.93 million or 54.0% of the total 109.03 million population of the Philippines lived in urban barangays. This represents an increase of 7.20 million persons from the 51.73 million urban residents in 2015. The level of urbanization or the proportion of the total population living in barangays classified as urban was recorded at 54.0 percent in 2020. This is 2.8 percentage points higher than the 51.2 percent level of urbanization in 2015. Metro Manila is in a perpetual process of densification, a megacity with more than 13 million people spanning 17 local government units. Among the country's 18 administrative regions, Metro Manila is the smallest region and most densely populated. However, urban densification is a complex process, though it is thought to be a viable solution to urban sprawl, it also has negative effects particularly on services such as power (DOE, 2015; Lima et al., 2019) and water (Chhipi-Shrestha et al., 2017; Lee et al., 2020), urban green space (Haaland & van den Bosch, 2015b), and even permeability (Rosenberger et al., 2021)(Lagmay et al., 2017).

Urban green spaces are valued for their ability to enhance the environmental quality of neighborhoods. This all changed when the COVID-19 pandemic spread across Metro Manila in 2020. Urban green spaces were prized for providing "multiple ecosystem services and direct/indirect benefits to mental and physical health" (Addas & Maghrabi, 2022), altering the human behavior towards open spaces (Larson et al., 2021); Metro Manila realized it needed more parks.

Though definitions of Urban Green Space (UGS) vary across disciplines, there are two broad interpretations that can be used. First is that Green Space is synonymous with nature; and second, that it is explicitly urban vegetation (Taylor & Hochuli, 2017). Thus, the importance of these spaces in assisting hydrological and ecological connectivity (Schuch et al., 2017) should be fully acknowledged, conserved, and expanded to reduce impacts of floods and increase permeability. The World Health Organization in their 2017 call for action outlines that people should have "universal-access," to UGS. The WHO further recommends that "urban residents should be able to access public green spaces of at least 0.5–1 hectare within 300-meter linear distance," equivalent to a 5-minute walk, from people's homes. However, the lack of metrics, regulation, management, and planning inclusion in the Philippines compared to other countries highlights the need for studies to be made, such that a desired minimum should be identified and implemented.

Urbanization is part of a process that generally leads to densification where there is a significant effect on urban planning & the environment. Urban Densification has been argued to be a positive response to urbanization and a solution to a more sustainable growth of cities, primarily because it counteracts the negative effects of urban sprawl and increased mobility challenges (Kaur et al., 2020; Rosenberger et al., 2021). The correlation between rapid urbanization and ecosystem services has been well-studied (Wang et al., 2020), however, further research is needed to better understand the unique spatiotemporal interactions between ecosystem services and the urbanization processes in cities and the rural-urban fringe that will lead to a better understanding of the urban ecosystem and help create a more sustainable approach to its management and development growth.

II. Review of Literature

II.01 Urbanization

The world's cities continue to expand and urbanize. According to a study by (Busso et al., 2021), Urbanization is caused by rural to urban migration as well as the natural changes in population. Migration is the movement of population from one area to another. Some migrations are forced, voluntary, permanent and temporary, and at different geographic levels. The United Nations (UN Population Division, 2018), estimates 55.3% of the world's population live in urban settlements and by 2030, urban areas are projected to house 60% of the population with one every three people will live in cities of at least half a million inhabitants. This projection underscores the change in the landscape brought about by the increase of people in urban centers. The rapid growth of the population is the definition of urbanization; however, the term urban should first be defined in context of population and the built environment, highlighting urban as an important indicator, metrics and basis for studies, policies and decisions pertaining to urban planning. The (PSA, 2003) in their NSCB Resolution No. 9 Series of 2003 defines "urban" as areas composed of barangays having the following criteria. That the barangay has a population size of 5,000 or more; or that the barangay has at least one establishment with a minimum of 100 employees, a barangay is considered urban; or the barangay has 5 or more establishments with a minimum of 10 employees, and 5 or more facilities within the two-kilometer radius from the barangay hall, then a barangay is considered urban. The barangay is the smallest political unit in the Philippines that make up cities and municipalities, the population metric in the barangays as well as within establishments direct toward population that live and work within the political unit. This gives clarification on what the context urban plays in the study of population and development.

II.02 Urban Sprawl

The increase in the built environment is a function of its population. The urbanization of cities primarily extends outward past rural boundaries and taking more land and converting this into urbanized extensions of the city (X. Wang et al., 2020). According to Wang et al. (2020), this urban sprawl is a problem affecting the world's cities and creates "start again cities" which are extensions of the original city that can permeate within the city's limits as well as outward. This migration pattern from urban to rural socioeconomic and political conditions (Mora & Deakin, 2019). Though the direction of sprawl varies due to factors such as topography and the human-built environment, the sprawl creates a change of the landscape into primarily residential and commercial use (Haaland & van den Bosch, 2015c).

The sprawling landscape perhaps is perhaps an American invention, with abundant land surrounding cities and the availability of interstates and highways (Mora & Deakin, 2019), it was easy to live far from the city to nearby rural areas and suburbs. Further to Mora & Deakin's (2019) study, the low cost of real-estate as well as the dream of a utopian suburb has been previous planning concepts like the Garden City of Ebenezer Howard. According to (Sharifi, 2016), the main characteristics of Howard's Garden City are ample green spaces, single-family residential units, and street patterns which is widely blamed for suburban sprawl, unfettered urban growth, and egregious impacts on resources and environment.

II.03 Urban Densification and Compact Cities

(Jacobs, 1961) wrote a book that critiques the 1950's style of planning. She argued that modernist urban planning concept, such as those of Robert Moses and Le Corbusier, "overlooked and oversimplified" the complexity of human interaction in diverse communities. The vast expanse of landscape was good design "on paper" but this created strain in terms of resources and transportation. Further into the present, a much denser albeit, compact urban framework is needed to make sustainable cities and it was two mathematicians that coined "compact cities" in 1973 (Dantzig & Saaty, 1973). According to Dantzig & Saaty (1973), a compact city is a more feasible by building a city that makes more effective use of the vertical dimension and the time dimension through around-the-clock use of facilities.

The compact city is the central paradigm of urbanism given its tremendous potential to respond to the mitigate urban sprawl and answers the challenges of sustainable development. A dense urban environment is compact and diverse, presenting a mixed land use, where planners can achieve sustainable transportation and urban green space.

II.04 Urban Green Spaces

Rapid urban expansion according to (Nor et al., 2017), "has had a significant impact on green space structure." Their study modeled and predicted urban expansion in three southeast Asian cities, Kuala Lumpur, Metro Manila and Jakarta, cities that are experiencing rapid urban expansion from 1989 to 1999. The study focused on determining the main drivers of change, including spatial planning, in the resulting spatial patterns. Using Land Change Modeller (LCM)-Markov Chain models they simulated urban expansion for the year 2030. The simulated 2030 spatial structure was then compared with the 2030 master plan for each city using spatial metrics and found evidence that suggests these spatial patterns are influenced by the forms of rapid urban expansion experienced in these cities and respective master planning policies of the municipalities of the cities. The conclude that the use of integrated simulation modelling and landscape ecology analytics can provide significant insights into the evolution of the spatial structure of urban expansion and identify constraints and provide informed interventions that can be used in spatial planning and policies in urban centers.

The importance of Urban Green Spaces to urban biodiversity and public health (WHO Regional Office for Europe, 2016) cannot be ignored and its study is essential to develop a collective understanding of how urban green space can be used for the advancement of population health and wellbeing within the context of rapid urbanization (Shuvo et al., 2020).

The global loss in biodiversity (Segan et al., 2016) highlights the need for conservation even within urban centers. In a study by (Kong et al., 2010) found that though urban green spaces cannot solve biodiversity conservation issues, “it is a step forward” for Jinan City, China. The authors conclude that by using graph theory and by combining with the gravity model, simplified and systematized the complex real landscape to help identify the relative significance of each green space, and guide urban green spaces planning.

A study conducted in Porto, Portugal by (Farinha-Marques et al., 2016) demonstrates how a survey of urban green spaces can be achieved by defining the characteristics of urban green spaces as a set of variables determined by their ecological, social and spatial importance for the occurrence of biodiversity. These variables are: (a) total area; (b) vegetation cover; (c) impermeable area; (d) water; (e) age; (f) dominant function and (g) space character.

A field study conducted by (Du et al., 2021), studies the relationship between UGS and the indicators of Public Health and Well-being (PHW). The authors concluded that to better increase the PHW, the answer does not rest with vegetation density alone and therefore needs a strategical design of the spaces and vegetation to effectively increase the PHW of the users. This includes: (a) accessible lawn and water bodies; (b) open squares; and (c) specific vegetation structure and height ratio. Though their research is subjective in nature, it can be a scientific reference for the urban management to increase the habitability urban greens through an optimized planning of future urban green spaces.

The study of (Gonzales & Magnaye, 2017) provides an analytical approach of assessing urban biodiversity of Green Spaces in the city of Manila. Using (a) spatial mapping, (b) vegetation inventory and profiling, (c) and Simpson's Index of Diversity; the authors established the relationship of urban biodiversity with human settlements resiliency that can be used as basis of determining the “level of exposure of human settlements to natural hazards” such as flooding. Their study can further be developed into development interventions such as proposing urban planning and development restrictions. However, their choice of terrestrial green spaces are the known parks and open spaces and did not include other urban greens such as general landscape found in the city, particularly because the software used, i-Tree Canopy, estimates "tree cover and tree benefits for a given area with through a random sampling process that lets the user easily classify ground cover types (i-Tree Canopy, n.d.).

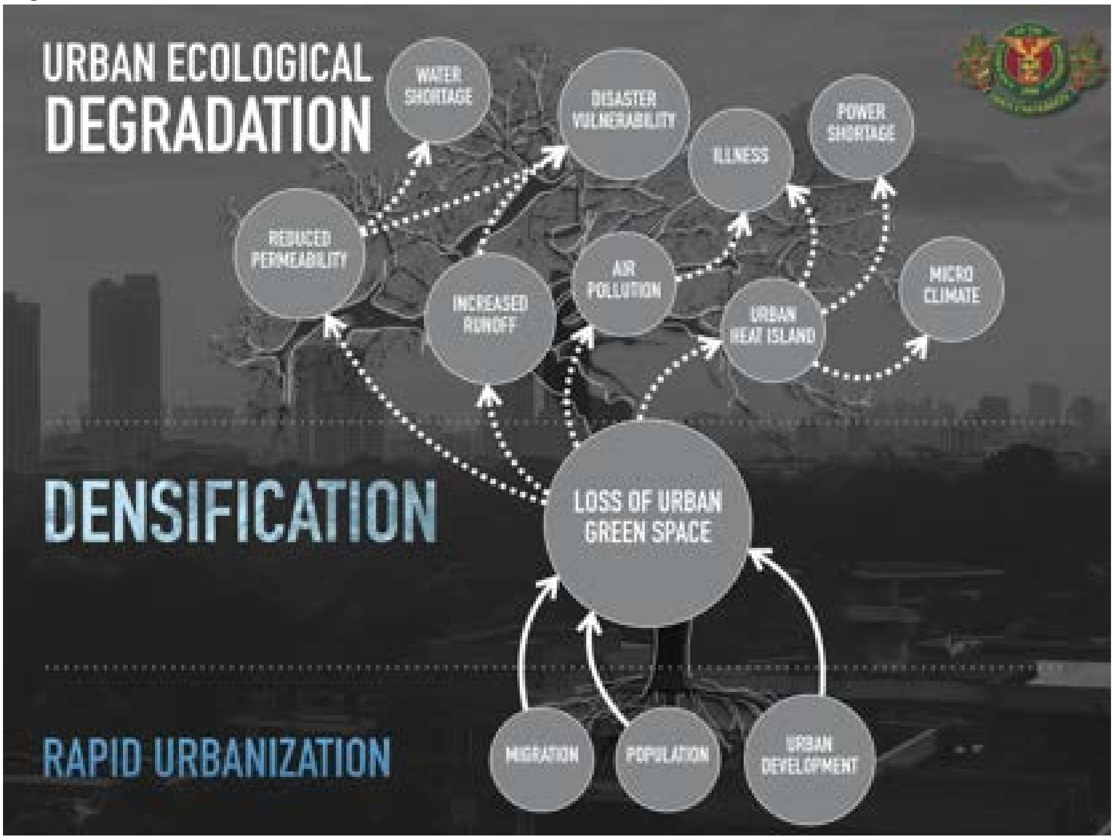
According to (Russo & Cirella, 2018), “the modern compact city is identified as a high-density and mixed-use pattern.” According to their study, this feature contributes to a form of functional urban design that supports sustainability highlights the importance of ecosystem services. Their research points to at least 9.0 square meters of green space per capita with an ideal UGS value of 50.0 square meter. They conclude that (a) on a daily basis, people need to be in contact with nature and UGS can supply this need; (b) UGS is often the only source of nature-based interaction readily available within any reasonable distance; (c) question of how much greenery a person needs is very relevant and determined by minimums prescribed by the World Health Organization and (d) at a societal level, urban dwellers are happier and healthier when those minimums are exceeded. However, definite research cannot be found pointing towards how 9.0 sqm and 50.0 sqm minimum UGS were identified and perhaps need further research.

In the Philippines, the Department of Environment and Natural Resources - Ecosystems Research and Development Bureau (DENR-ERDB) hosted a conference entitled: “Urban Parks and Green Cities: A Sustainable Future in Southeast Asia.” The conference aims to provide “a platform for the government, research community, and institutions for the exchange of information generated from R&D as it targets sustainable development and management of parks and green cities." (DENR, 2022) The conference brought member countries of the ASEAN together with DENR-ERDB officials in a three-day event where a total of thirty-nine papers on the management and impact of urban parks and urban governance and policies for greener cities were highlighted along with topics on Green and Resilient Urban Communities; Urban Biodiversity, Ecosystem, and Economics; Management and Impact of Urban Parks and Urban Governance and Policies for Greener Cities were presented.

III. Statement of the Study

There is no halting the advance of urbanization and the densification of our cities. The COVID-19 pandemic came as a wake-up call that the city has neglected the value of urban green spaces leading to the realization that the urban ecological balance of Metro Manila needs to be checked and managed. With the recent advancements in remote sensing, GIS and the availability of data, environmental research should be able to use these new analytical methodologies to detect and monitor environmental variables to learn how our world works and understand how humans interact with the urban environment; ultimately to find better ways to deal with environmental problems for a more sustainable future.

Figure 1: Problem Tree



This special problem assesses the land cover change in Metro Manila from 1992 to 2022, identifying the dynamics of its change and determining its effects to the urban green space allotment.

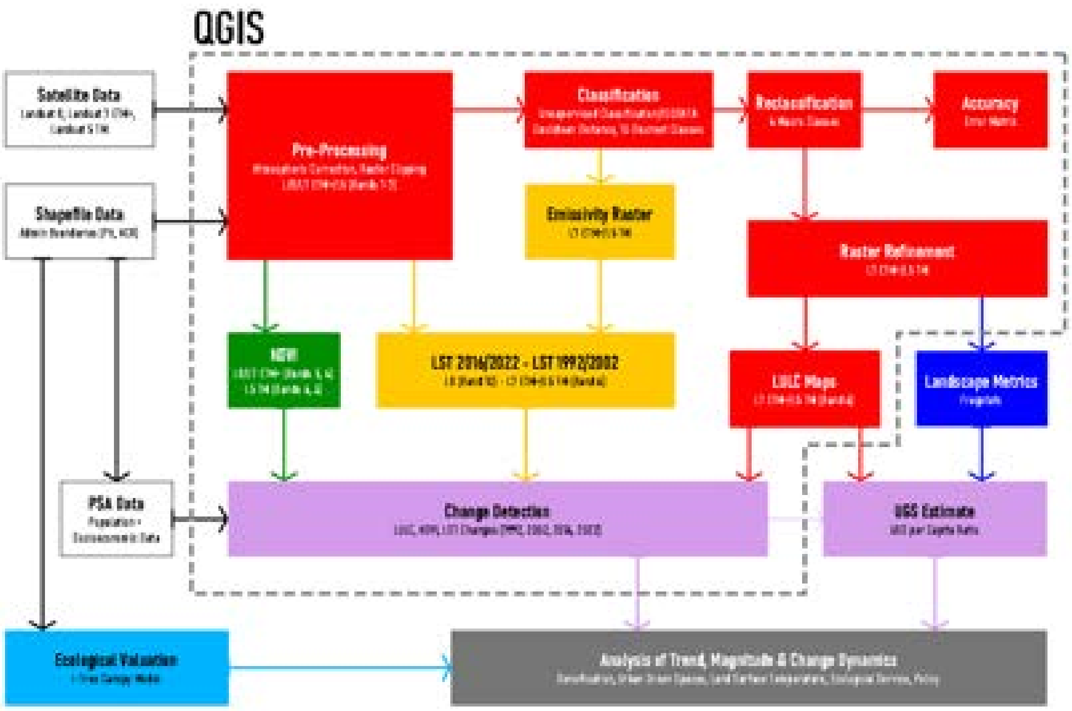
IV. OBJECTIVES OF THE STUDY

The three main objectives of this study are:

1) Determine the level of densification through an assessment of the urban landscape change for the years 1992, 2002, 2016 and 2022 in Metro Manila;
2) Determine the UGS per capita from 1992, 2002, 2016 and 2022;
    a. Examine vegetation change by calculating NDVI from 1992 to 2022;
    b. Calculate Land Surface Temperature (LST) in the study area from 1992, 2002, 2016 and 2022;
    c. Examine the relationship between LST and NDVI from 1980 to 2020 in Metro Manila;
    d. Determine the value of the current UHS availability in Metro Manila;
3) Identify the current urban green space allotment in Metro Manila;

The study will determine the current rate of densification of Metro Manila and will require a spatiotemporal analysis of Metro Manila's Land Cover change analysis from 1992 to 2022 using the QGIS 3.26.3 and the Semi-Automatic Classification Plugin (SCP) (Cogedo, 2020) to perform an unsupervised classification of the study area. Using specific landscape metrics to determine the changes in the landscape, descriptive landscape statistics shall be performed, and the data generated will be used to the status of Metro Manila's urban green spaces and ultimately aims to answer, the question:” What is the current state of densification in Metro Manila in the context of Urban Green Space per capita?”

Figure 2. Conceptual Framework



V. Rationale

The growing population in urban centers necessities the study of interaction between living organisms and urban environment (Cengiz, 2013). Metro Manila presents a unique and interesting candidate for this study as it exhibits the textbook definition of a changing landscape.

According to (Niemelä, 1999), urban environments are environments that are surrounded by man-made structures, such as residential and commercial buildings, paved surfaces and within this scope, urban ecology developed as a branch of ecology in the last few decades. Urban expansion and sprawl have in the past led to degradation of urban ecology which resulted in destruction and or fragmentation of natural or semi-natural vegetation and water ways (Haaland & van den Bosch, 2015a). To meet the development needs of urbanization, urban ecological management is needed that includes a set of methods that are adaptable measures across different scales (C. Wang et al., 2020). Open Spaces and Green Spaces has been the popular solution to densification.

However, in the Philippines, there is no holistic approach to urban ecological governance such that, development controls and restrictions in development that incorporates the need to maintain a degree of Urban Green Spaces and diversity. PD 1216 (1977) stated a definition of “Open Spaces” that is being referenced by the National Building Code as well as the Subdivision Law; under this definition, Open Spaces are 30% of the subdivision area that includes parks, amenities roads and walkways. It is at this level where governing restrictions must be clearly defined that define how

(a) urban residents should have adequate opportunities for exposure to nature; (b) urban biodiversity is maintained and protected; (c) environmental hazards such as air pollution or noise are reduced; (d) the impacts of extreme weather events (heatwaves, extreme rainfall or flooding) are mitigated; (e) the quality of urban living is enhanced; (f) the health and well-being of residents is improved. These define the relevance of Urban Ecological Governance can and should be encapsulated within our existing laws. This paper aims to review and address the gaps in environmental governance or Urban Green Spaces.

VI. Scope and Limitations

The study considers Metro Manila Regional in its regional scale within four distinct time periods. Calculations and interpretation are based on the Metro Manila as a megacity and will not delve into the municipal aspects of the study. The scale of time is largely based on the availability of Landsat products, PSA statistical data and the time that has been allotted for this research, thus four years have been selected (1992, 2002, 2016 and 2022) have been selected from the series of 1992 to 2022.

This study envisions a methodology that can be easily applied by local government units, using low-budget surveillance, spatial analysis methods and rapid assessment of urban areas thus the study is purely remote in nature.

VII. Description of the Study Area

VII.01 Physical Profile

The National Capital Region (NCR), also known as Metro Manila, is one of the 17 administrative regions in the Philippines (refer to Figure 3). It is a special administrative region and the Philippines' political, economic, and educational center. Urban planners consider Metro Manila as a conurbation (Tomeldan et al., 2014) comprised of 17 local government units covering an area of 619 km^2 (PSA, 2021b) this includes the City of Manila, City of Mandaluyong, City of Marikina, City of Pasig, Quezon City, City of San Juan, Caloocan City, City of Malabon, City of Navotas, City of Valenzuela, City of Las Piñas, City of Makati, City of Muntinlupa, City of Parañaque, Pasay City, Taguig City and the municipality of Pateros.

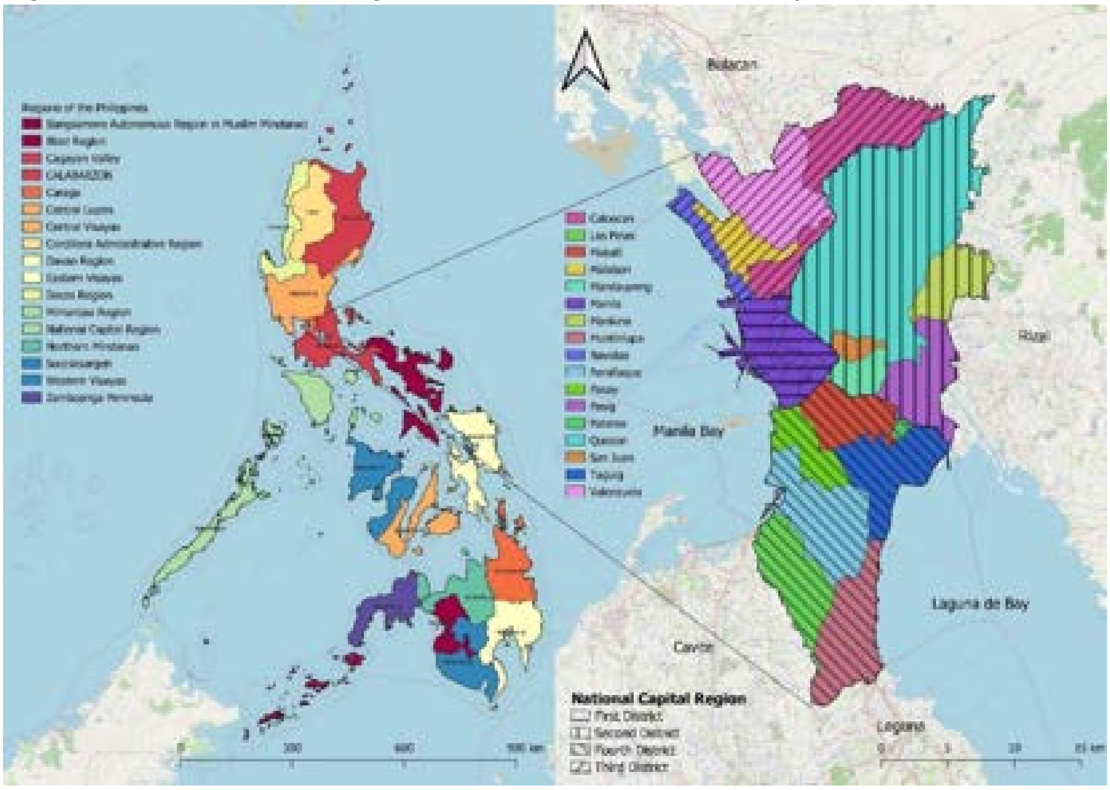
Metro Manila is geographically located in the southwestern portion of island of Luzon at 14.6091° N, 121.0223° and is generally characterized as flat to rolling with a gradient ranging from 0% to 15%. It is divided morphologically into three major parts, according to a (JICA, 2010) study:

1) the Central Plateau is composed of welded tuffaceous materials where the ground elevation ranges from 20.00m to 40.00m and gradually becomes lower at the west side where the area becomes narrower along the Pasig River. In the northwest area, the ground elevation ranges from 70.00m to over 100.00m;
2) the Marikina Flood Plain on the other hand, consists of soft, unconsolidated Fluvial deposits due to the active deposition of the Marikina River and Deltaic deposits as it nears Laguna de

Bay The Deltaic deposits of Pasig River along Manila Bay shoreline blend well with coralline and other coastal deposits forming a significant part of the. Its elevation ranges from 2.00m on the Laguna de Bay side to 30.00m on its northern edge of Montalban, surrounded by the Central Plateau and mountains.

3) the Coastal Lowland is a flat and low plain facing Manila Bay along the shores of the City of Manila as well as suburban of Las Piñas and Parañaque areas are located here. Ground elevation ranges from 0.00m on the Manila Bay side to 5.00m at the west side of the Cities of Mandaluyong and Makati. This morphological unit can be subdivided into sand bar, backmarsh including tidal flat, Pasig River delta and reclaimed land.

Figure 3. Metro Manila Regional Administrative Boundary

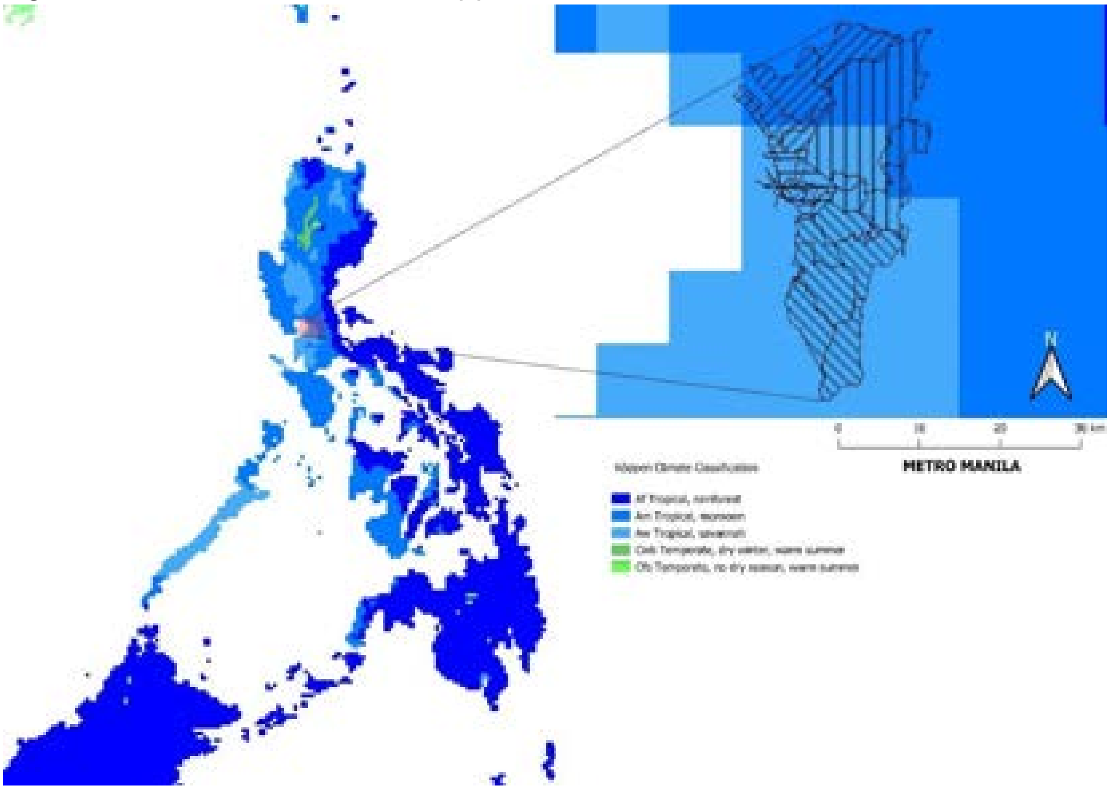


Source: Adapted from (OCHA, 2015; PSA, 2022b)

VII.02 Climate

Regional climate is widely regarded as a determinant of both biodiversity and productivity patterns (Fei et al., 2018). In this study, the Köppen climate classification will be used instead of the Modified Coronas Classification used by PAGASA. Köppen's climate classification system is one of the most common climate classification systems in the world (Arnfield, 2020) and is used to denote different climate regions on Earth based on precipitation and local vegetation.

Figure 4. Metro Manila under Köppen's climate classification



Source: Adapted from (Beck et al., 2018)

Climate plays a major role in a region's urban ecology such that changes in the climate affects urban temperatures, hydrology, habitats, and biodiversity. Metro Manila can best be classified as having a tropical monsoon climate, with a temperature mean of 25.5 °C and annual rainfall of 2,348 mm (Beck et al., 2018; World Bank, 2021).

VII.03 Socioeconomic Profile

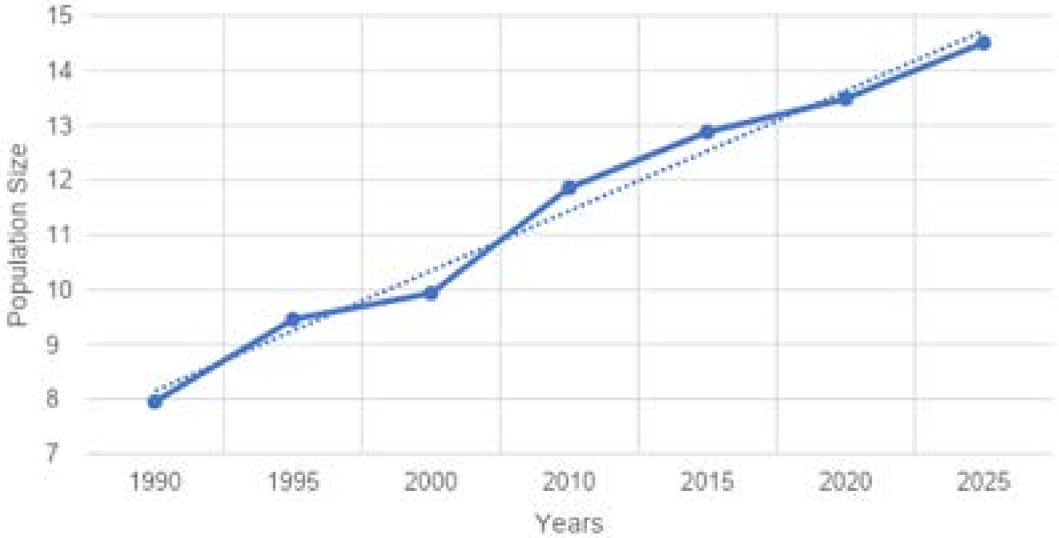
Metro Manila is the smallest administrative region of the Philippines and the most densely urbanized (see Table 1). According to the 2020 Census of Population released by the Philippine Statistics Authority, Metro Manila has a population density of 21,765 per square kilometer. Though the population growth rate has steadily decreased from 1.78% in 2010 to 1.58% in 2015 and 0.97% in 2020, by 2025, NCR's population is estimated to reach 14.5 million (NEDA, 2017).

Table 1: Total population, area, and density by region: 2020

#	Region	Population	Area (sq-km)	Density
1	NCR Metro Manila	13,484,462.00	619.54	21,765
2	IV-A CALABARZON	16,195,042.00	16,576.26	977
3	III Central Luzon	12,422,172.00	21,906.19	567
4	VII Central Visayas	8,081,988.00	15,872.58	509
5	I Ilocos	5,301,139.00	12,964.62	409
6	VI Western Visayas	7,954,723.00	20,778.29	383
7	V Bicol	6,082,165.00	18,114.47	336
8	XI Davao	5,243,536.00	20,433.38	257
9	X Northern Mindanao	5,022,768.00	20,458.51	246
10	IX Zamboanga Peninsula	3,875,576.00	16,904.03	229
11	XII SOCCSKSARGEN	4,901,486.00	22,786.08	215
12	VIII Eastern Visayas	4,547,150.00	23,234.78	196
13	XIII Caraga	2,804,788.00	21,120.56	133
14	II Cagayan Valley	3,685,744.00	29,836.88	124
15	BARMM Bangsamoro Autonomous Region in Muslim Mindanao	4,404,288.00	36,650.95	120
16	MIMAROPA MIMAROPA Region	3,228,558.00	29,606.25	109
17	CAR Cordillera Administrative Region	1,797,660.00	19,818.12	91

Source: (PSA, 2022b)

Figure 5: Human population trends in the Metro Manila, 1990 to 2025



Source: Compiled from (NEDA, 2017; PSA, 2021a)

With rapid urbanization and the rise in population comes an increased demand for health and social services, infrastructure and support services that adds up as environmental stressors (Lin & Fuller, 2013). In 2021, (PSA, 2022b) reported that Metro Manila contributed 1.4 percentage points to the total 5.7 percent growth in the country's economy. This accounted for 31.5 percent of the total GDP, the highest among the regions with the per capita HFCE in metro Manila recorded at ₱231,686 in 2021; this is higher than the national level per capita HFCE of ₱132,580. Lands in Metro Manila are among the highest-priced in the country and is reported in the Residential Real Estate Price Index (RREPI) where Metro Manila is at 142.8% compared to other regions with only 127.4%, 10.6% higher than the national average (BSP, 2021).

At the regional level, Metro Manila (NCR) is the region with the lowest poverty incidence among families in 2021, closely followed Cordillera Administrative Region (CAR), Region III, and Region IV-A. Table 2 below shows that Metro Manila has a lower incidence of poverty compared to the national average.

Table 2: Poverty Incidence among families: 2015, 2018, and 2021

Region	Poverty Incidence among Families					
	Estimates (%)			Coefficient of Variation		
	2015	2018	2021	2015	2018	2021
Philippines	18.0	12.1	13.2	2.1	1.4	1.4
NCR	2.8	1.4	2.2	10.7	10.4	6.7
CAR	17.1	8.6	6.9	11.0	5.3	5.4
Region I	14.0	7.0	11.0	8.4	9.6	6.8
Region II	13.1	12.5	11.7	7.9	6.4	7.1
Region III	8.3	5.2	8.3	9.7	6.4	5.7
Region IV-A	9.2	5.1	7.2	8.6	7.3	6.4
MIMAROPA	18.0	10.5	15.0	11.0	6.5	5.1
Region V	31.0	20.0	21.9	5.4	4.0	4.0
Region VI	18.5	11.9	13.8	7.6	6.2	5.3
Region VII	24.9	13.4	22.1	5.8	6.1	5.1
Region VIII	33.0	23.9	22.2	6.2	3.6	4.1
Region IX	29.7	25.4	23.4	7.0	4.3	4.3
Region X	32.3	17.3	19.2	6.3	3.8	4.4
Region XI	18.0	13.9	11.9	8.0	5.1	4.8
Region XII	31.2	22.4	21.4	7.0	4.8	4.6
Caraga	31.1	24.1	25.9	5.8	3.5	3.5
ARMM/BARMM	53.8	54.2	29.8	5.2	2.6	4.0

Source: Adapted from (PSA, 2022c)

The average family income in Metro Manila needed to meet the minimum basic food and non-food needs of a family with five members in 2021 was estimated at ₱12,030 per month, see Table 3. Statistically, this is the poverty threshold, where family that falls below this level is considered poor. From 2015, this threshold was higher by 13.87% in in 2018. In 2021, the poverty threshold also increased at a rate of 14.98%. Overall, the poverty threshold in Metro Manila is higher than the national average by 14.23% in 2021.

Table 3: Annual Per Capita Poverty Thresholds by Region

Region	Annual Per Capita Poverty Threshold (in ₱)		
	2015	2018	2021
Monthly Poverty Threshold for a Family of Five	9,478	10,756	12,030
Philippines	22,747	25,813	28,871
NCR	25,188	28,682	32,978

CAR	22,985	24,907	28,304
Region I	22,762	27,055	31,113
Region II	22,622	25,099	28,292
Region III	22,867	26,954	31,584
Region IV-A	25,642	27,928	31,059
MIMAROPA	20,369	23,315	26,321
Region V	22,503	24,461	27,675
Region VI	21,921	24,494	27,083
Region VII	22,644	25,745	31,220
Region VIII	22,398	24,987	26,848
Region IX	22,557	25,650	28,739
Region X	23,020	24,835	28,836
Region XI	23,146	25,953	28,102
Region XII	21,341	25,023	26,443
Caraga	22,788	25,375	27,335
ARMM/BARMM	22,650	27,715	28,293

Source: Adapted from (PSA, 2022c)

VII.04 Construction and Development

The increase in Metro Manila population created the need to build new housing and other uses. A survey conducted by the PSA from 1992 has shown that up until 2016, there was an increase in total floor space for both residential and non-residential construction to as much as 32,526,542 square meters at an estimated ₱11,483.53 per square meter. This went down in 2020 but continued to increase in the 1st quarter of 2022 with the PSA recording 7,720,289 square meters of new floor space amounting to ₱86,781,856,000.

Table 4: Newly started construction metrics in Metro Manila

	1992	2002	2016	2020	2022 (1Q)
Number	2,047	4,050	147,998	6,462	37,270
TFA (sqm)	384,634	926,383	32,526,542	5,397,991	7,720,289
Value '000	1,439,739	8,038,186	378,895,886	76,289,871	86,781,856
Cost/sqm	3,743.14	8,676.96	11,648.82	14,133.01	11,240.75
Rate	-	1.41	34.11	(0.83)	0.43

Source: Compiled from the (PSA, 2022a) *web archives*

VII.05 Administration & Land Use

Under Executive Order No. 7924, citing (Faulan, 2018): *"the MMDA shall perform planning, monitoring, coordinating, and implementing functions, and exercise regulatory and supervisory authority over delivery of metrowide* *services; Metropolitan Manila is treated as a special development and administrative region subject to the direct supervision of the President."*

Thus, the MMDA is mandated to perform Development Planning, Zoning & Land Use Planning, Health, Sanitation and Pollution Control, Transport & Traffic Management, Flood Control and Sewage Management, Public Safety as well as Solid Waste Disposal and Management.

Under Republic Act No. 7924, Sec. 6, Par (e) the MMDA shall perform: *"Urban renewal, zoning and land use planning, and shelter services which include the formulation, adoption and implementation of policies, standards, rules and regulations, programs and projects to rationalize and optimize urban land use and provide direction to urban growth and expansion, the rehabilitation and development of slum and blighted areas, the development of shelter and housing facilities and the provision of necessary social services thereof."*

However, the Local Government Units (LGUs) thru their respective City/Municipal Planning Offices prepare individual Comprehensive Land Use Plans (CLUPs) and Zoning Ordinances (Zos) pursuant to Republic Act No. 7160 (Local Government Code). The HLURB (DHSUD) then reviews and ratifies each LGU's compliance with national standards and guidelines (RA No. 7160). The MMDA, in Metro Manila, assists in the review of the CLUPs and ZOs pursuant to Executive Order No. 72-HLURB Law.

The land use in Metro Manila (see Table 5) is largely classified as Residential, that accounts for 44.8% of the total space where 36% of the total population in Metro Manila are informal settlers; Commercial or Business sits at about 12.2% percent; Industrial occupies about 7.6% of the total land area;

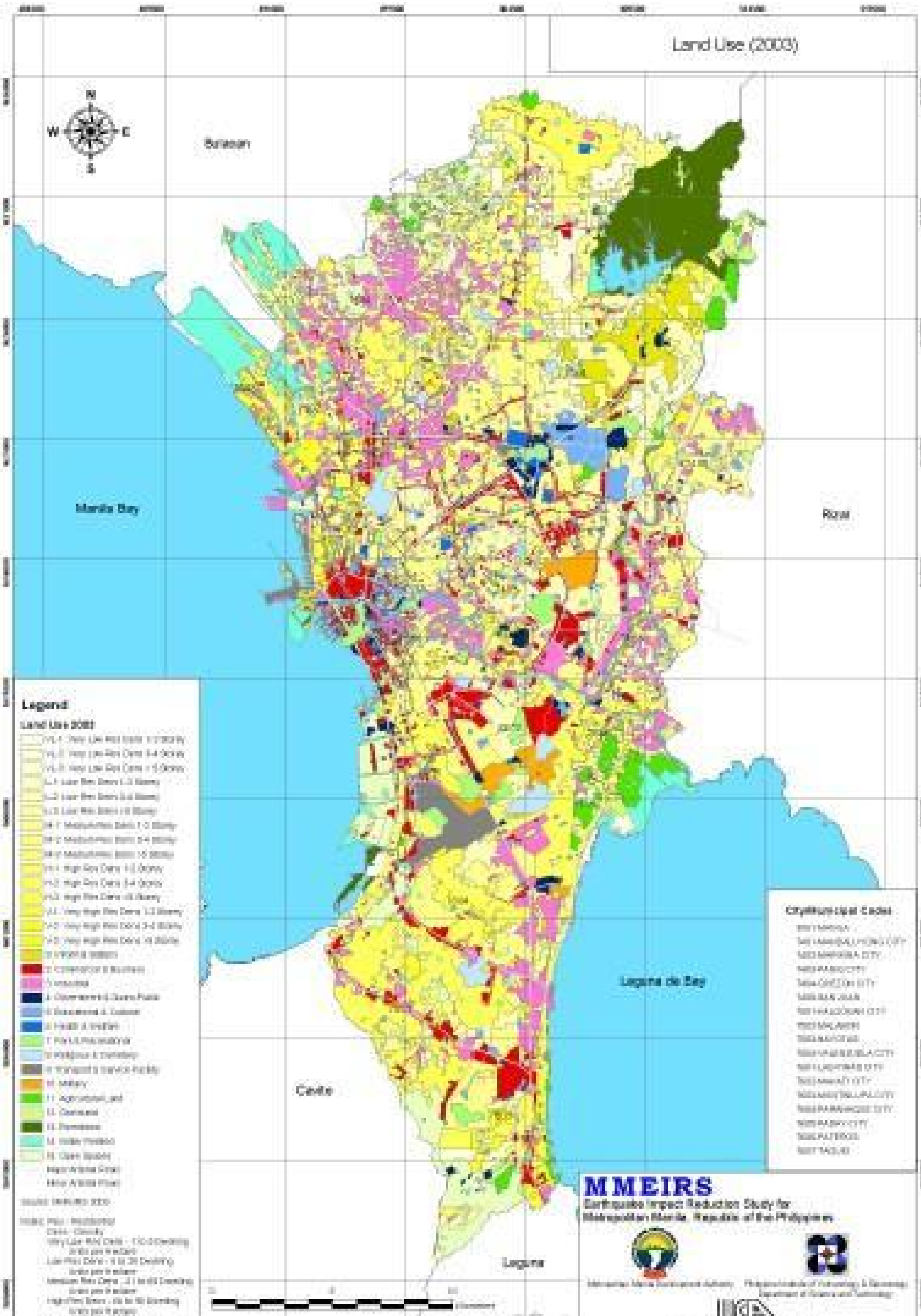
Institutional is at 6.9% and Open Spaces at 28.4% of the total land. Urban green spaces usually diminish in size due to urbanization. Much of the agricultural land use is also present found at the urban fringes outside the Metro Manila proper.

Table 5. Metro Manila Land Use 1938-2003

Classification	% Total land area				
	1938*	1980*	1990*	1994*	2003**
Residential	14.2	29.4	65.0	65.0	44.8
Commercial	-	3.0	3.4	8.0	12.2
Industrial	-	4.7	4.0	3.0	7.6
Institutional	-	4.5	5.2	10.6	6.9
Utilities	-	1.4	4.0	4.0	-
Agricultural	55.6	12.5	8.4	4.4	-
Open Space	5.1	24.3	8.0	4.0	28.4
Forest Land/Parks	25.1	20.2	2.0	1.0[c]	-
Total	100.0	100.0	100.0	100.0	100.0

Source: Adapted from *(JICA, 2001) **(Reg *citing the MMIERS 2004 Report*

Figure 6. Metro Manila Land Use Map, MMIERS 2003



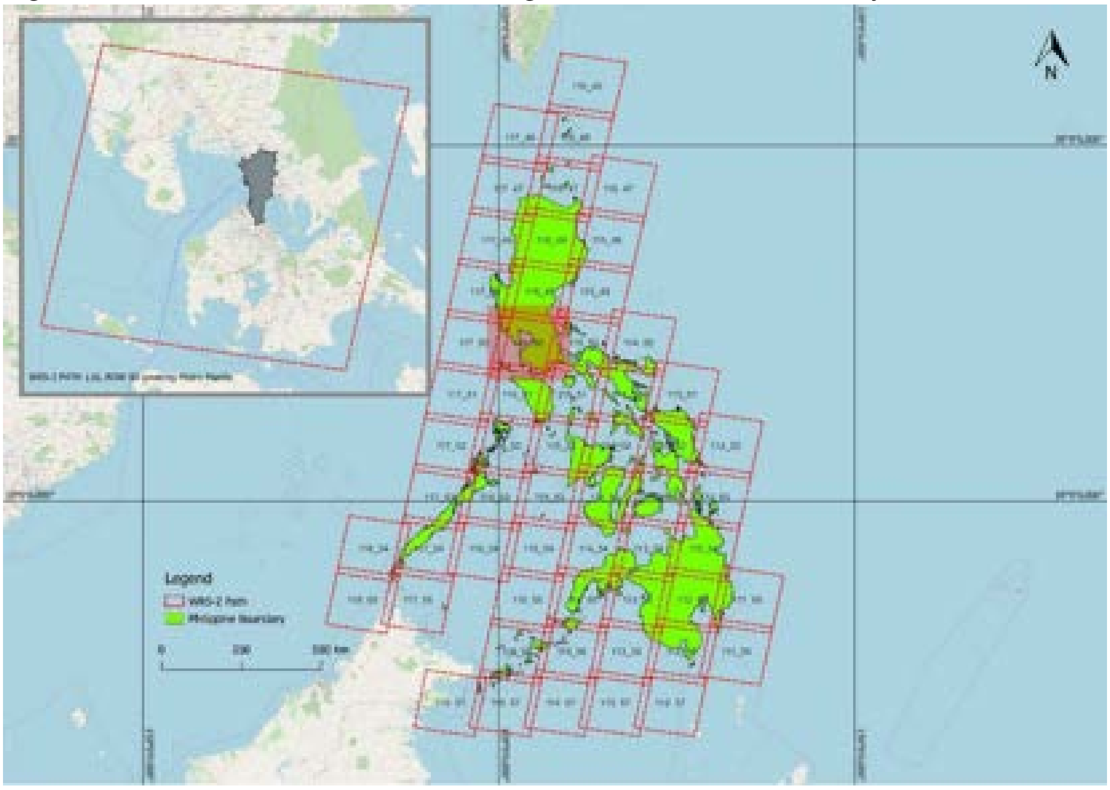
Source: (JICA, 2001)

VIII. METHODOLOGY

VIII.01 Remote Sensing

Land use and land cover (LULC) change has been one of the most perceptible transformations on the earth's surface (Alam et al., 2019), particularly, the growth cities have been the interest of research and analysis. Data taken from space has been invaluable such that, remote sensing has been used to create thematic maps showing the spatial distribution of identifiable earth surface features (Schowengerdt, 2007). Landsat 8 was first launched on February 11, 2013, and it orbits the Earth in a sun-synchronous, near-polar orbit, at an altitude of 705 km, inclined at 98.2 degrees, and completes one Earth orbit every 99 minutes (NASA, 2022). The satellite acquires about 740 scenes a day on the Worldwide Reference System-2 (WRS-2) path/row system, with a swath overlap varying from 7 percent at the equator to a maximum of approximately 85 percent at extreme latitudes. Metro Manila's data can be found among PATH 116, ROW 50 as shown in Figure 7.

Figure 7. WRS-2 Rath and Row Designation used int the study



Source: Adapted from (NASA, 2022)

The study employs a series of Landsat satellite images acquired in the years 1992 to 2022. The images downloaded from the Earth Explorer website were selected from the available Landsat 5TM, Landsat 7 ETM+ and Landsat 8 spacecraft with 116 and 50 as the path and row scene (see Table 6) with all the Landsat images used having the same 30-meter resolution. QGIS version 2.63.3 is the main GIS software used in the study that handles and processes both vector and raster data.

Table 6: Characteristics of Landsat data used in the study

Year	Landsat Type	Date of Acquisition	Path	Row	Cloud Cover over Land
2022	Landsat 8	2022-01-12	116	50	14.78
2016	Landsat 8	2016-02-13	116	50	4.05
2002	LANDSAT 7 ETM+	2002-04-03	116	50	2.00
1992	LANDSAT 5 TM	1992-01-26	116	50	11.00

Source: Authors' Compilation from (USGS, 2022)

Landsat measures different ranges of frequencies along the electromagnetic spectrum, Table 7 shows the specific bands used in each type of Landsat spacecraft in the study.

Table 7: Landsat Bands used in the study

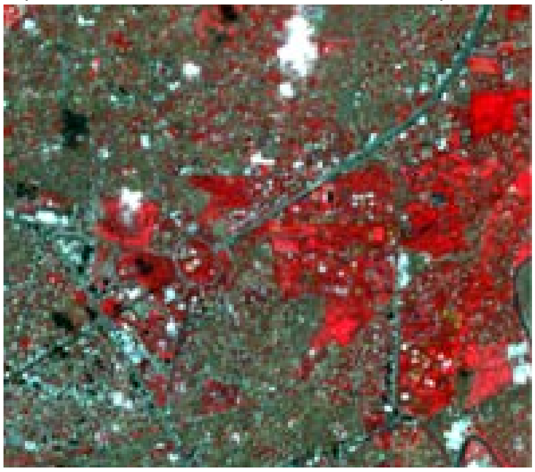
Spacecraft	Band	μm	Resolution (m)
Landsat 5 TM	Band 1	0.45-0.52	30
	Band 2	0.52-0.60	30
	Band 3	0.63-0.69	30
	Band 4 Near-Infrared	0.76-0.90	30
	Band 5 Near-Infrared	1.55-1.75	30
	Band 6 Thermal	10.40-12.50	120 (30)
	Band 7 Mid-Infrared	2.08-2.35	30
Landsat 7 ETM+			
	Band 1	0.45-0.52	30
	Band 2	0.52-0.60	30
	Band 3	0.63-0.69	30
	Band 4	0.77-0.90	30
	Band 5	1.55-1.75	30
	Band 6 Thermal	10.40-12.50	60 (30)
	Band 7	2.09-2.35	30
Landsat 8			
	Band 1 - Coastal aerosol	0.43-0.45	30
	Band 2 - Blue	0.45-0.51	30
	Band 3 - Green	0.53-0.59	30
	Band 4 - Red	0.64-0.67	30
	Band 5 - Near Infrared (NIR)	0.85-0.88	30
	Band 6 - SWIR 1	1.57-1.65	30
	Band 7 - SWIR 2	2.11-2.29	30
	Band 10 - Thermal Infrared	10.6-11.19	100
	Band 11 - Thermal Infrared	11.50-12.51	100

Source: Compiled from (ESRI, 2013)

To visualize the landscape, the spectral bands are arranged as a composite, particularly, Bands 5, 4 and 3 for Landsat 8 and Bands 4, 3 and 2 for Landsat 7 ETM+ and Landsat 5 TM. In this false color combination (Figure 8), vegetation appears in shades of red, urban areas are cyan blue, and soils vary from dark to light browns. While water appears black, coniferous trees will appear darker red than hardwoods. Generally, deep red hues indicate broad leaf and/or healthier vegetation while lighter reds signify grasslands or sparsely vegetated areas. In an urban context, this imagery shows a stark contrast between Vegetation, Water and Built-up land cover classes.

Figure 8. False Color Image combination (14.65142248, 121.04909489)

(a) Google Map Image



(b) False Color Combination

Source: (a) (Google., n.d.) *(b) False Color Composite* (GIS Development Team, 2022)

VIII.02 LULC Classification

(a) Pre-Processing

Image pre-processing was performed using the Semiautomatic Classification Plugin (SCP) for QGIS. A key step in the processing of satellite imagery is the radiometric correction of the images that accounts for that reflectance that water vapor, atmospheric matter, and other atmospheric elements may have added the images. Without this correction, inaccuracies may arise from the variables of interest as estimated at ground level, a Dark Object Substract 1 (DOS1) atmospheric correction is used to correct the Landsat images (Almadrones-Reyes & Dagamac, 2022; Laborde et al., 2017).

After the conversion and correction of the satellite data, resulting raster packages were cut into the shape of the the region of interest. The Philippine Administrative shapefile, which contains all 17 regions in the Philippines was used to subset and obtain our region of interest (Metro Manila) in QGIS. Selection by attribute was done to extract a new layer of Metro Manila from the Philippine shapefile and the new Metro Manila layer was overlaid on the radiometrically calibrated Landsat images.

(b) Classification Scheme

According to (LaGro, 2005) *"Classifying and mapping land cover is an integral step in understanding the Earth's biophysical systems."* This study aims to look at the physical process of change between the natural and built environment within an urban setting, thus, a simplified classification system between pervious, impervious and water surfaces were chosen as Macro Classes were chosen. The FAO provides a good guideline in selecting land cover classes (FAO, 2022):

a. *First, land cover should describe the whole observable (bio)physical environment and therefore deals with a heterogeneous set of classes;*
b. *Secondly, two distinct land cover features, having the same set of classifiers to describe them, may differ in the hierarchical arrangement of these classifiers in order to ensure a high mapability;*

By tailoring the set of classifiers to the major land cover features, all combinations can be made without having a tremendous number of theoretical but redundant combinations of classifiers. Metro Manila is a highly urbanized metropolitan and areas are predominantly pervious, impervious and water in general. In addition, clouds do not belong to any type of LULC, but it is widely present in the available Landsat images. A case study by (Laborde et al., 2017) concludes that the availability of cloud-free observations stays a major limiting factor, especially in wet tropical areas like Southeast Asia, therefore shadow is presented here an individual type. Pervious land cover is composed mainly of trees, shrubs, and grass. The unsupervised classification identified three types of vegetation based on their spectral signatures. Water in the study area is comprised of water from river, lakes, and ponds, as well as portions of the city along the Manila Bay. Finally, the impervious areas are composed of disturbed land, devoid of vegetation and are predominantly man mad such as roads, buildings, and other structures. The decision to use these land cover classes were informed by the work of (Puplampu & Boafo, 2021) and the report published by (JICA, 2010).

Table 8. Macro Land Cover Classes Used in the Study

Macro Class ID		Class	Attributes
1	Pervious	Vegetation	Forest and trees within the metropolis;
		Grassland	Urban agriculture, lawns, golf courses, shrubs, and bushes within the urban environment;
2	Water	Water Body	All forms of water surfaces within the study area, such as La Mesa Watershed, Pasig River, portions of the Manila Bay;
3	Impervious	Built-up	Temporary and permanent buildings, paved surfaces;
		Bare Land	Disturbed soil, void of greens and vegetation;
4	Cloud	Cloud/Shadow	

Source: Author's compilation based on (Cai et al., 2019; FAO, 2022)

(c) Unsupervised Classification

An unsupervised classification is used to group pixels into land cover classes using the Semiautomatic Classification Plugin (SCP). Unlike a supervised classification where the user inputs sample training data, the unsupervised classification autonomously groups pixels based on spectral clustering and provides a high extent of objectivity (X. Yang & Lo, 2010). By utilizing the ISODATA algorithm, this will be used to cluster 10 output classes from each year in the study from the combined Spectral Bands 1-7. Though the computer processes the clustering without much user intervention, the resulting classes are all individually reclassified by the user by grouping the resulting pixels with common characteristics into its Macro Classes through photo interpretation.

VIII.03 Accuracy Assessment

An accuracy assessment is a fundamental step preceding land cover classification and is done to evaluate errors both globally and for each class as well as to evaluate the reliability of the map and the resulting classification. In this accuracy assessment, an adequate number of samples for each class needs to be determined even if the class area proportion (Wi) is low (Olofsson et al., 2014). The number of samples (N) should be calculated as:

Equation 1.

$$N = \left(\sum i = \frac{1\ (Wi \times Si)}{So}\right)2$$

where:

$Wi = mapped\ proportion\ area\ of\ class\ i$

$Si = standard\ deviation\ of\ stratum\ i$

$So = expected\ standard\ deviation\ of\ overall\ accuracy$

$c = total\ number\ of\ classess$

In this study, So is assumed having a value of 0.01 and conjecture the Si values reported in the following table, $Wi \times Si$ is calculated based on the output from the classification of each raster data.

Table 9. Sample Conjectured standard deviations for year 2022

Year	Class	% Area	Wi	Si	$Wi \times Si$
2022	1	16.1509	0.1615	36.2	5.85E+00
2022	2	4.2693	0.0427	22.8	9.72E-01
2022	3	76.6556	0.7666	1,775.3	1.36E+03
2022	4	0.0403	0.0004	1.2	4.76E-04
					1.87E+10

Source: Calculated values based on (Olofsson et al., 2014)

As shown on Table 10, $N = (1.87E + 10)^2 = 1.84E + 10$ is the number of samples that we should distribute among classes. To stratify the sample, the study uses a conjecture user's accuracy and standard deviations of strata. A rough approximation is used considering the mean value between equal distribution $\left(Ni = \frac{N}{c}\right)$ and weighted distribution $(Ni = N * Wi)$, which is:

Equation 2.

$$Ni = \frac{\frac{N}{c} + N * Wi}{2}.$$

Table 10. Sample Stratification for year 2022

Year	Class	Weighted	Equal	Mean	Samples
2022	1	3.02E+09	4.68E+09	3.85E+09	8
2022	2	7.99E+08	4.68E+09	2.74E+09	5
2022	3	1.43E+10	4.68E+09	9.51E+09	19
2022	4	7.54E+06	4.68E+09	2.34E+09	5

Source: Calculated values based on (Olofsson et al., 2014)

Randomly selected single pixel Training Areas (ROIs) and the attribution of a land cover class based on photointerpretation of each ROI are created through the Semiautomatic Classification Plugin (SCP), however, to reduce the amount of data to be photo interpreted, $Mean$ is divided accordingly to reduce the number of samples required for photointerpretation in this study:

Equation 3.

$$Nuber\ of\ Samples\ = \frac{Mean}{5x10^{8}}.$$

A photo interpretation of all the samples are performed for all of the dates in the study, the process identifies the random pixels on the map and the user identifies each cover class. Note that the map's spatial resolution remains at 30 meters therefore may include mixed pixels showing multiple types of cover class on the ground, in this case, the user must consider the most prevalent land cover in the region of interest (ROI).

Several statistics are calculated including (a) overall accuracy, (b) user's accuracy, (c) producer's accuracy, and (d) Kappa coefficient. SCP calculates these statistics according to the area-based error matrix where each element represents the estimated area proportion of each class (Olofsson et al., 2014). The resulting product is an estimation of the unbiased user's accuracy and producer's accuracy, the unbiased area of classes according to reference data, and the standard error of area estimates and the confidence intervals. It is well to note that the standard errors are influenced by number of samples that have been used in the study, thus, to increase this, samples need to be proportionally increased.

Overall, the Kappa coefficient will be the study's measure of how the classification results compare to values assigned by chance (Rwanga et al., 2017), if kappa coefficient equals to 0, then there is no agreement between the classified image and the reference image.; if kappa coefficient equals to 1, then the classified image and the ground truth image are totally identical; therefore, the higher the kappa coefficient, the more accurate the classification will be and considered.

VIII.04 Landscape Statistics and Spatial Metrics

Specific landscape metrics was used for this study based on similar studies identifying landscape patter changes in an urban setting (Do et al., 2018; Maimaitiyiming et al., 2014; Weng, 2007). Fragstats was used to derive landscape statistics including percentage of landscape (PLAND) and area (CA) which are indicators of landscape composition; as well as Total edge (TE), edge density (ED), number of patches (NP), Patch density (PD) and largest patch index (LPI) are used as indicators of landscape fragmentation, refer to Table 11 below.

Table 11. Landscape metrics used in the study

Abbr.	Landscape Metrics	Description	Range
PLAND	Percentage of Landscape	The proportion of total area occupied by a particular land-use type in Hectares.	0 < PLAND ≤ 100
CA	Class Area	The total (class) area sums the area of all patches belonging to class. It shows if the landscape is.g. dominated by one class or if all classes are equally present.	CA > 0
TE	Total Edge	It measures the configuration of the landscape because a highly fragmented landscape will have many edges.	TE >= 0
ED	Edge Density	The sum of the lengths (m) of all edge segments in the landscape, divided by the total landscape area, converted to hectares or m/Ha.	ED ≥ 0
NP	Number of Patches	Identify the number of patches in each of the urban land uses Number	NP > 1
PD	Patch Density	It describes the fragmentation of a class, the number of patches per 100 hectares.	PD > 1
LPI	Largest Patch Index	It is the percentage of the landscape covered by the corresponding largest patch of each class i. It is a simple measure of dominance.	0 < LPI <= 100

Source: Adapted from (McGarigal & Marks, 1995)

VIII.05 Normalized Difference Vegetation Index (NDVI)

The NDVI is a commonly used to quantify vegetation greenness and is useful in understanding vegetation density and assessing changes in plant health, it is as widely used remote sensing index (Viana et al., 2019) citing (Bhandari et al., 2012). NDVI values range from +1.0 to -1.0. In areas of barren rock, sand, or snow usually show very low NDVI values (<0.1); water shows values close to -1.0; sparse vegetation such as shrubs and grasslands or senescing crops may result in moderate NDVI values (0.2 to 0.5). High NDVI values (0.6 to 0.9) correspond to dense vegetation such as that found in temperate and tropical forests or crops at their peak growth stage. In Landsat missions, NDVI is calculated as the ratio between Top of Atmosphere (TOA) reflectance of a red band around 0.66*μm* and a near-infrared (NIR) band around 0.86*μm*. The NDVI of a densely vegetated area will tend toward positive values, whereas water and built-up areas will be represented by near zero or negative values (Viana et al., 2019). NDVI is used to quantify vegetation “greenness” and is useful in understanding vegetation density and assessing changes in plant health. NDVI is calculated as a ratio between the red (R) and near infrared (NIR) values:

Equation 4.

$$NDVI = \frac{(NIR - R)}{(NIR + R)}.$$

Values for the Landsat bands used for determining NDVI is shown in the table below:

Table 12. Landsat Bands used to derive NDVI

Year	Landsat	NDVI Derivative
1992	Landsat 5 TM	$NDVI = \frac{(Band\ 4 - Band\ 3)}{(Band\ 4 + Band\ 3)}$

2002	Landsat 7 ETM+	$NDVI = \frac{(Band\ 4 - Band\ 3)}{(Band\ 4 + Band\ 3)}$
2016	Landsat 8	$NDVI = \frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4)}$
2022	Landsat 8	$NDVI = \frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4)}$

Source: Adapted from (USGS, n.d.)

VIII.06 Land Surface Temperature

The Land Surface Temperature (LST) is a general term describing the joint temperature of objects existing on Earth's surface. This estimate in temperature can be estimated by converting brightness data captured by the Landsat spacecraft to into temperature (Konda et al., 1994). The LST for 2016 and 2022 will be generated using the Landsat 8 thermal bands (see Table 7), estimating the LST can be processed using the Semiautomatic Classification Plugin (Congedo, 2021). The conversion of Landsat data to LST involves three major steps:

1) First, the $L\lambda$ the values were estimated to spectral radiance. This has already been done in the LULC assessment.

Second, the spectral radiance value was changed to temperature by using:

Equation 5.

$$T = \frac{K_2}{\ln ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

2) Third, Landsat data is measured in Kelvin, therefore conversion to Celsius (C°) is required:

Equation 6.

$$T = \left(C^{\circ}\right) = T(K) - 273.15$$

This method is only applicable for Landsat 8 products, for Landsat 7 and Landsat 5 (2002 and 992 respectively), the emissivity of each type of cover will be inputted manually and calculated using the raster calculator in

QGIS. Because of the different approaches, comparisons between 1992 and 2002 will have a different accuracy compared to 2016 and 2022; the emissivity of objects on the ground can be calculated automatically from Landsat 8, for Landsat 7 ETM+ and Landsat 5 TN, the values are given on the table below:

Table 13. Emissivity values for Landsat 5 TM and Landsat 7 ETM+

Land surface	Emissivity e
Water	0.98
Built-up	0.94
Vegetation	0.98
Bare soil	0.93

Source: Data adapted from (Congedo, 2017)

VIII.07 Ecological Benefit

Ecosystem services valuation has been used more frequently to include the environmental variable in the environmental management process (Olivatto, 2019). To achieve a similar level of valuation for Metro Manila, the study will use the i-Tree Canopy model in a supervised classification to obtain (a) a urban green space inventory of land cover types within the study area and (b) provide an equivalent valuation of selected ecosystem services. i-Tree is a suite of web-based software programs developed by the United States Department of Agriculture Forest Service (USDA) for valuing and quantifying the benefits of trees (USDA, 2022). It is designed to allow researchers to estimate tree, vegetation, and other cover classes. The Metro Manila shapefile processed for the LULC is imported into the tool that is used to delimit the boundary of the area of analysis. Cover classes are selected from the tool's default classification that represents seven classes (see Figure 9). The tool randomly selects a user specified number of points within the set boundary that will be used in the photo interpretation using 30-meter resolution satellite images. 500 samples were chosen for this analysis to improve the accuracy of the analysis as shown in the table below (Table 14).

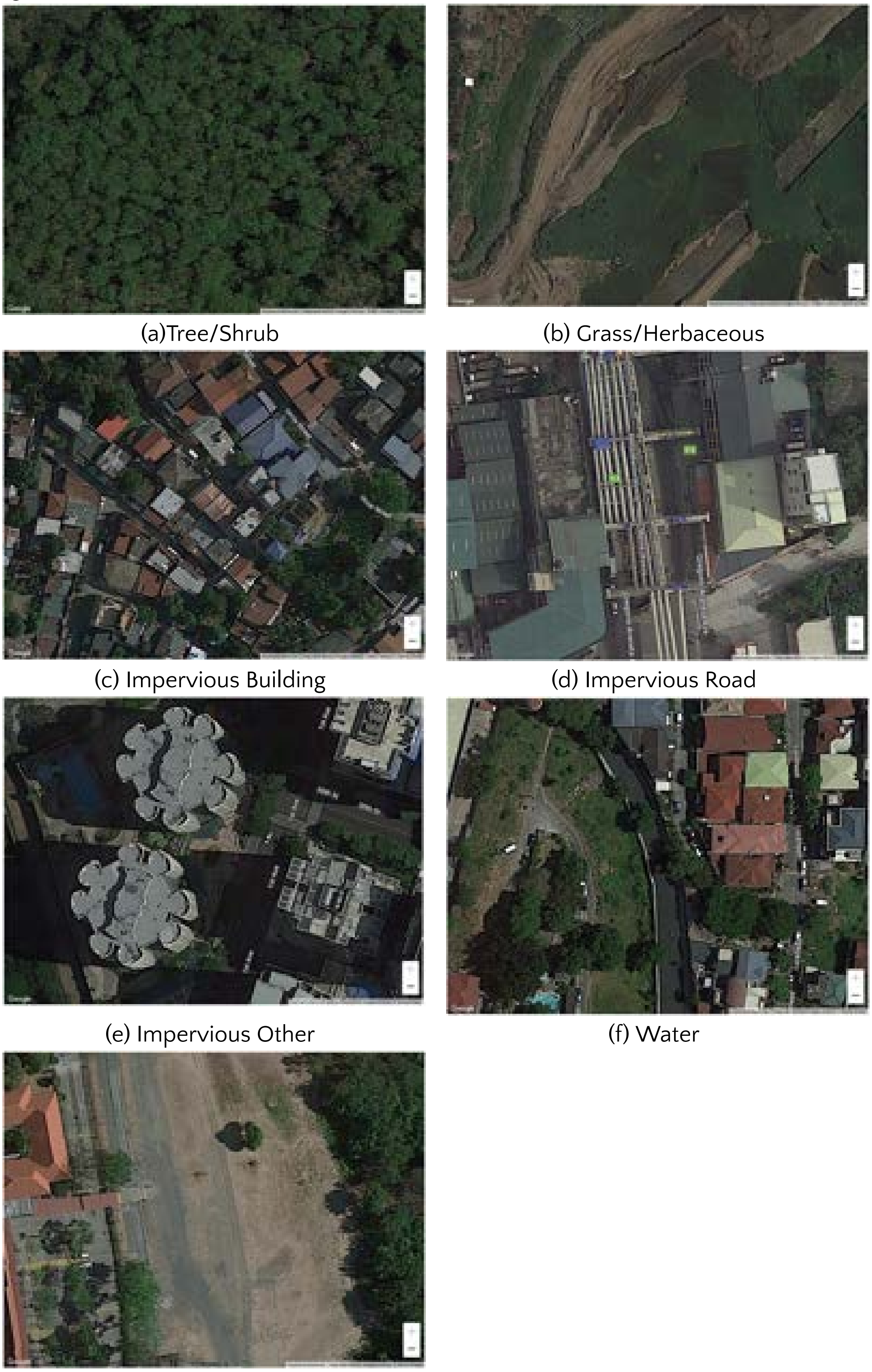
Table 14. Land Cover Sampling Results of the i-Tree Canopy inventory

Abbr.	Cover Class	Samples	% Cover ± SE	Area (km²) ± SE
H	Grass/Herbaceous	44	8.80 ± 1.27	52.99 ± 7.63
IB	Impervious Buildings	201	40.20 ± 2.19	242.07 ± 13.20
IO	Impervious Other	42	8.40 ± 1.24	50.58 ± 7.47
IR	Impervious Road	75	15.00 ± 1.60	90.33 ± 9.62
S	Soil/Bare Ground	46	9.20 ± 1.29	55.40 ± 7.78
T	Tree/Shrub	70	14.00 ± 1.55	84.30 ± 9.34
W	Water	22	4.40 ± 0.92	26.50 ± 5.52
		500	100	602.17

Source: Results compiled from the i-Tree Canopy tool (USDA, 2022)

Currently, i-Tree Canopy estimates tree benefits data for the US based on its weather stations, pollution monitors, tree growth rates, and building construction methods (USDA, 2022). There is currently no tree benefit standard selection for use in the Philippines however, when one considers climate based on precipitation and vegetation, we can draw a parallel from certain US States. The Köppen climate classification divides climates into five main climate groups based on seasonal precipitation, temperature patterns and vegetation (Beck et al., 2018; World Bank, 2017), from the climate map, Miami Florida is represented as having the same climate classification as Metro Manila with Florida's southern coast, Miami is classified as having Af (tropical rainforest), Am (tropical monsoon) and Aw (tropical savannah), using the parameters for US/Florida, the Tree Benefit Valuation for Metro Manila can be given as shown on Table 15. Metro Manila tree benefits rates and value

Figure 9. Land cover classes used in the i-Tree model



(a)Tree/Shrub

(b) Grass/Herbaceous

(c) Impervious Building

(d) Impervious Road

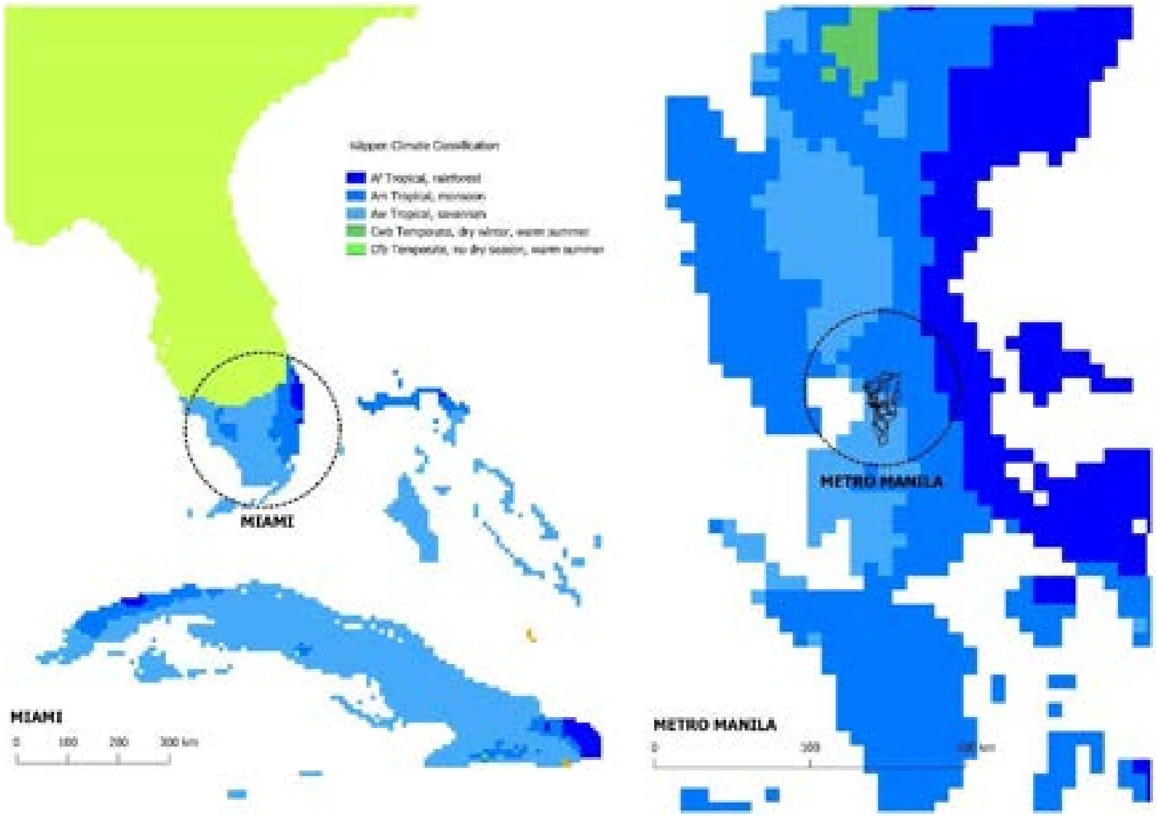
(e) Impervious Other

(f) Water

(g) Soil/Bare Ground

Source: Adapted from Google Earth Engine using i-Tree Canopy

Figure 10. Köppen's climate classification: Miami and Metro Manila



Source: Adapted from (Beck et al., 2018)

Table 15. Metro Manila tree benefits rates and value

Abbr.	Tree Benefit	Amount	Rate	Value
CO	Carbon Monoxide removed annually	0.155	$g/m^2/yr$	₱83,345.38
NO2	Nitrogen Dioxide removed annually	0.964	$g/m^2/yr$	₱45,817.91
O3	Ozone removed annually	6.482	$g/m^2/yr$	₱357,299.59
PM10	Particulate Matter greater than 2.5 microns and less than 10 microns removed annually	2.611	$g/m^2/yr$	₱391,784.11
PM2.5	Particulate Matter less than 2.5 microns removed annually	0.299	$g/m^2/yr$	₱14,318,731.69
SO2	Sulfur Dioxide removed annually	0.000	$g/m^2/yr$	₱57,000.16
AVRO	Avoided Runoff	38.694	$L/m^2/yr$	₱133.85
	Carbon Price		₱/t	₱10,632.63
	CO2 Equivalent Price		₱/t	₱2,899.81
	Carbon Sequestered annually in trees	4.750	t/ha/yr	₱10,793.64
	CO_2 Sequestered annually in trees	17.417	t/ha/yr	₱2,943.72
	Carbon Stored in trees	76.848	t/ha	₱10,793.64
	CO_2 Stored in trees	281.776	t/ha	₱2,943.72

Source: Adapted from (USDA, 2022) *using similar climate*

VIII.08 Urban Greenspace Planning

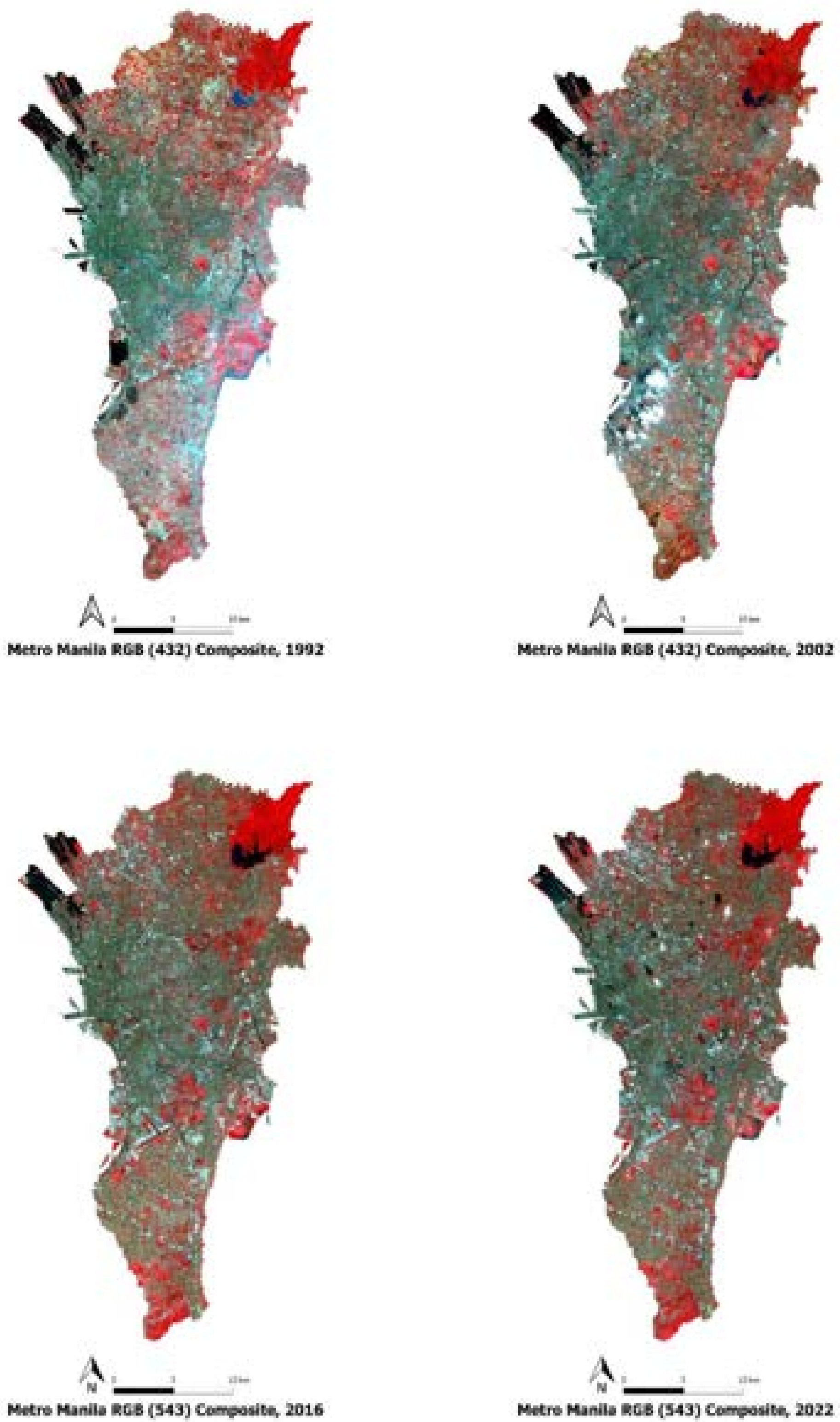
The importance of Urban Green Spaces to urban biodiversity and public health cannot be ignored (WHO, 2016) and its study is essential to develop a collective understanding of how urban green space can be used for the advancement of population health and wellbeing within the context of rapid urbanization (Shuvo et al., 2020). However, the question remains, “how much urban green space UGS is sufficient per person?” There currently are no set standards for UGS provision in Metro Manila, however, the World Health Organization (WHO, 2010) recommends providing a minimum of 9 sqm of urban green space per person. Other criteria for the establishment of UGS are essential to mitigate UGS as a metric of size, such that it should be safe, accessible, and functional (supports biodiversity) (Frumkin, 2003; Houlden et al., 2021; Takano et al., 2002). From the generated LULC maps, a map of the existing UGS in Metro Manila will be used to present the current inventory and calculate the amount of UGS available per capita.

IX. Results

IX.01 Landscape Cover Classification

Landscape structure expresses the spatial pattern of landscape elements and the connections between the different ecosystems or landscape elements, it also assesses relationships between ecosystems as measure, number, size, and shape (Gkyer, 2013). Structure, function, and change are the three fundamental landscape characteristics when studying the ecology of landscapes (Botequilha et al., 2002). Using the available Landsat data packages, a composite image of Metro Manila through various temporal states were produced. Figure 13 presents the visual landscape changes that occurred in Metro Manila in 1992, 2002, 2016 and 2022. The images show healthy vegetation in a deep red color surrounded by blue and cyan patches representing built-up areas. Water is represented as black and in clouds shown as white. In 1992, on the western edge of Metro Manila along Manila Bay, a huge patch of water can still be seen. This is portion of the reclamation project that has yet to be completed, by 2002, this area has already been covered up with material.

Figure 11. Composite LANDSAT Image of Metro Manila (1992 to 2022)



Source: Landsat Images processed through QGIS

The landscape cover classification was obtained automatically using QGIS and SCP. Through SCP's Band processing tool, Clustering was done using K-means Classification method to produce 10 distinct Macro Classes. The process is done with 10 iterations using the Minimum Distance algorithm that calculates the Euclidean distance between spectral signatures of image pixels and training spectral signatures to distinguish between classes (Table 16).

Table 16. Parameters for Classification Cluster

Distance Threshold	0.0001000
Max Number of Iterations	10
ISODATA Max Standard Deviation	0.2
ISODATA Min Size in Pixels	10
Distance Algorithm	Minimum Distance

The analysis classified the landscapes (1992, 2002, 2016 and 2022) into 10 distinct classifications based on spectral signatures taken from the dataset (Figure 12). Because an unsupervised classification was done to produce the distinct classes, each of the 10 classes is given a unique color automatically. This color has no bearing on the actual nature of the landscape, this is only used to reference the map to a distinct cluster (or signature). Each class and signature (Figure 13) will need to be visually cross-referenced on the map to check what type of land cover is existing using the available Landsat false color image as well as maps from Google Earth engine can be used to achieve this verification.

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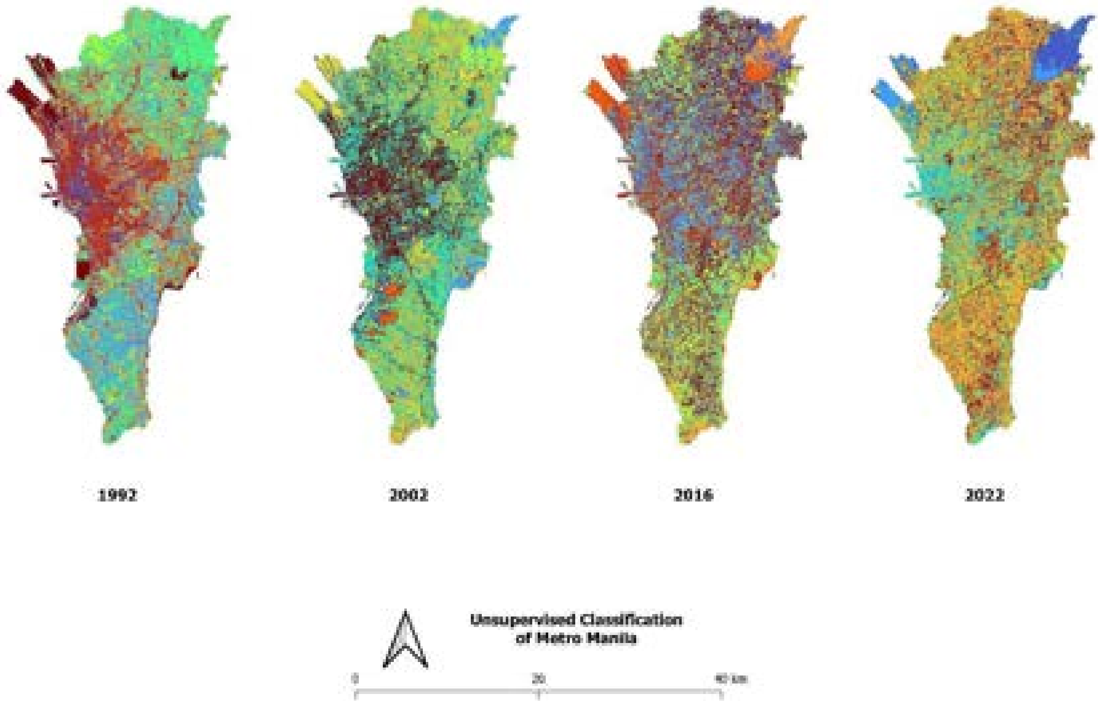
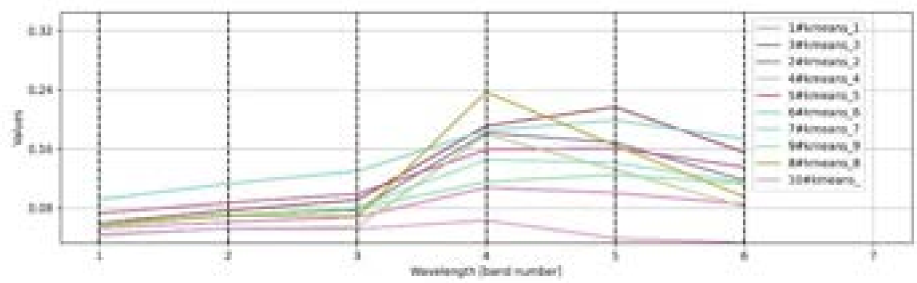
This color has no bearing on the actual nature of the landscape, this is only used to reference the map to a distinct cluster (or signature). Each class and signature will need to be visually cross-referenced on the map to check what type of land cover is existing using the available Landsat false color image as well as maps from Google Earth engine can be used to achieve this verification.

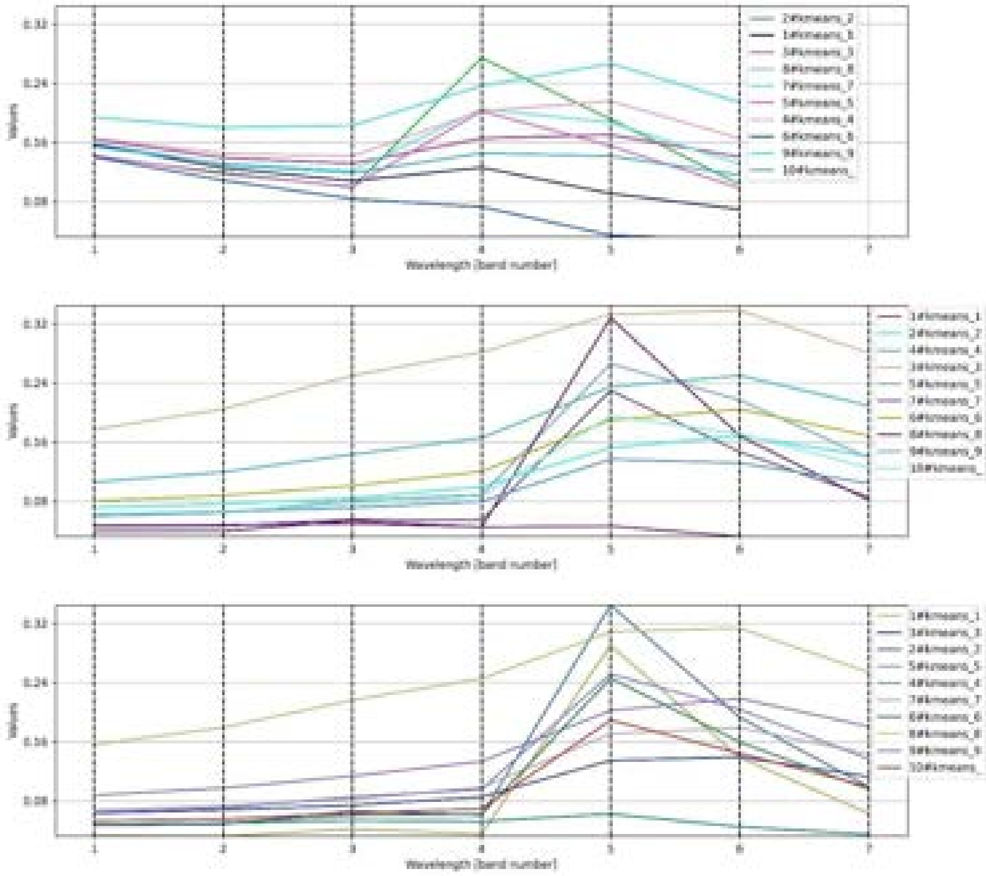
Figure 12. Unsupervised classification maps: 1992, 2002, 2016 and 2022



Source: (GIS Development Team, 2022)

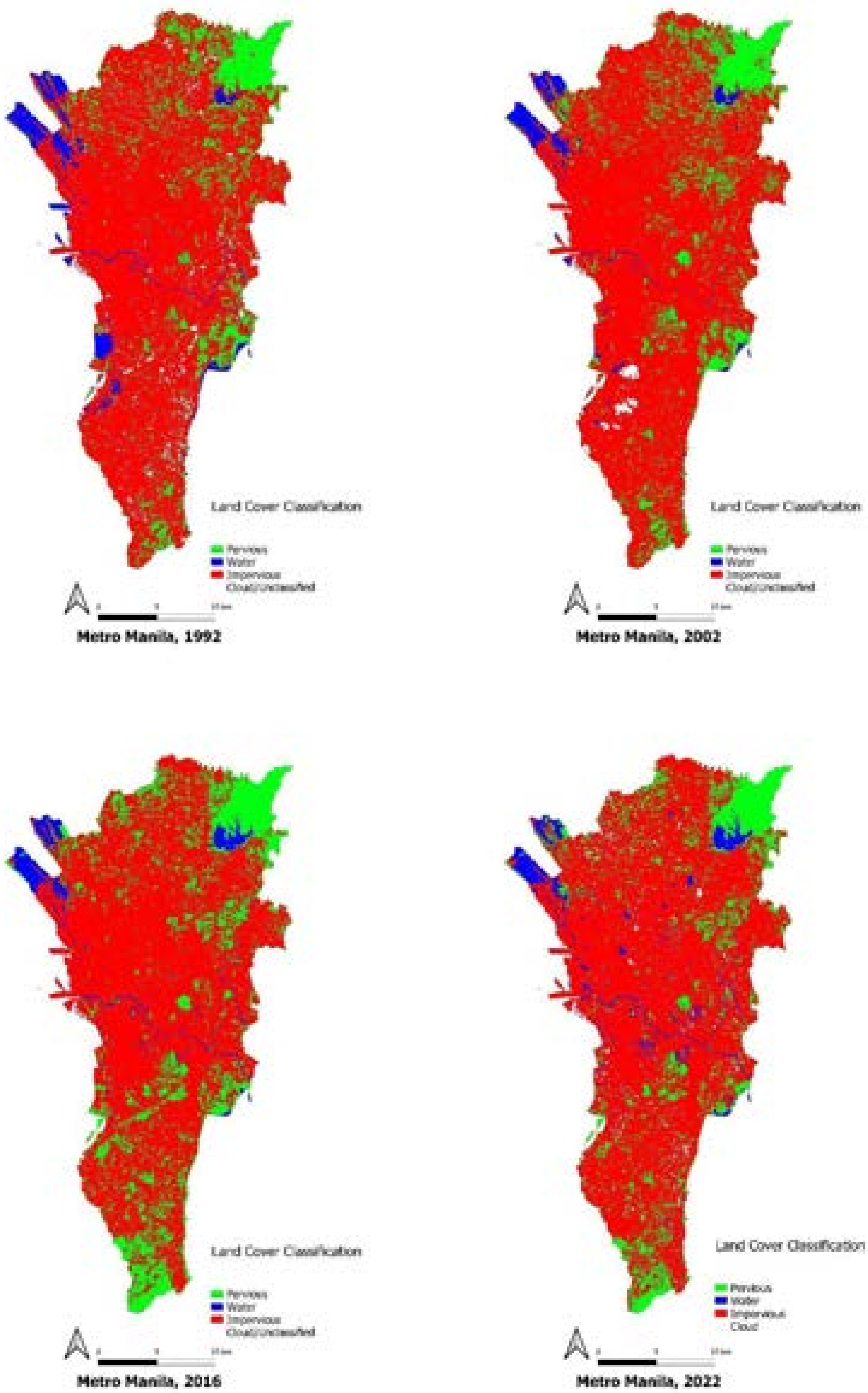
Figure 13. Spectral Angle Map from 1992, 2002, 2016 and 2022





Source: (GIS Development Team, 2022)

Figure 14. LULC map for 1992, 2002, 2016 and 2022



Source: (GIS Development Team, 2022)

A reclassification of the 10 original classes into 4 distinct macro classes were done using the Semiautomatic Classification Plugin (SCP) in QGIS. This produced a land cover classification map that shows the significant difference between vegetation (pervious), water and built-up (impervious) cover classes within the urban context as shown in Figure 14 where pervious land cover is represented as green; water is shown in blue; impervious land cover is shown in red and percentage of cloud is shown in in white. Table 17 below shows the landscape cover changes that have occurred in Metro Manila across the four time periods, PLAND represents the percentage of the landscape occupied by each class; CA depicts this in area (Hectares).

Table 17. Landscape composition of Metro Manila.

Class	1992		2002		2016		2022	
	PLAND	CA	PLAND	CA	PLAND	CA	PLAND	CA
P	14.48	8,668.08	16.39	9,815.31	21.90	13,107.96	16.15	9,667.71
W	4.63	2,768.94	3.04	1,819.89	3.67	2,200.05	4.27	2,555.55
IP	78.00	46,697.40	79.85	47,808.90	74.43	44,558.64	77.69	46,503.72
C	2.89	1,732.59	0.71	426.87	-	-	1.89	1,131.66

IX.02 Classification Accuracy

An accuracy assessment was done to determine the quality of classified map using the Semiautomatic classification plugin for QGIS. This was achieved by stratified random sampling where the sample sizes were calculated and allocated based the mapped proportion of the area. Each of the four classified maps were given an error matrix assessment, as shown in Table 18 below, although good overall accuracy was achieved in the study (92.51%), there are some classes that have lower accuracies resulting in overall lower map accuracy for year 2002. Overall, the classified maps have a Kappa coefficient of 0.783 which is rated as substantial.

Table 18. Summary accuracy assessment (1992, 2002, 2016, 2022)

		1992							2002				
		Referenced							Referenced				
		P	W	IP	C	Total			P	W	IP	C	Total
Classified	P	5	0	0	0	5	Classified		2	1	2	0	5
	W	0	4	0	0	4		W	0	3	0	0	3
	IP	1	0	15	0	16		IP	0	0	12	0	12
	C	0	0	0	0	0		C	0	0	0	3	3
	Total	6	4	15	0	25		Total	2	4	14	3	23
		2016							2022				
		Referenced							Referenced				
		P	W	IP	C	Total			P	W	IP	C	Total
Classified	P	3	0	1	0	4	Classified	P	3	1	0	0	4
	W	0	3	0	0	3		W	0	1	2	0	3
	IP	0	0	8	0	8		IP	0	0	10	0	10
	C	0	0	0	0	0		C	0	0	0	3	3
	Total	3	3	9	0	15		Total	3	2	12	3	20

	1992	2002	2016	2022
Overall map accuracy	92.23%	90.16%	9.12%	93.11%
Kappa hat	0.806	0.669	0.851	0.805

IX.03 Landscape Structure

The LULC from the five classes across four time periods indicate an overall subtle change in the landscape composition. As shown in Table 19, the pervious land cover class which comprises of urban trees and vegetation has seen increase 1.67% or 999.63Ha from 1992 to 2022; this corresponds to the decrease of other land cover classes such as water (-0.36%) and impervious (-0.31%) overall. Cloud cover in this study represents the land cover class that has been contaminated by the presence of cloud or shadows of clouds, overall, it has seen a 1% decrease in landscape cover. The notable decrease in the landscape over varying periods was seen in the water cover class from 1992 to 2002 (-1.59%); impervious cover class from 2002 to 2016 (-5.42%); and pervious cover class from 2016 to 2022 (-5.74%).

Table 19. Landscape Cover Dynamics

Class	1992-2002		2002-2016		2016-2022		1992-2022	
P	1.92%	1147.23	5.50%	3292.65	-5.74%	-3440.25	1.67%	999.63
W	-1.59%	-949.05	0.64%	380.16	0.59%	355.50	-0.36%	-213.39
IP	1.85%	1111.50	-5.42%	-3250.26	3.26%	1945.08	-0.31%	-193.68

C	-2.18%	-1305.72	-0.71%	-426.87	1.89%	1131.66	-1.00%	-600.93

(a) Landscape Level

With the spatial metrics at the landscape level (PLAND, CA) shows a subtle change in the composition of the landscape, at the class level (see Table 20), the metrics show that previous land cover has seen an increase of 18.28% in the number of patches (or 671) from 1992 to 2022, likewise, the class patch density (PD) has increased from 6.31 to 7.25 patches per 100 hectares. Though overall there is an increase in pervious landscape class, the increase in number of patches and its patch density defines a fragmented landscape. The water landscape class has seen an overall landscape decrease but at the class level, the number of patches has increased 147% from 1992 to 2022 (or 548 patches) with a slight patch density increase of 0.92 per 100 hectares. The impervious cover class has shown a 136 overall increase of the number of patches (or 25.61%) and its patch density has seen a 0.23 increase per 100 hectares. With the number of patches of cloud cover steadily reducing from 1992 to 2022, the landscape cover map as well as the landscape metrics gain an increase in accuracy overall.

(b) Class Level

The largest patch index (LPI) of all the cover classes has seen a decrease which denotes a decrease in the percentage of landscape covered by the largest patches of each of the cover classes, -0.13% for pervious, -0.14% for water, -0.62% or impervious and -0.01% for the cloud cover class. The total edge (TE) of the cover class has increased in length by 359.49kms for the pervious cover classes, 253.02kms for the water class, 178.77kms for the impervious. For the cloud cover class, a total edge reduction of 330.24kms was observed. Both the LPI and TE are correlated with patch density (ED) which denotes an increase for the pervious (6.01 m/Ha), water (4.23 m/Ha), and impervious (3.0 m/Ha) classes.

Table 20. Spatial metrics changes at the class level

Year	Class	NP	PD	LPI	TE	ED
1992	P	3,670.00	6.13	3.83	2,737,230.00	45.72
	W	371.00	0.62	0.96	436,590.00	7.29
	IP	531.00	0.89	77.28	4,044,420.00	67.56
	C	2,217.00	3.70	0.05	947,700.00	15.83
2002	P	4,772.00	7.97	4.28	3,439,440.00	57.45
	W	279.00	0.47	0.96	305,760.00	5.11
	IP	603.00	1.01	78.81	3,787,350.00	63.26
	C	90.00	0.15	0.23	72,330.00	1.21
2016	P	4,437.00	7.41	5.06	3,690,420.00	61.64
	W	587.00	0.98	0.92	459,930.00	7.68
	IP	736.00	1.23	72.49	3,984,930.00	66.56
	C	-	-	-	-	-
2022	P	4,341.00	7.25	3.70	3,096,720.00	51.73
	W	919.00	1.54	0.81	689,610.00	11.52
	IP	667.00	1.11	76.66	4,223,190.00	70.55
	C	1,550.00	2.59	0.04	617,460.00	10.32

At the class level, there are positive correlations with PD and NP (*r*=1.0, *p*<.05); TE and LPI (*p*=.73, r<.05); as well as AREA_AM and LPI (*r*=.99, p<.05); conversely, there are negative correlations between TE (*r*=.67, *p*<.05) and ED (*r*=0.67, p<.05), Table 21 below shows the correlation between landscape metrics.

Table 21. Class Level Correlation Matrix

		NP	PD	LPI	TE	ED	AREA_MN
NP	Pearson's r	—					
	p-value	—					

		NP	PD	LPI	TE	ED	AREA_MN
PD	Pearson's r	1.000 ***	—				
	p-value	< .001	—				
LPI	Pearson's r	-0.358	-0.358	—			
	p-value	0.190	0.190	—			
TE	Pearson's r	0.372	0.372	0.723 **	—		
	p-value	0.172	0.172	0.002	—		
ED	Pearson's r	0.372	0.372	0.723 **	1.000 ***	—	
	p-value	0.172	0.172	0.002	< .001	—	
AREA_MN	Pearson's r	-0.423	-0.423	0.987 ***	0.663 **	0.663 **	—
	p-value	0.116	0.116	< .001	0.007	0.007	—

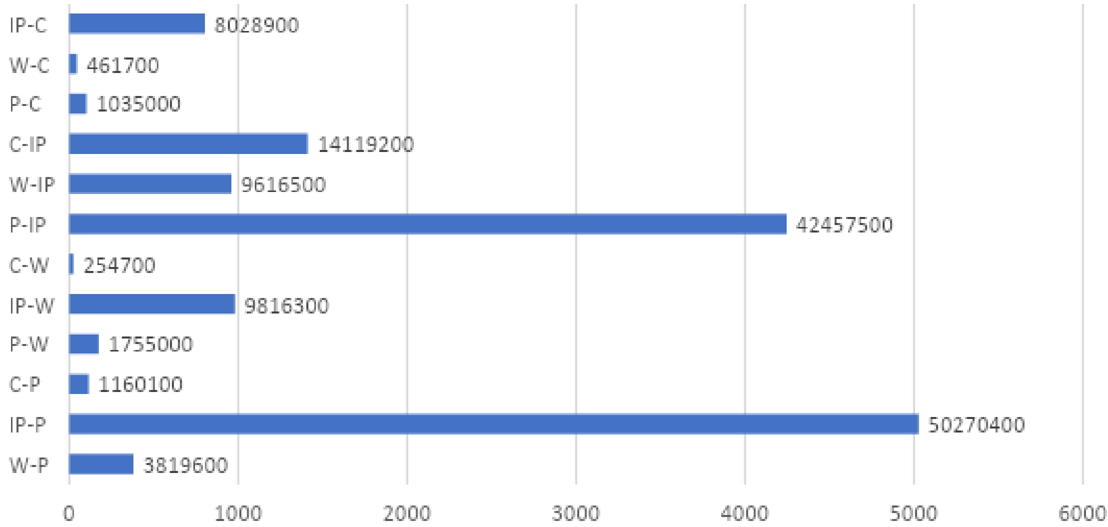
Note. * p < .05, ** p < .01, *** p < .001

Source: Calculated using (R Core Team, 2021; The jamovi project, 2021)

IX.04 Landscape Change

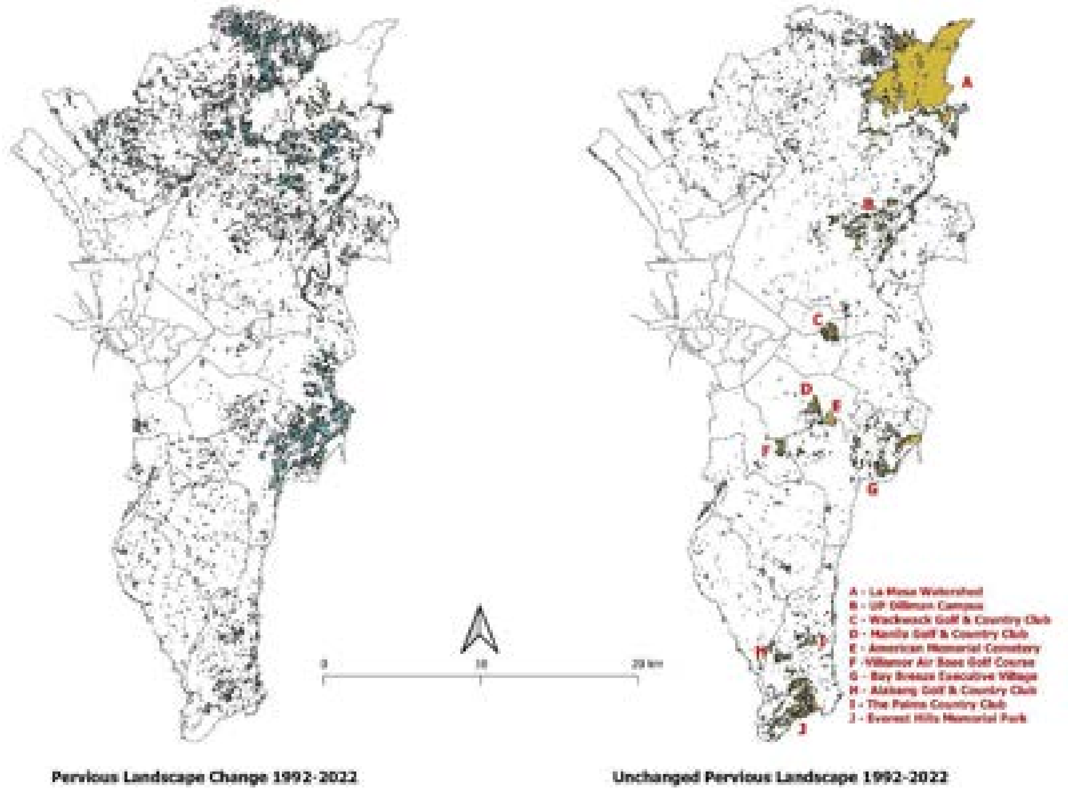
The total landscape change from 1992 to 2022 is shown in Figure 15 below. A total of 4,529.79 Ha of pervious surfaces have been converted to the other cover classes such as water (175.5 Ha), impervious (4,245.8 Ha) and cloud (103.5 Ha) as well as 5.04 Ha that was undetermined (-999). The results also reveal a substantial area of previously impervious cover class has been converted into pervious land cover (5,027.04 Ha).

Figure 15. Landscape change from 1992 to 2022



Much of the reduction in pervious cover classes in Metro Manila occurred in the northern, easters and southern parts of the metropolis. As show in Figure 16, the conversion of pervious cover classes identified in this study as urban trees and vegetation have occurred in the cities of Valenzuela, northern portion of Caloocan, Quezon, Marikina, Pasig, Taguig and Muntinlupa. There are, however, unchanged pervious landscapes (4,138.29 Ha) that are mainly focused on private parks and golf courses as well as the La Mesa watershed which is a protected area.

Figure 16. Dynamics of the pervious land cover class in Metro Manila

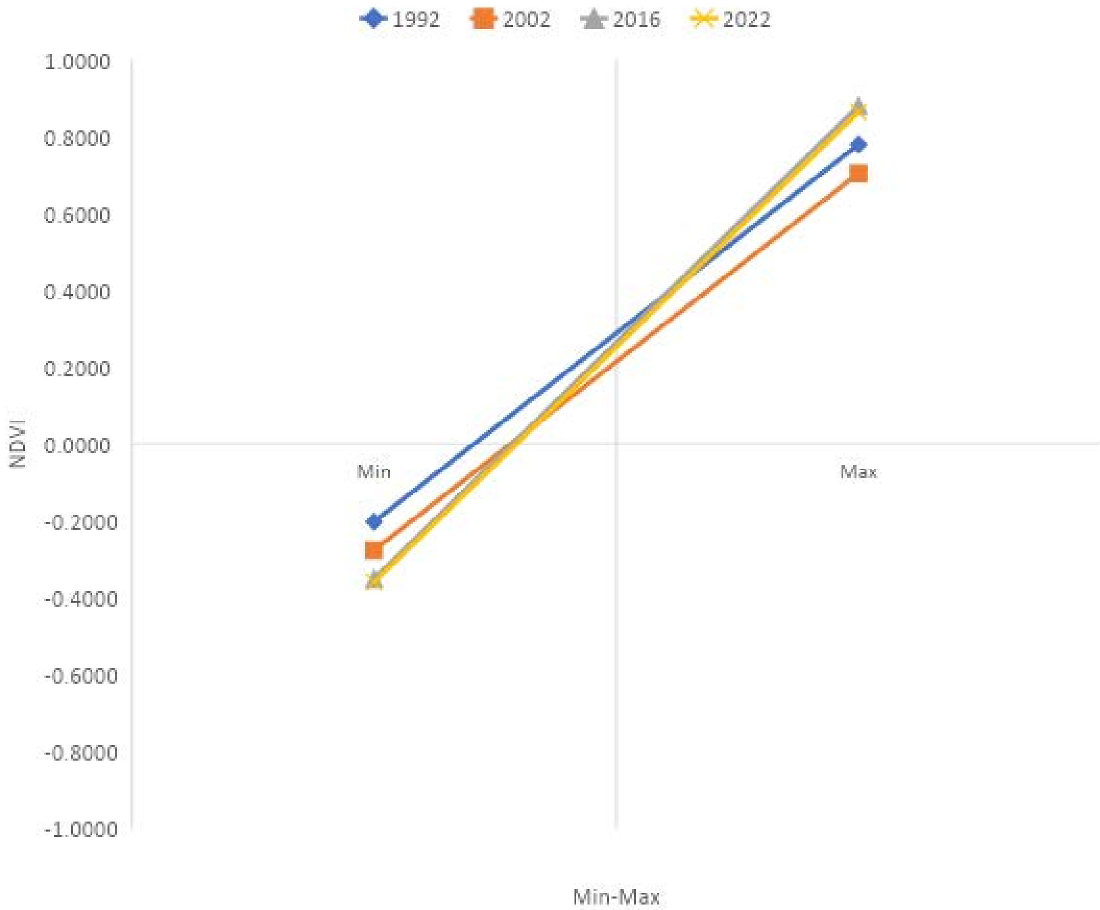


Source: (GIS Development Team, 2022)

IX.05 Normalized Difference Vegetation Index (NDVI)

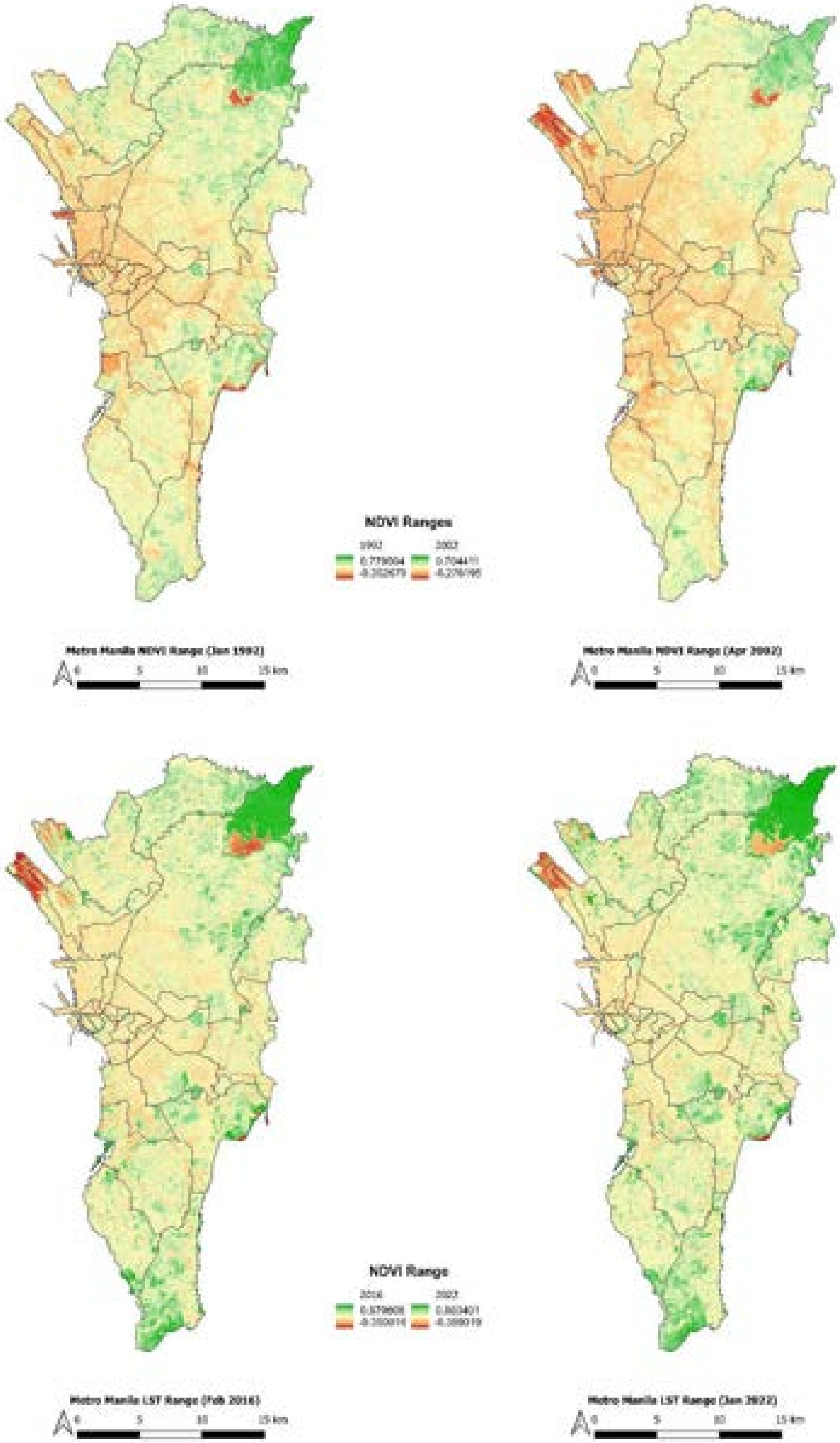
The assessment of NDVI using Landsat image is based on the spectral properties of vegetation to absorb visible light as energy used during photosynthesis, thus reflects near-infrared (NIR) radiation with a higher NDVI value for healthy vegetation (Sun & Kafatos, 2007). The NDVI model derived through Landsat 5 TM for 1992, Landsat 7 ETM+ for 2002, Landsat 7 for 2016 and 2022 is shown in Figure 17. The NDVI values ranges in in 1992 ranged from -0.2027 to 0.7795; in 2002 the minimum value decreased to -0.2762 and the maximum also went down to 0.7044; by 2016 minimum NDVI value was -0.3509 to a maximum of 0.8798; by 2022 the NDVI minimum value has increased to -0.3593, the maximum NDVI value likewise increased to 0.8634.

Figure 17. NDVI minimum and maximum for 1992, 2002, 2016 and 2022.



The NDVI map (see Figure 18) concurs with the LULC change analysis results in that, areas such as the La Mesa Watershed and private parks and golf courses exhibit higher NDVI values overall. However, it also shows that significant changes occurred during the four time periods and showed a decrease in vegetation health from 1992 to 2002, this is evident in the ranges as well as an average decrease in the NDVI from 0.2884 to 0.2141 (1992 to 2002) indicating poor vegetation quality. An increase in vegetation health followed from 2002 to 2016 where the NDVI averages increased by 0.0503, registering the highest NDVI values for the four time periods at 0.2644 in 2016. By 2022, the NDVI values went down by 0.0124.

Figure 18. NDVI maps for 1992, 2002, 206 and 2022



Source: (GIS Development Team, 2022)

IX.06 Land Surface Temperature (LST)

The LST spatiotemporal patters and shifts corelate the changes in LULC. In 1992, LST registered an estimated the range of 19.74°C to 28.39°C; in 2002 the LST registered as 31.33°C to 68.91°C; in 2016 the LST was in the range of 23.25°C to 51.25°C, and the LST ranged 16.50°C to 34.91°C in 2022.

Figure 19. LST minimum and maximum for 1992, 2002, 2016 and 2022.

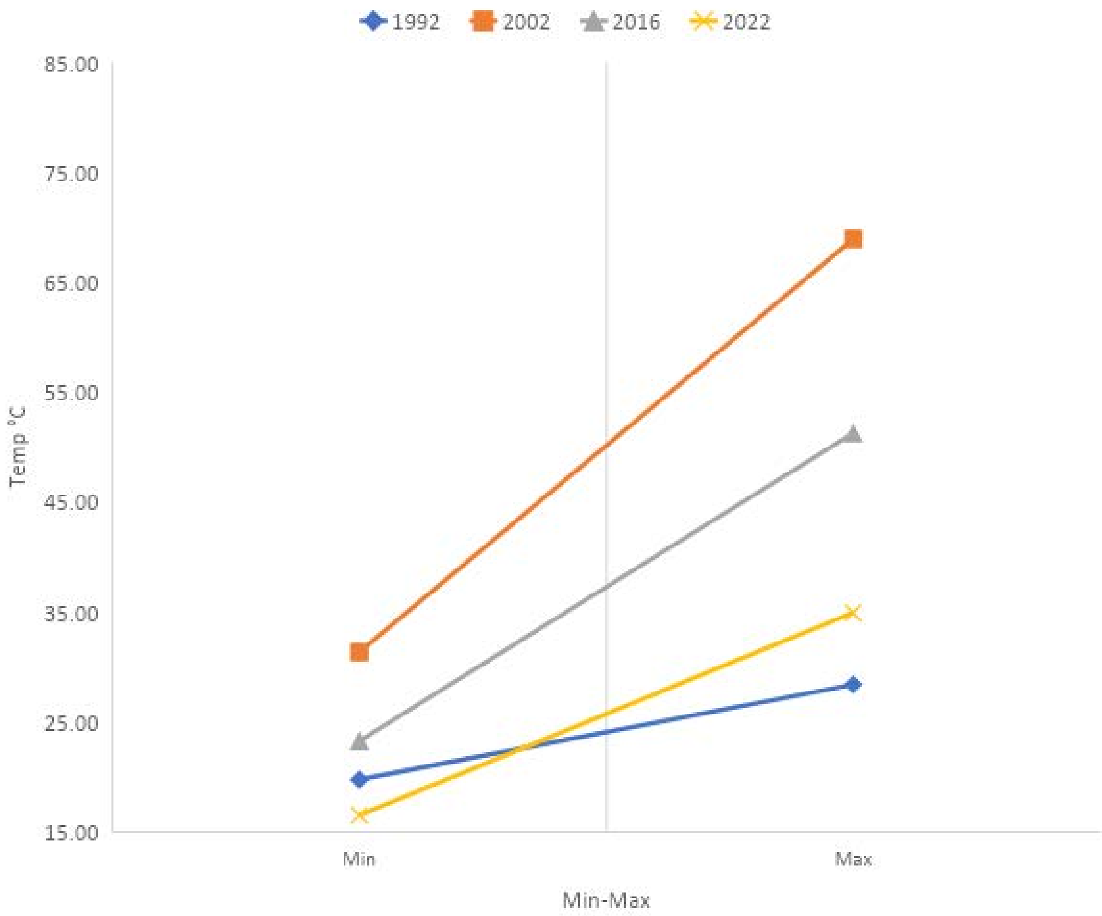
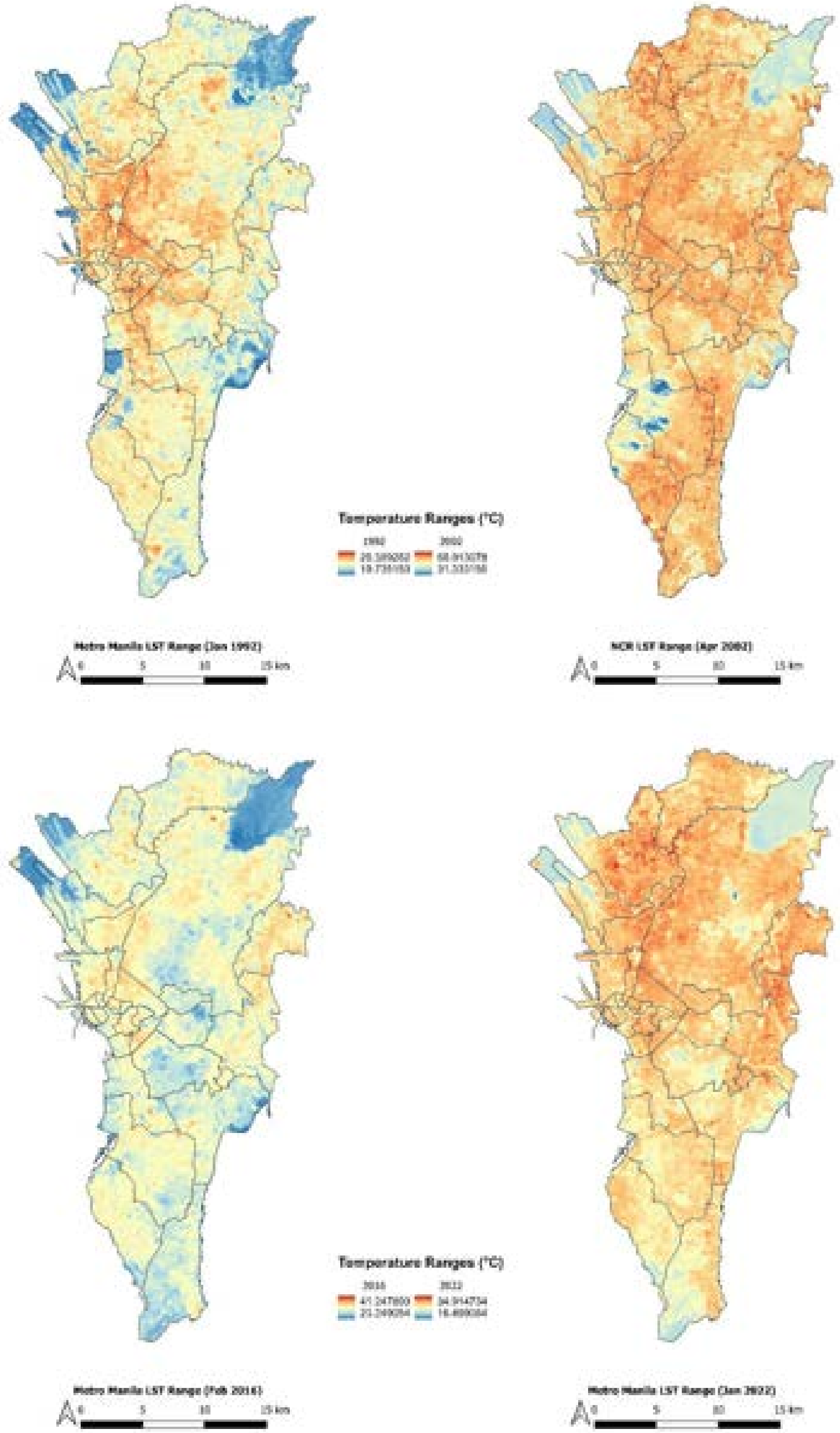


Figure 19 shows a chart of the minimum and maximum ranges of the Land Surface Temperature from 1992 to 2022; from this in 1992, the maximum range of he LST was significantly lower than the latter years. 10.8–45°C during 2000, and 11.2–44.7°C during 2020. During 2002, the minimum and maximum LST were ate the highest, followed by 2016. In 2022, LST ranges were significantly lower where the minimum range was the lowest among the four time periods. Figure 20 shows that in 1992, much of the high temperature ranges occur in the district of Manila. The La Mesa watershed area shows a deep blue color which is characteristic of lower temperatures. In 2002, LST temperatures were at the extreme, where much of the high LST readings can be found in among the built-up areas of Metro Manila; here the La Mesa watershed registered LST ranges higher compared to 1992. In 2016, LST readings were lower compared to 2002, the La Mesa watershed registers a significantly lower temperature than in 2002; though the LST maxes out above 41°C, it is largely distributed around the city in very small hotspots, particularly, industrial areas (14.66438894, 121.11628610), NAIA Terminal 3 (14.52019493, 121.01339856), and malls (14.51570765, 120.99122674). The lowest LST readings can be found in areas of lush UGS such as the La Mesa Watershed (14.73572485, 121.08915827), golf courses (14.59234443, 121.04965151), parks (14.65071201, 121.04372538) and along the Pasig River (14.59461880, 120.98259287). Though LST ranges were lower in 2022 compared to 2016, a larger area registers high LST to now include much of the commercial areas (14.65289344, 121.03296698), residential complexes (14.56685168, 121.07767230) and impervious public spaces (14.58417929, 120.98138187). Pasig River also registers higher LST readings compared to the previous year, denoting that the temperature of the river is rising.

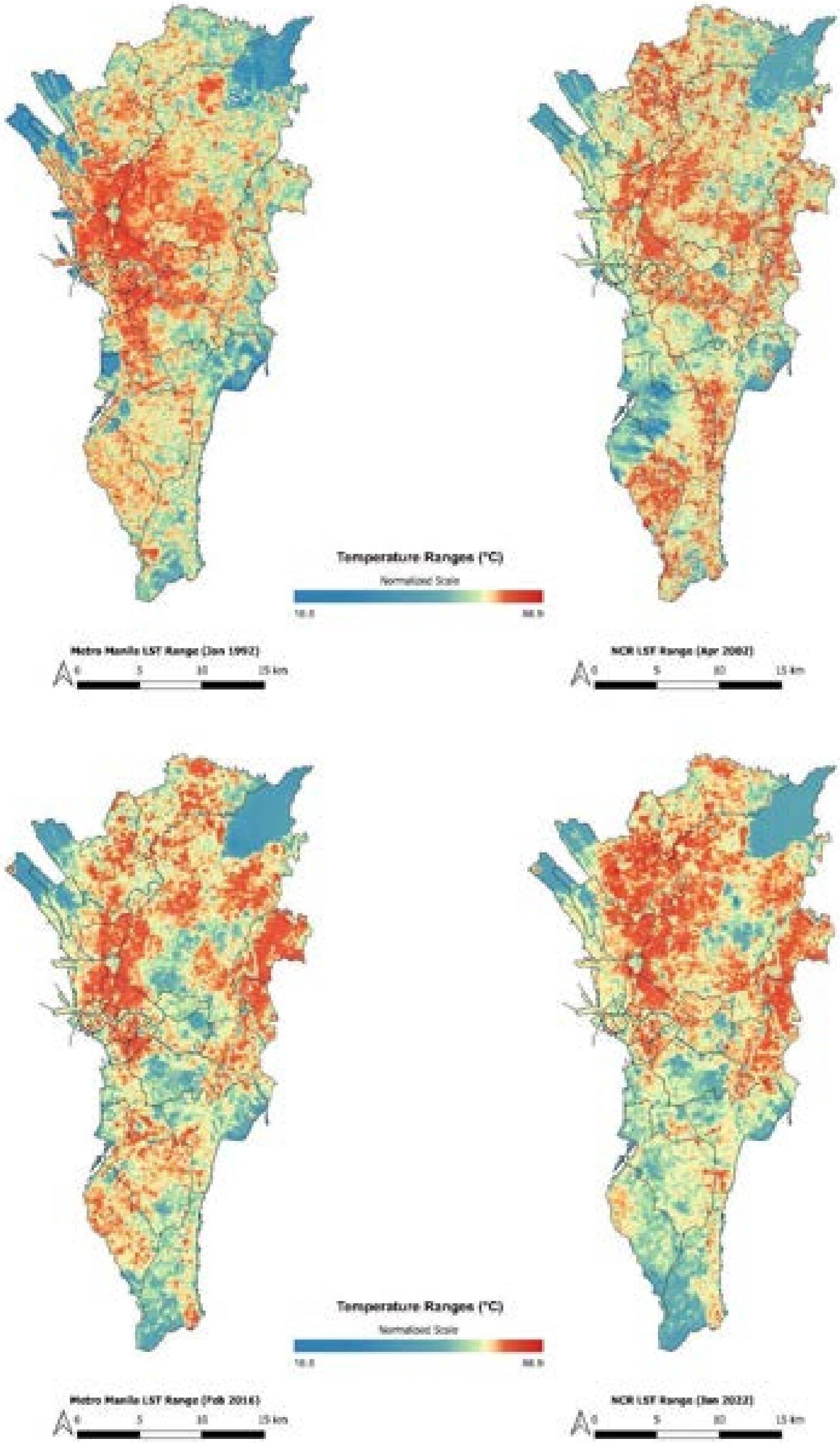
Figure 20. LST Maps for 1992, 2002, 2016 and 2022



Source: (GIS Development Team, 2022)

The temperature ranges in Figure 20 show the individual ranges that had occurred during the four time periods, we can normalize the temperature ranges by adjusting the scale to the minimum (16.5°C) and maximum (68.9°C) LST scale to show a comparison between 1992, 2002, 2016 and 2022. Using Figure 21, we can then compare the four time periods and look at where the high low and high LST readings are concentrated. Areas of urban greens, water, and soft ground registers with low LST readings. The 1992, 2002, 2016 and 2022 LST map shows heat emanating from the district of Manila, with a few low LST areas such as the Manila Chinese Cemetery (14.63422412, 120.98893738) and the Pasig River (14.59449007, 120.99546482).

Figure 21. Normalized LST ranges for 1992, 2002, 2016 and 2022

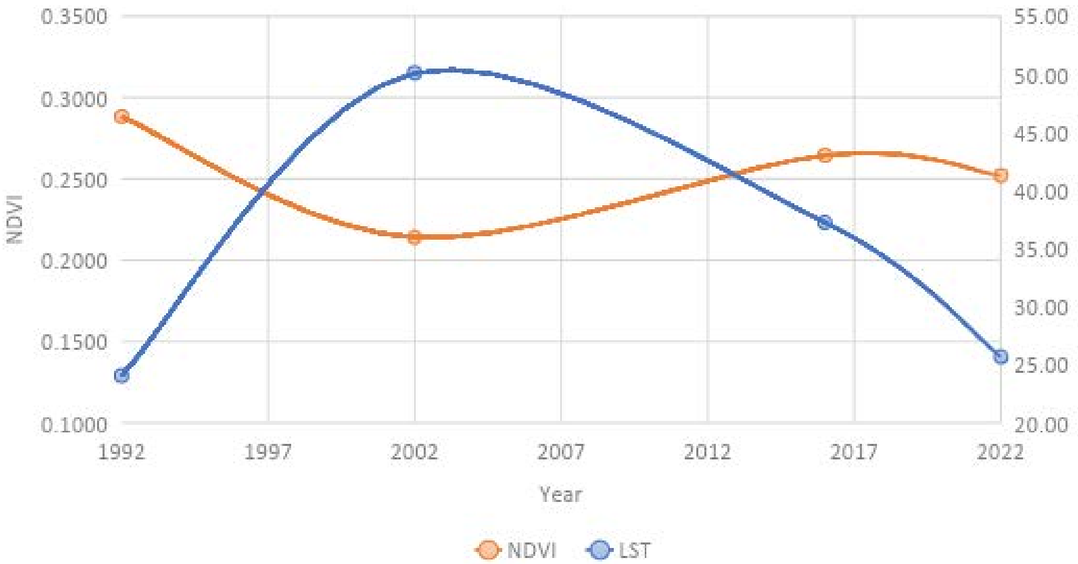


Source: (GIS Development Team, 2022)

IX.07 Relationship of NDVI and LST Values

In general, the results showed that LST is inversely related to NDVI, irrespective of any season as shown on Figure 22. It is perceived that the NDVI values have decreased from 1992 to 2002 due to increasing urban growth and decreasing vegetation area within the metropolis, this has negatively affected the LST showing a proportional increase. Beginning in 2002 where the NDVI values begun to increase and the LST values have recorded a decrease. Vegetation coverage has a significant influence on the land Surface Temperature (LST) distribution.

Figure 22. NDVI x LST Relationship



IX.08 Ecological Benefit Valuation

The urban green space inventory using the i-tree canopy model highlights three regulatory ecosystem services. 500 hundred samples were taken randomly and have been equally distributed (see Figure 23).

Figure 23. Distribution of cover classes from the i-Tree Model

Source: From the report generated by the i-Tree Canopy tool

From the results of 500 samples, the overall estimated value of Metro Manila's ecosystem services is valued at ₱1,511,125,056 annually. This is the sum of the annual benefits from carbon sequestration estimated at 40.04 kilotons with an estimated value of ₱426,857,443; total air pollution benefits estimated at 886.12 tons which are valued at ₱647,645,883 and the avoided runoff measured at 3,262.06 kiloliters estimated at ₱436,621,730. Additionally, carbon stored in trees are estimated at 647.86 kilotons with an estimated value of ₱6,905,931,729. Overall, the ecological benefit brough by the urban green spaces of Metro Manila is valued at ₱8,417,056,785.

Table 22. Value of selected ecosystem services in Metro Manila

Tree Benefit		Amount	Value
Carbon	Sequestered annually in trees	40.04 (kt)	₱426,857,443
	Stored in trees*	647.86 (kt)*	₱6,905,931,729 *
Air Pollution	(CO2, NO2, SO2, PM2.5, PM10*)	886.12 (t)	₱647,645,883
Hydrological	Avoided Runoff	3,262.06 (KL)	₱436,621,730

*Note: *This is not an annual rate*

IX.09 Urban Green Space per Capita

The urban landscape mosaic Metro Manila it comprised primarily of the pervious land cover characterized by urban greens and vegetation, the impervious land cover characterized by built-up areas, pavements, disturbed land and soils devoid of vegetation; and water that it summarized by the presence of rivers, lakes and coastal region. Based on the land cover classification for the four periods, the pervious land cover class area (CA) was extracted and correlated with the projected population for the same years. Since the PSA releases official population statistics every five years (1990, 2000, 2010, 2020), the projected population for years 1992, 2002, 2016, and 2022 using the Equation 7 published by (George et al., 2004).

Equation 7.

$$N_t = P \times (1 + \frac{r}{100})^t$$

Table 23 shows that in 1992, the available UGS per capita is 10.9 sqm per capita; this increased to 9.88 sqm per capita in 2002 and continued to increase to 10.02 sqm per capita in 2016 before going down significantly to 7.17 sqm per capita in 2022. The study however does not distinguish between private UGS such as golf courses and public parks, therefore, the study considers the regional profile of Metro Manila in determining UGS per capita.

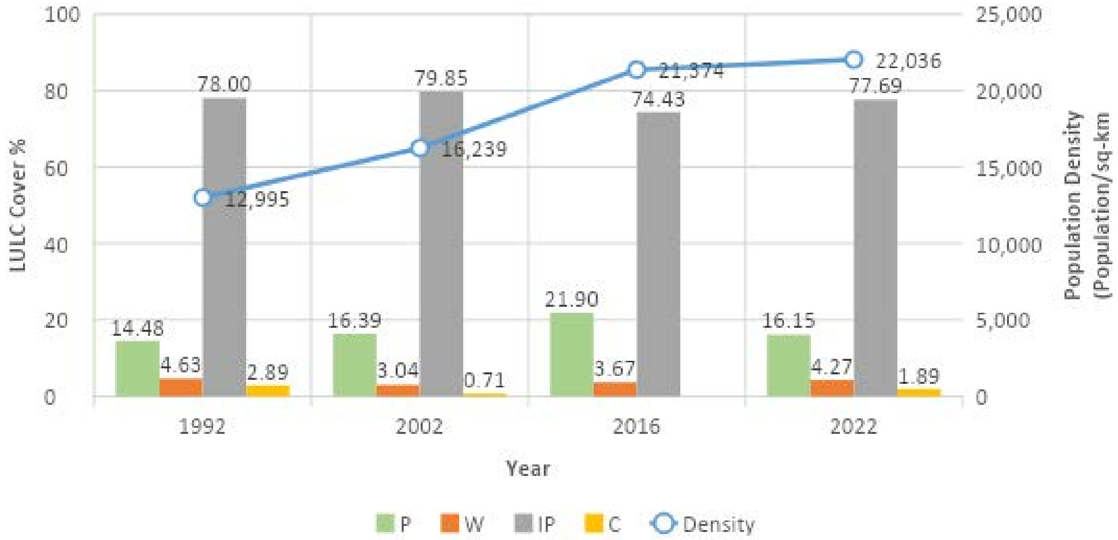
Table 23. UGS availability in Metro Manila (1992-2022)

Population P	1990	2000	2015	2020
	7,948,392	9,932,560	12,877,253	13,484,462
% Rate r	2.35	2.35	1.58	0.97
Projected N_t	1992	2002	2016	2022
	7,952,781	9,938,045	13,080,714	13,485,731
UGS (Ha)	8,668.08	9,815.31	13,107.96	9,667.71
Population per Ha	917	1,013	998	1,395
sqm/capita	10.90	9.88	10.02	7.17

IX.10 Population and Urban Expansion

The results show a connection that exist between population and urban expansion, due to the similarity in trends of population density and the spatial structure of built-up areas in Metro Manila Figure 24. Figures from the LULC classification of 1922, 2002, 2016 and 2022 were superimposed with the calculated projected population of the same year showing a paralleled increase in built-up areas and population density from 2016 to 2022.

Figure 24. Correlation between LULC change and population density



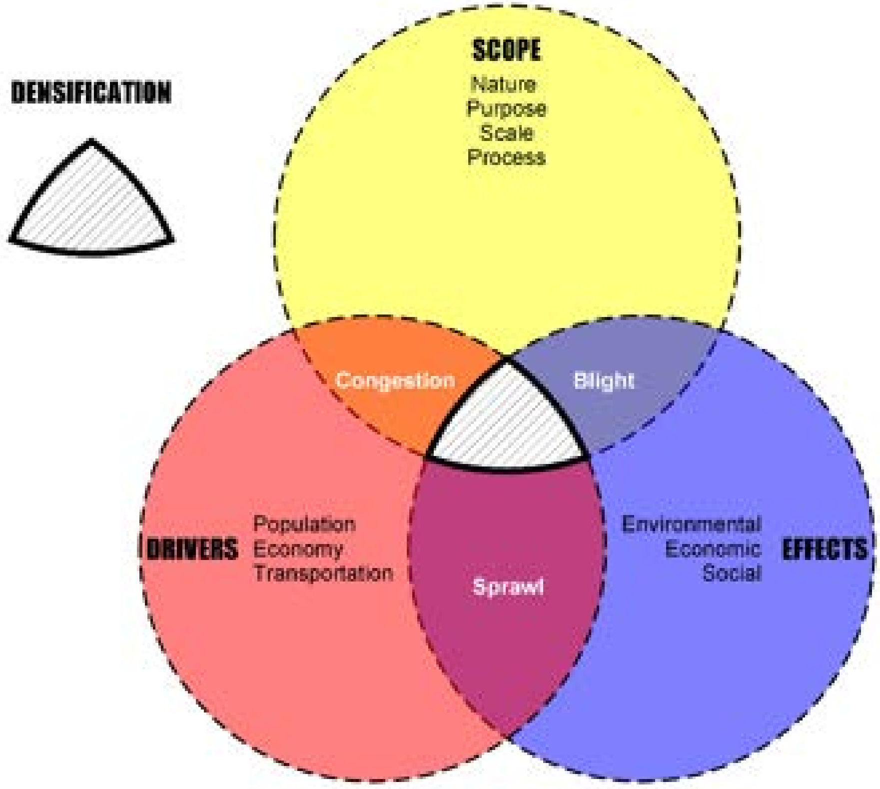
X. Analysis and Discussion

X.01 Defining Densification

(Teller, 2021b) presents urban densification as an increasingly accepted and important alternative to sprawl that encapsulates a no-net land take. In most developing and fast-growing cities, densification occurs naturally with a combination of demographic and economic changes that puts pressure on existing transportation and infrastructure. Teller highlights the need for a deeper understanding of urban density's potential effects (direct, indirect, or cumulative) that may be environmental, economic, and social, within or outside the urban dimension that bear both costs and benefits. To understand, pressures the need to first identify variables that will produce the most value for a particular scenario and enable planners to locate places within the urban fabric that will be most appropriate for future expansion or conservation.

Teller citing (Angel et al., 2021; Berghauser Pont & Haupt, 2010; Giddings & Rogerson, 2021; Godoy-Shimizu et al., 2021; Kostourou, 2021; Li & Sunikka-Blank, 2021; Livingstone et al., 2021; Martino et al., 2021; Rinkinen et al., 2021; Schiller et al., 2021) postulates that densification can be presented as a measurable set of factors (categorical variables), he defines urban densification as a multifactorial, nonlinear process which must be addressed at various scales and scope. This requires multifactorial metrics of density that can outline various urban forms and define how its inhabitants and users experience them. Using Teller's work, we can categorize these variables into *Scope, Drivers, and Effects.*

Figure 25: Venn diagram representing spheres of densification



Source: Adapted from (Teller, 2021a, 2021b)

X.02 Comparison of Land Cover of 1992, 2002, 2016 and 2022

Metro Manila has undergone significant changes in the last three decades. Although it will be biased to say that Metro Manila has turned for the worst, the study has shown that the landscape cover changes that has happened is a cycle, and that the city is in its path of recovery. Overall, the study has shown that Metro Manila has improved from the LULC of 1992, with a 16.15% permeable green space within its boundary. This translates to a 7.17 sqm per capita urban green space allotment, just short of the WHO prescription of 9.0 sqm per capita, if the city continues to improve its urban ecological management, Metro manila will be able to surpass this in the future. This pattern of change may reflect the increasing attention towards a more sustainable future (SDG 11), incorporating urban green spaces during development. Despite the importance of green space, urban growth and urban densification are contributing to some reduction and isolation of the green space structure which continuously fragment the landscape.

X.03 Reduced Permeability and Loss of Green Space

The spatial pattern of change from previous to impervious cover classes are not random. The evidence suggests that these conversions happened at the urban fringes. The rural urban migration where cities like Muntinlupa (1.58%), Taguig (2.06%), Valenzuela (3.03%) all experienced higher population rates of increase. It is however noteworthy that even with the increase in total area (sqm) of built-up area, permeable cover classes have increased since 1992. This can be attributed to the verticality of development indicating a higher floor to lot area ratio (FAR) of construction.

X.04 Unchanged Pervious Cover

The study has shown that in the last 30 years, there are 4,138.29 Ha of untouched urban green spaces present in Metro Manila. A good portion of this vegetation is the Ninoy Aquino Parks and Wildlife Center; UP-Diliman Campus; Arroceros Forest Park; Las Piñas-Parañaque Habitat and Ecotourism Area that's declared a critical habitat under Proclamation No. 1412 in 2006; La Mesa watershed that was declared a protected area in 2007 under Proclamation No. 1336. Other notable unchanged pervious cover belongs to the various executive villages and gated communities and private cemeteries. Their resilience to change is the best example of the success of declared protected areas and land use policy and management and the role of local governments in provisioning urban green spaces (Bush, 2020).

X.05 Increasing Pervious Cover Class

The increase in pervious cover is marginal (1.67%) overall but the spatial data at the class level has shown that they're fragmented with a smaller over an AREA_MN and they are not random. These patches (5,027.04 Ha) are spread across the landscape where low-density developments such as single-family subdivisions are located as well as old industrial areas that have long been abandoned, some of the increases were growth of trees from existing cemeteries. From 1992 to 2022, there has been an overall increase of Green Spaces in Metro Manila, from the landscape pattern analysis, fragmentation of the vegetation areas is present. This increase in pervious surfaces may be attributed to additional construction of vertical residential and non-residential development within the megacity.

X.06 Minimizing the Urban Heat Island Effect

Landscape ecology analysis provides scientists, planners, architects, and the policy makers a clear picture of the state of our urban centers. This will enable precise solutions to the various conditions of the different cities being affected by UHI. Reducing UHI requires application of various techniques from promulgating policies to application of design interventions and determining which one is applicable to a locality would guarantee its success. The study shows that the 2022 minimum temperature is lower than the 1992 but the maximum is higher. The study has identified areas of increased UHI from 1992, where primarily are large commercial complexes, open paved surfaces, and industrial areas. Improving the ratio between impervious and impervious surfaces within parcels of lot is shown to reduce UHI, and planting trees that process enough transpiration may reduce this altogether (L. Yang et al., 2016).

In existing urban centers, UHI is directly caused by the rapid urbanization (Sussman et al., 2019) and densification (Duan et al., 2019). The natural increase in population in the cities as well as the migration of the rural population to the urban centers have been attributed to economic development especially in developing nations (Harris, 1988). Controlling the rate of population growth and migration is a daunting task that requires providing economic alternatives to rural areas aimed towards reducing, if not eliminating, the need for the population to move to the urban centers. This requires policies and infrastructure development that will take time and resources as well as the political will to make them work. However, even if there are socio-political and natural environment limitations in the rural districts, the population who are hit the worst, those whose livelihood and ecology has been rendered unproductive, will ultimately leave and migrate to the more productive, albeit critically dense, urban centers. Environmental Possibilism models have shown that opportunities and challenges may well impose certain restrictions but has given people an infinite number of possibilities, each of which could be followed by different groups of people (Vallero, 2016). However, regulating rural-urban migration may result in an overall decline in production and an imbalance of the labor workforce (Au &

Henderson, 2006) and looking to other solutions for the UHI in our urban centers will lead to a more physical response.

X.07 Urban Green Spaces

Urban green spaces, an important component of urban ecosystems, provide many environmental and social services that contribute to the quality of life in cities (Badiu et al., 2016; Uy & Nakagoshi, 2008). One of the key tasks of architects and planners is determine how to optimize the benefits of urban green spaces that help mitigate the effects of UHI through Patch Corridor Matrix Modeling and Land Suitability Analysis designers can determine that (1) both the composition and configuration of green space elicits urban heat island; (2) optimizing the configuration of green space which increases the patch density and edge density should be prioritized in sustainable urban planning and development to mitigate urban heat island effects. A study by (Uy & Nakagoshi, 2008) introduces a program for developing green spaces in urban areas through (1) land suitability analysis based on GIS; (2) quantifying green areas based on the ecological factor threshold method to maintain ecological balance; and (3) applying landscape-ecology principles in organizing green spaces in urban areas.

The most used quantitative indicator to assess urban green infrastructure is urban green space per capita. A case study was made for Hanoi (Uy & Nakagoshi, 2008), Vietnam and its results show that most of the planned green spaces in the 2020 Hanoi Master Plan are suitable for development. It identified an area of 18m2 green area per capita seems not to be enough to maintain ecological balance and organization of the green spaces in the 2020 plan seems to lack a theoretical basis, or a holistic framework, at different scales. In countries like Romania, UGS is maintained at 26 square meters per capita (Badiu et al., 2016) , in contrast, in the Philippines, PD1096 prescribes an open spaces as small at 10% of land used.

X.08 Socioeconomic Changes

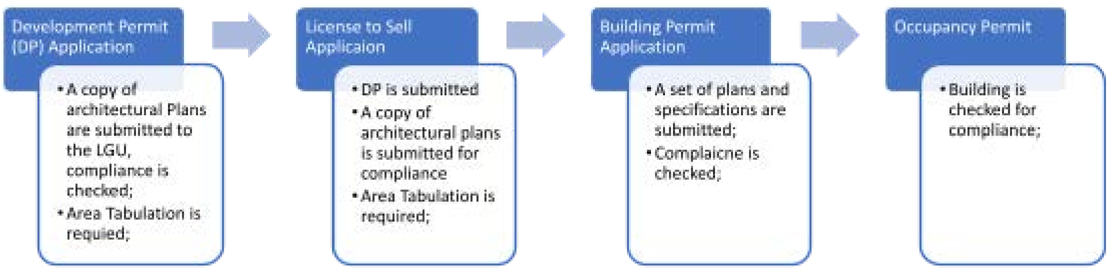
Although the PSA reports a decrease in the poverty rate along with the slowing down of population increase in Metro Manila. This trend highlights the negative effects of densification social and economic spheres.

X.09 Local UGS Policy

Presidential Decree 1216 of 1977 defines “Open Spaces” as areas reserved exclusively for parks, playgrounds, recreational uses, schools, roads, places of worship, hospitals, health centers, barangay centers and other similar facilities and amenities. This is however geared towards residential subdivisions. PD 1216 likewise amends Section 31 pf Presidential Decree 957 requiring subdivision owners to provide roads, alleys, sidewalks and reserved open space for parks and recreational use. These areas reserved for parks, playgrounds and recreational are considered non-buildable and non-alienable public lands. On such parts of the subdivision, as may be designated by the Authority (referring to National Housing Authority), projects and plans of the subdivision project include tree planting. Subdivision projects one (1) hectare or more, according to PD1216 shall reserve thirty percent (30%) of the gross area for open space having the following allocated exclusively for parks, playgrounds and recreational use: 9% of gross area for high density or social housing (66 to 100 family lot per gross hectare); 7% of gross area for medium-density or economic housing (21 to 65 family lot per gross hectare); 3.5 % of gross area low-density or open market housing (20 family lots and below per gross hectare).

The current policy defines a “quantitative” requirement for open spaces within an area. A descriptive analysis or *ex post* analysis of this can be generated through a traditional policy study using a scientific assessment focusing on analyzing the facts through quantitative modelling. The most used quantitative indicator to assess urban green infrastructure is urban green space per capita. A case study by (Uy & Nakagoshi, 2008) for Hanoi, Vietnam show that most of the planned green spaces in the 2020 Hanoi Master Plan are suitable for development. It identified an area of 18m2 green area per capita seems not to be enough to maintain ecological balance and organization of the green spaces in the 2020 plan seems to lack a theoretical basis, or a holistic framework, at different scales. In countries like Romania, UGS is maintained at 26 square meters per capita (Badiu et al., 2016) , in contrast, in the Philippines, RA 6541 prescribes an open space as small at 10% of land used and PD 957, 9% for high-density residential development.

Figure 26. The Permit Process in Residential Building Application



In the four stages in the design, construction, and operation of the building (Figure 26), compliance in open spaces and other relevant code compliance requirements are checked particularly, open spaces are scrutinized since it is also a factor in requirements for fire safety compliance. However, there is grave disconnect on how the Government defines Open Spaces. For one, the DHSUD does not account for Open Spaces that are not at ground level (such as garden decks or green roofs) but they do include the Amenity Decks (which are on the upper floors) to be counted as open spaces. Another example is the open space requirement of the National Building code that is based on lot (parcel) density. In this case, a typical R1 residential zoned lot is allowed a minimum 20% open space but only 10% is prescribed as permeable. This issues on how the current law is defined and implemented bust first be addressed, with a more accurate definition to be declared with a more appropriate open space per capita be defined.

Table 24. Maximum allowable Percent of Site Occupancy (PSO)

Approved Zoning	PSO	ISA	USA
Residential 2 /Medium Density Housing	55%	30%	15%
w/ firewall	60%	30%	10%
Residential-2 /Medium Density Housing (multiple family dwelling units within one building/ structure with a BHL of 15.00 meters)	60%	30%	10%
	70%	20%	10%
Residential 3 (R-3)/High Density Housing (single family dwelling unit with a BHL of 10.00 meters)	65%	20%	15%
w/ firewall	80%	10%	10%
Residential 4 (R-4)/ Individual Townhouse Units	70%	20%	10%
w/ firewall	80%	10%	10%
Residential 5 (R-5)/ Condominiums	70%	20%	10%
w/ firewall	80%	10%	10%
Commercial 1 (Com-1)	70%	20%	10%
w/ firewall	80%	10%	10%
Commercial 2 (Com-2)	75%	20%	5%
w/ firewall	85%	10%	5%
Commercial 3 (Com-3)	80%	15%	5%
w/ firewall	90%	5%	5%
Industrial 1 (Ind-1)	70%	20%	10%
w/ firewall	80%	10%	10%
Industrial 2 (Ind-2)	70%	15%	15%
w/ firewall	80%	5%	15%
Industrial 3 (Ind-3)	70%	15%	15%
w/ firewall	80%	5%	15%
Institutional	50%	20%	30%
w/ firewall	60%	20%	20%
Cultural	60%	20%	20%

w/ firewall	70%	20%	10%
Utility/Transportation/ Services	50%	40%	10%
w/ firewall	60%	30%	10%
Sidewalks/ Arcades at RROW	-	22.22%	11.11%
Parks and Open Recreational Spaces	20%	30%	50%
PUD at a reclamation area close to an operating airport	70%	15%	15%
PUD at a reclamation area	70%	15%	15%
PUD at a coastal area	70%	15%	15%
PUD at an inland area close to an operating airport	70%	10%	20%
PUD at an inland area	70%	10%	20%
Cemetery	85%	10%	5%

Source: Adapted from (National Building Code of the Philippines, 1977) *Section 8, Table VIII.1*

Currently, Open Spaces prescribed under PD1216 is interpreted as a mix of a percentage of area percentage standards and population-ratio where gross lot area to the number of populations within that 1 hectare is considered. Though this gives scale, the range of 9% of gross area for high density or social housing (66 to 100 family lot per gross hectare); 7% of gross area for medium-density or economic housing (21 to 65 family lot per gross hectare); 3.5 % of gross area low-density or open market housing (20 family lots and below per gross hectare) is confusing and promotes a disparity in providing a standard amount of open space for everyone.

Table 25. Current open space requirement equivalent per subdivision

Provision	Required Parks & Playground Per Dwelling Unit/Lot per Ha 70% Saleable/30% Open Space Ratio	
PD 1216	66-100*	9.0%
	21-65	7.0%
RA 6541	Open Space	10.0%
PD 957	20 and below	3.5%
	21-25	4.0%
	26-35	5.0%
	36-50	6.0%
	51-65	7.0%
	66 and above*	9.0%
BP 220	150 and below	3.5%
	151-225 per	7.0%
	225 and above per*	9.0%

The monitoring of policies is already being done both by the Local Government Units (LGU) as well as the National government represented by the DHSUD. This is done through a strict application process, incremental inspection, and issuance of the “License to Sell,” qualifying that the development has satisfactorily achieved compliance with the development guidelines including the open space requirement. National laws referring to the definition of PD 1216 for Open Spaces such as PD 957, BP 220 and PD1096 are all “Developmental Controls,” these controls directly impact what can and cannot be done on a particular site and what must be included as part of the development. Subdivision & Condominium Plans submitted to the Department of Human Settlements & Urban Development (DHSUD) present two key statistical data needed for this study. First, the total area to be developed into a residential subdivision that shows the allotment of “Saleable” lots as a total area as well as the number of lots that is equivalent to one Household. Second, the Subdivision Plans shows the total area broken down into allotments of the total area, highlighted, is the total Open Space for the development.

However, after the construction have been completed or the License to Sell was issued, open spaces that were originally indicated on the drawings are changed to a different type or use. Neither the Local Government nor the DHSUD checks this compliance unless: (a) the subdivision or condominium is applying for a Certificate of Completion thus turning over the property to either the LGU or Homeowners Association, in which case, the DHSUD as well as the LGU conducts a visual inspection during turnover; (b) an incident has occurred that requires an inspection, typically a Homeowner filing a case against a developer for lack of open spaces. During the November 2020 DHSUD Workshop, it was highlighted that less than 10% of developers file a Certificate of Completion and Turnover within 5-10 years of development and occupancy. During this time, no monitoring of compliance is done unless cases are filed.

Overall, the policy meets the first objective in a community setting. Much of the subdivision parks and playground regulated by the laws are centered towards specific users and not the public, this creates a need to look at UGS on a regional setting to achieve the WHO recommended standard of at least 9.0 sqm per person. As a megacity of 13 million people, Metro Manila currently affords its residents with 7.17 sqm per capita, 1.83 sqm short of the WHO recommendation.

Internationally, there are five standard criteria that has been commonly used in open space planning. They are population-ratio, area percentage, catchment area, facility specification and local standards (Veal, 2013). Population-ratio is the most common type of standard used by the planners in many countries and remains as the major planning criteria for the provision of green space and recreation area (Maryanti et al., 2016). Through the population-ratio, the amount of urban green space per 1000 population or per person is usually fixed by the national or the state planning standards that should be achieved and maintained, no matter how high the rate of densification occurs in the city. The amount of urban green space per 1000 population or per person requires the calculation be based on its specific formula or a set of rules that is applied uniformly to all situations (Veal, 2013).

Table 26. Green Space Standards (Veal, 2013)

Policy Type	Evaluation
Population-ratio/fixed standards	A prescribed level of provision of open space related to the level of population – typically per 1000 population;
Area Percentage Standards	A specified percentage of land to be allocated for open space (e.g., 10% from the total development area is allocated for open space);
Catchment area-based standards	Distances which residents should have to travel to gain access (e.g., ¼ mile walking distance from users' neighborhood);
Facility standards	Specifications (size, markings, and equipment for a sports field);
Local standards	Standards of provision specific to a local area based on local conditions and data, locally determined, or expressed in any of the above formats;

A UGS policy should also incorporate the Green and Open Spaces' accessibility such that one does not need to travel to be able to experience the abundant greenery within the city. The majority of the 43% green spaces in the city are in La Mesa and the various cemeteries and golf courses. PD 1216's Policy Type falls below the minimum 10% requirement of the international standard as defined by (Veal, 2013).

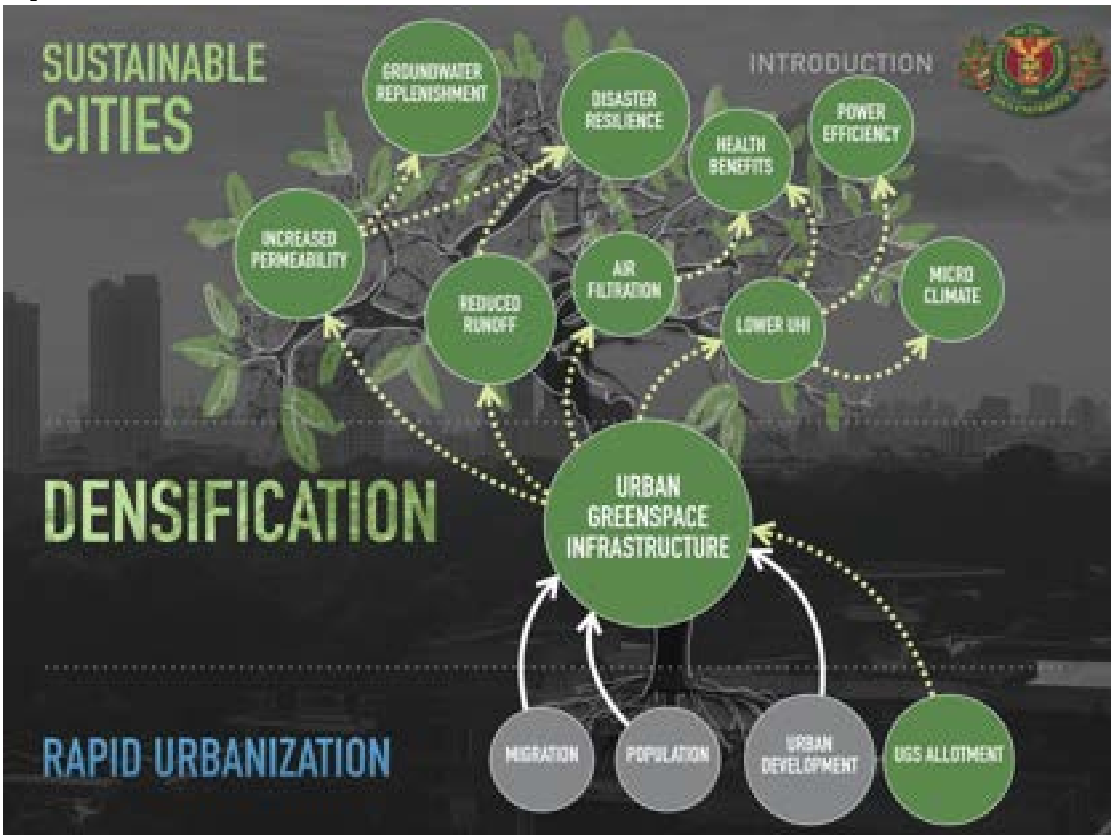
Cities have their unique urban ecology and primarily, combating urban sprawl is basis for all modern policies. The Compact City model (Mouratidis, 2019) is an answer to urban sprawl and however this results in accelerating the densification of the city and consequently this fuels UHI, creating the need to balance the trajectory of internal development with the need to have green spaces. Urban green spaces provide the "cooling effect" that the cities need to combat UHI. In addition, urban green spaces are also able to influence physical wellbeing of the area (Aram et al., 2019). Green spaces, planting trees and other vegetation lowers surface and air temperatures and cools the surrounding through evapotranspiration. Trees and vegetation lower land surface temperature and decrease the need for air conditioning (Buyadi et al., 2013). In selecting the best alternative to enact Open Space policy, weight is given towards the policy which affords the greater amount of open space for the greatest number of people.

A clarification in the terminology should be made to understand how our laws determine spaces. “Public space” pertains to the use of domain, as it’s shared by everyone. “Open Space” it refers to “an area reserved exclusively for parks, playgrounds, recreational uses, schools, roads, places of worship, hospitals, health centers, barangay centers and other similar facilities and amenities,” according to Presidential Decree 1216. Under Sustainable Development Goal (SDG 11), “make cities and human settlements inclusive, safe, resilient, and sustainable”, the indicator to measure progress is “the average share of the built-up areas of cities in open space in public ownership and use.” Currently the residents of Metro Manila share in the urban green spaces at a rate of 1,394 persons per every hectare of available UGS. This is greatly diminished when we look at accessibility since most of the available UGS are private. The study reveals that the majority of the undisturbed UGS in Metro Manila are the La Mesa Watershed protected area as well as the provide parks and golf courses. This presents the need to increase UGS in the public realm accessible to everyone. Parks and playgrounds are listed as basic needs of human settlements, as per Batas Pambansa 220 (Rule III, Section 5B). Most of the built-up land cover in Metro Manila are streets. Streets are defined as *“any thoroughfare or public space which has been dedicated or deeded to the public for public use,”* according to the National Building Code (RA 6541, Annex: Definition of Terms). Thus, expanding UGS within the public realm is necessary to improve the UGS availability within the metropolis as well as uplift and enhance the ecosystem services provided by the UGS.

XI. Conclusion and Recommendations

Metro Manila has undergone significant changes in the last 30 years. The Nature of its growth is both Functional and Structural and in the last decade the population density has surpassed the city's structural growth. The Purpose of the city's densification can be outlined as a deliberate increase in urban density, capitalizing on the economics of growth in Metro Manila that has surpassed those of the other regions. The scale of the densification is regional with the last thirty years showing no less than 70% built-up areas within the region, and though the Process was incremental, population increase has shown signs of slowing down. Primarily, the driver of Metro Manila's densification is population, it Is in a state of perpetual growth as the city continues to re-invent itself to cope up with the future. With this increase in population, real estate values continue to go up, increasing the value of land commodity that is sought after by stakeholders such as developers for its promise of wealth, the working public because of the availability of jobs and commerce, as well as residents for the availability of services and infrastructure. Mobility and transportation continue to hinder a more sustainable densification that the city needs to focus on as a necessary ecosystem service. The effects of densification vary within the city but as a region, The economic and social effects of densification can be seen in all the government statistics, but urban green spaces are still lacking with much of the urban parks and vegetation remain inaccessible to the public.

Figure 27: Solution Tree



XI.01 Urban Greenspace Policy

Policy on Urban Green Space (UGS) is needed to prioritize the urgent need for urban greens, this can be made locally through the various local government units, as well as the MMDA. Metro Manila does not need to wait for the National Land Use Act to be passed into law before the proper allocation of UGS is afforded to Metro Manila's residents.

Open Spaces & Green Spaces should be established as street greenery, urban gardens, and green trails in close vicinity to urban residents using public open spaces for greenery. Urban residents should be able to access public green spaces of at least 0.5–1 hectare within 300 meters or within a 5-minute walk. Internal green spaces such as deck gardens and terraces should be considered as part of the open space requirements. The primary goal of establishing Open Spaces, Urban Green Spaces, Public Spaces or Urban Landscape is to provide people with a livable, heathy, and productive environment; thus, the provision of an urban green space is necessary to strengthen the efforts of the local authority to create a livable city and encourage urban development towards a sustainability framework within the Urban Landscape.

Table 27. Recommended Urban Green Space Criteria

Scale	Population*	Urban Green Spaces (Ha)		
		Current*	Require	Deficit
Metro Manila	13,485,731	9,667.71	12,137.16	-2,469.45

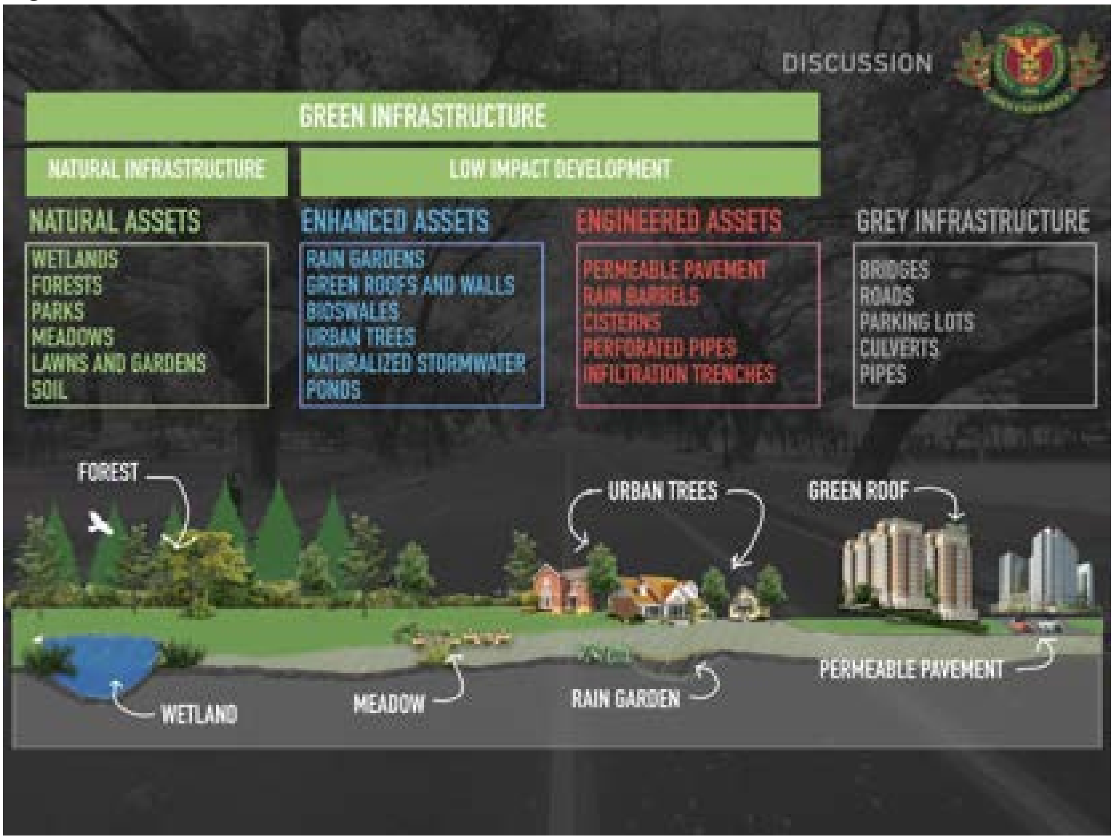
Source: Estimate is based on the WHO requirement (WHO, 2010)

This UGS policy requires us to look at providing green space through a per capita metric rather than a percentage of land development. This focuses more on the people's need for green spaces rather than green spaces as a cosmetic implement of development.

XI.02 Green Infrastructure

What Metro Manila needs is a connected and cohesive infrastructure. A strategically planned network of natural and semi-natural areas that are managed will deliver better ecosystem services. A Green Infrastructure is this network that connects the landscape and highlights natural assets within the urban environment.

Figure 28: Green Infrastructure Framework

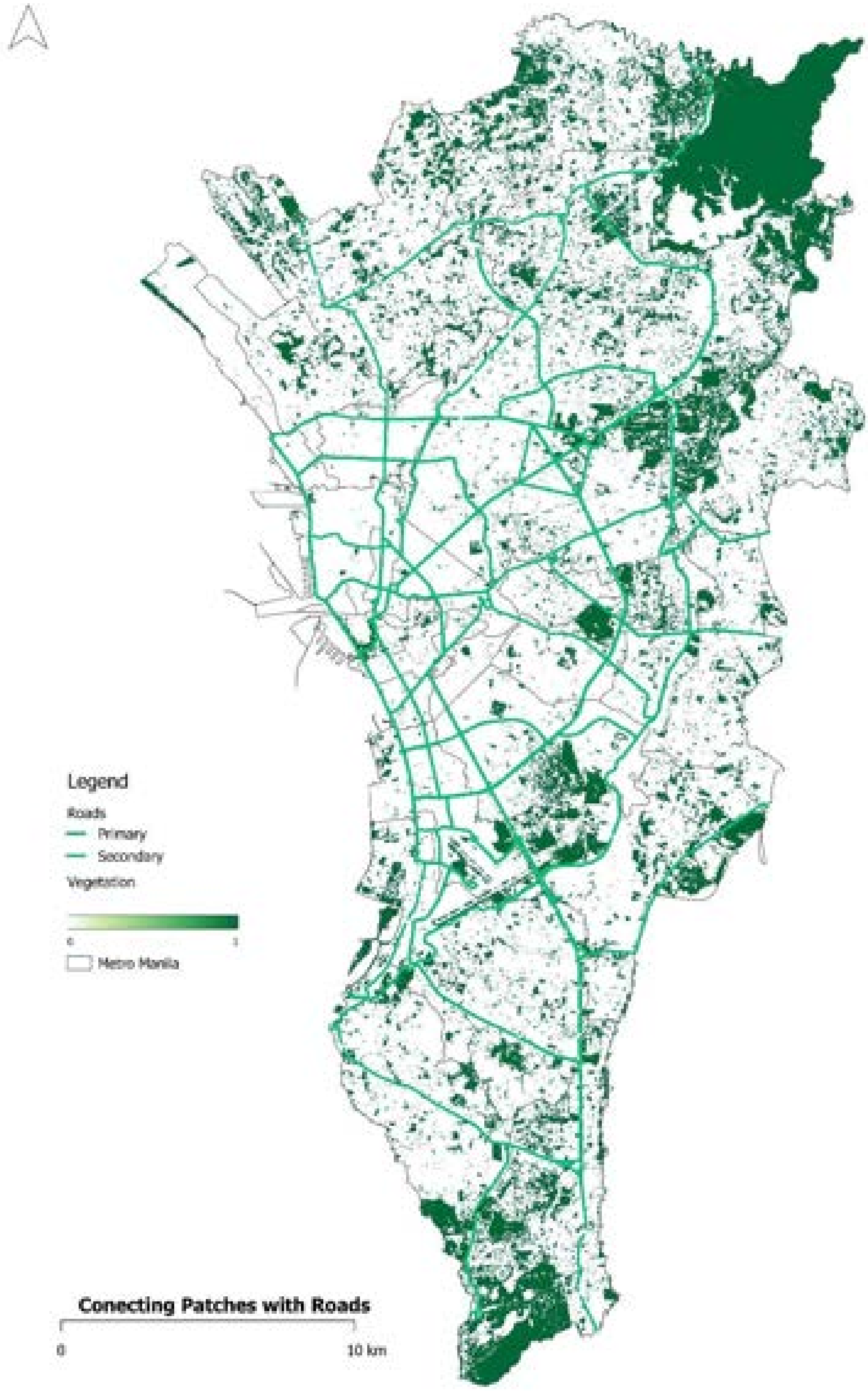


Source: Adapted from (European Commission, n.d.)

XI.03 Increasing UGS in Public areas and Infrastructure

In a 2010 Open JICA Report, Metro Manila has 3,091.3 kilometers of road. These roads right of ways (RROW) have been designed to carry specific carriage way requirements as well as sidewalks and planting strips. If these roads networks are properly utilized and planted with specific tree species and flora which that can survive the harsh urban microclimate, such as those recommended by the DENR , UGS capacity can be increased exponentially. Figure 29 overlaps the existing greenspace inventory of Metro Manila with the primary and secondary road networks. This shows a connected network of tree-lined streets and thoroughfares that can increase UGS within the city.

Figure 29: Green Infrastructure Network along Metro Manila Roads



This is in no way a novel idea. Some cities and municipalities already have been greening streets such as in Makati. What is important is that the green patches are connected with one another. Proper road design not only creates a fresh atmosphere, but this also makes the roads safer by creating spaces for pedestrians and connects patches of greens with one another to support urban biodiversity.

Figure 30: Tree-lined streets of Makati

Source: Google Street View

Along roads, infrastructure such as bus stops and waiting sheds can be used to increase UGS by creating “living roofs.” In the UK, Clear Channel partnering with ecologists to support native biodiversity and help create healthier local communities and bring greenery back into urban areas by creating “Living Roofs,” affectionately nicknamed “Bee Bus Stops.” Not only do these living roofs reduce the effects of UHI, but they are also planted with a mix of 13 native wildflower and 5 sedum species; selected by experts to aid and support bees and other pollinators, whose numbers have sadly been in decline in the UK in recent years (Clear Channel, n.d.).

Figure 31: A living roof in Cardiff planted with pollinator friendly plants.

Source: (Clear Channel, n.d.)

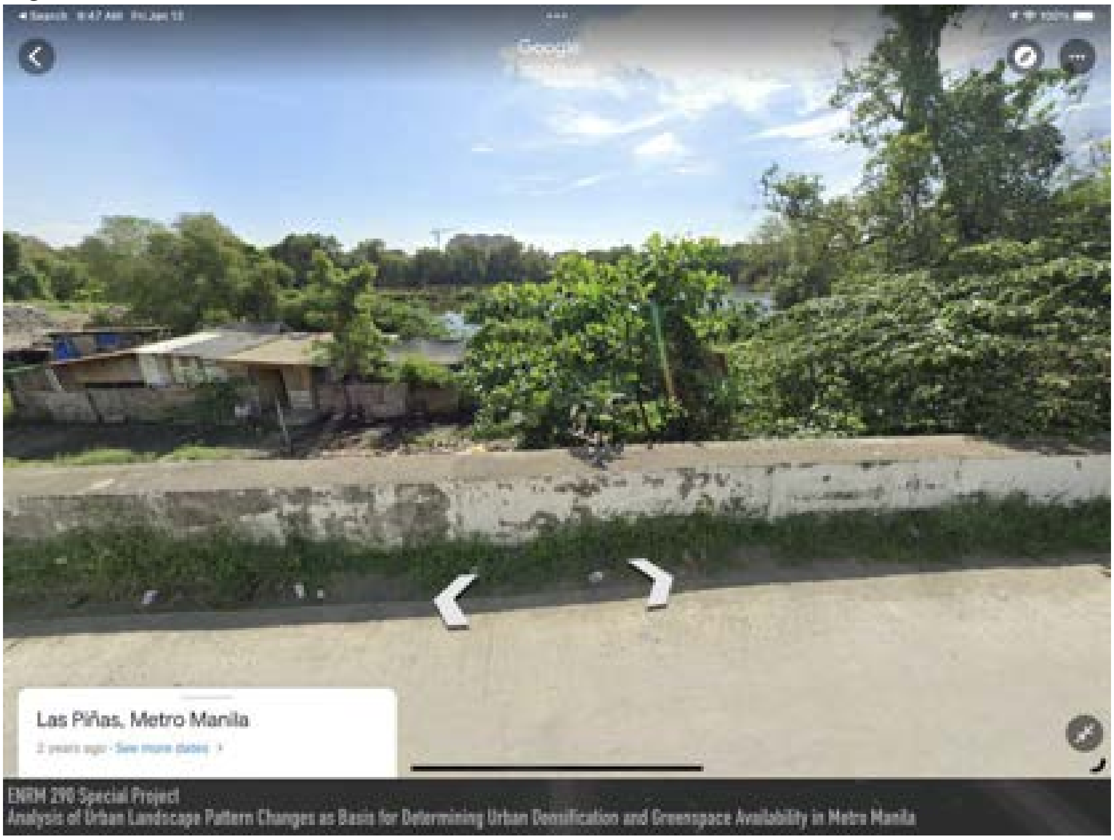
Metro Manila is a flood prone city (Pornasdoro et al., 2014). Areas along the coastal lowland, Marikina flood plain and the Laguna Lake plain are all prone to flooding because mainly of its elevation.

Figure 32: 25 Year Flood Hazard Map of Metro Manila

Source: Noah Studio (DOST, n.d.)

Figure 32 shows the areas in Metro Manila that are prone to floods. These areas like those found in Las Piñas, can be rehabilitated as urban wetlands that can host a wide range of biodiversity. Much of these areas can be utilized through infill development and Metro Manila has plenty of underutilized land that can be improved as green-blue areas.

Figure 33: Flood Prone Area in Las Piñas



Source: Google Street View

In the UK, urban wetlands are prized not only for their flood mitigation, carbon sequestration and biodiversity. They also provide residents with places for recreation and relaxation. Figure 34 shows an example of a manmade wetland in the UK that is teeming with life.

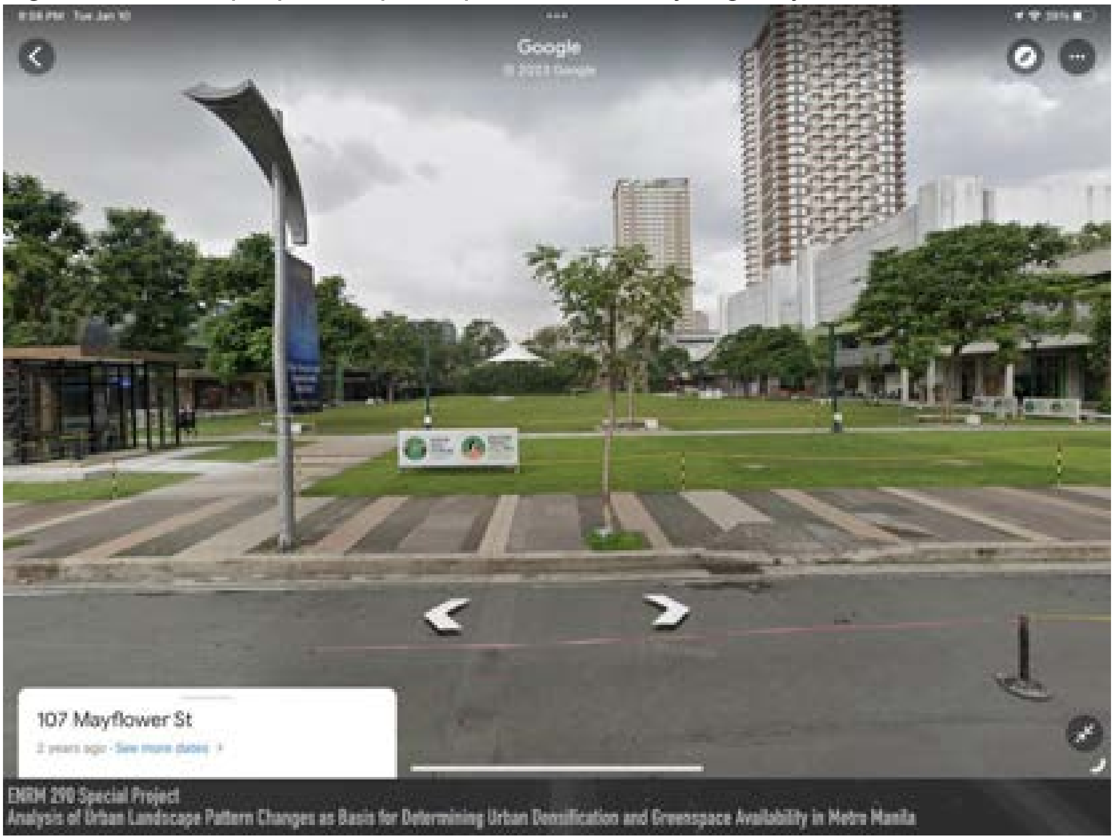
Figure 34: Manmade Wetland, UK

Source: London Wetland Centre. Photograph: Pawel Libera/Getty Images

XI.04 Increasing UGS in Privately Owned Spaces

The open space requirements found both in PD1216 and PD 1096 (Rev RA6541) prescribes an open space development control based on a percentage of the total lot area of development. Much of these spaces are left to be parking lots (which some consider as open space) and ancillary building spaces. Creating a more bio-diverse landscape within these open spaces that cater to individuals rather than used a regulatory compliance. In some districts, these are already being done but they are largely up to the developer or property owner to pursue.

Figure 35: Multi-purpose Open Space, Mandaluyong City



Source: Google Street View

Setback form part of the open space requirements, in most cases they are left as spaces for parking and storage. In some places, setbacks between buildings are made into lush green environments teeming with insect life. This increases permeable surfaces that act as a sponge during rain and mitigates runoff.

Figure 36: Image Taken from Bonifacio Global City

Green roofs offer a cooler environment and can help reduce the urban heat island in very dense areas (Sailor et al., 2012). These green spaces add value to the buildings, making the interiors cooler as well as supporting a connected ecosystem in highly urbanized and dense areas.

Figure 37: Green Roofs and Rooftop Gardens, BGC

Enhancing and expanding Urban Greensapces need not be expensive or high-tech, with policy backing up practical solutions done in a cohesive manner, the green footprint of Metro Manila can be improved for future generations to enjoy.

XII. References

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ANNEXES

Annex 1: Accuracy assessment and Error Matrix for 1992

ErrMatrixCode	Reference	Classified	PixelSum
1	1	1	5
6	1	3	1
5	2	2	4
10	3	3	15

> ERROR MATRIX (pixel count)
> Reference

V_Classified	1	2	3	4	Total
1	5	0	0	0	5
2	0	4	0	0	4
3	1	0	15	0	16
4	0	0	0	0	0
Total	6	4	15	0	25

> AREA BASED ERROR MATRIX
> Reference

V_Classified	1	2	3	4	Area	Wi
1	0.1448	0.0000	0.0000	0.0000	86680800.0000	0.1448
2	0.0000	0.0463	0.0000	0.0000	27689400.0000	0.0463
3	0.0488	0.0000	0.7313	0.0000	466974000.0000	0.7800
4	0.0000	0.0000	0.0000	0.0000	17325900.0000	0.0289
Total	0.1935	0.0463	0.7313	0.0000	598670100.0000	
Area	115866675	27689400	437788125	0	598670100	
SE	0.0488	0.0000	0.0488	0.0000		
SE area	29185875	0	29185875	0		
95% CI area	57204315	0	57204315	0		
PA [%]	74.8108	100.0000	100.0000	nan		
UA [%]	100.0000	100.0000	93.7500	nan		
Kappa hat	1.0000	1.0000	0.7674	nan		

Overall accuracy [%] = 92.2308
Kappa hat classification = 0.8055

Area unit = metre^2
SE = standard error
CI = confidence interval
PA = producer's accuracy
UA = user's accuracy

Annex 2: Accuracy assessment and Error Matrix for 2002

ErrMatrixCode	Reference	Classified	PixelSum
1	1	1	2
2	2	1	1
5	2	2	3
4	3	1	2
12	3	3	12
16	4	4	3

> ERROR MATRIX (pixel count)
> Reference

V_Classified	1	2	3	4	Total
1	2	1	2	0	5
2	0	3	0	0	3
3	0	0	12	0	12
4	0	0	0	3	3
Total	2	4	14	3	23

> AREA BASED ERROR MATRIX
> Reference

V_Classified	1	2	3	4	Area	Wi
1	0.0656	0.0328	0.0656	0.0000	98153100.0000	0.1639
2	0.0000	0.0304	0.0000	0.0000	18198900.0000	0.0304
3	0.0000	0.0000	0.7985	0.0000	478089000.0000	0.7985
4	0.0000	0.0000	0.0000	0.0071	4268700.0000	0.0071
Total	0.0656	0.0632	0.8641	0.0071	598709700.0000	
Area	39261240	37829520	517350240	4268700	598709700	
SE	0.0402	0.0328	0.0402	0.0000		
SE area	24042501	19630620	24042501	0		
95% CI area	47123302	38476015	47123302	0		
PA [%]	100.0000	48.1077	92.4111	100.0000		
UA [%]	40.0000	100.0000	100.0000	100.0000		
Kappa hat	0.3579	1.0000	1.0000	1.0000		

Overall accuracy [%] = 90.1635
Kappa hat classification = 0.6691

Area unit = metre^2
SE = standard error
CI = confidence interval
PA = producer's accuracy
UA = user's accuracy

Annex 3: Accuracy assessment and Error Matrix for 2016

ErrMatrixCode	Reference	Classified	PixelSum
1	1	1	3
5	2	2	3
4	3	1	1
9	3	3	8

> ERROR MATRIX (pixel count)
> Reference

V_Classified	1	2	3	Total
1	3	0	1	4
2	0	3	0	3
3	0	0	8	8
Total	3	3	9	15

> AREA BASED ERROR MATRIX
> Reference

V_Classified	1	2	3	Area	Wi
1	0.1642	0.0000	0.0547	131079600.0000	0.2190
2	0.0000	0.0367	0.0000	22000500.0000	0.0367
3	0.0000	0.0000	0.7443	445586400.0000	0.7443
Total	0.1642	0.0367	0.7990	598666500.0000	
Area	98309700	22000500	478356300	598666500	
SE	0.0547	0.0000	0.0547		
SE area	32769900	0	32769900		
95% CI area	64229004	0	64229004		
PA [%]	100.0000	100.0000	93.1495		
UA [%]	75.0000	100.0000	100.0000		
Kappa hat	0.7009	1.0000	1.0000		

Overall accuracy [%] = 94.5262
Kappa hat classification = 0.8512

Area unit = metre^2
SE = standard error
CI = confidence interval
PA = producer's accuracy
UA = user's accuracy

Annex 4: Accuracy assessment and Error Matrix for 2022

ErrMatrixCode	Reference	Classified	PixelSum
1	1	1	3
2	2	1	1
5	2	2	1
8	3	2	2
12	3	3	10
16	4	4	3

> ERROR MATRIX (pixel count)
> Reference

V_Classified	1	2	3	4	Total
1	3	1	0	0	4
2	0	1	2	0	3
3	0	0	10	0	10
4	0	0	0	3	3
Total	3	2	12	3	20

> AREA BASED ERROR MATRIX
> Reference

V_Classified	1	2	3	4	Area	Wi
1	0.1211	0.0404	0.0000	0.0000	96677100.0000	0.1615
2	0.0000	0.0142	0.0285	0.0000	25555500.0000	0.0427
3	0.0000	0.0000	0.7769	0.0000	465037200.0000	0.7769
4	0.0000	0.0000	0.0000	0.0189	11316600.0000	0.0189
Total	0.1211	0.0546	0.8054	0.0189	598586400.0000	
Area	72507825	32687775	482074200	11316600	598586400	
SE	0.0404	0.0428	0.0142	0.0000		
SE area	24169275	25626523	8518500	0		
95% CI area	47371779	50227986	16696260	0		
PA [%]	100.0000	26.0602	96.4659	100.0000		
UA [%]	75.0000	33.3333	100.0000	100.0000		
Kappa hat	0.7155	0.2948	1.0000	1.0000		

Overall accuracy [%] = 93.1161
Kappa hat classification = 0.8045

Area unit = metre^2
SE = standard error
CI = confidence interval
PA = producer's accuracy
UA = user's accuracy

Annex 5: Landscape Metrics

LID	TA	LPI	TE	ED	AREA_MN
1992	59867.01	77.2785	4082970	68.2007	8.8182
2002	59870.97	78.8115	3802440	63.5106	10.4232
2016	59866.65	72.4916	4067640	67.945	10.3935
2022	59858.64	76.6556	4313490	72.0613	8.0057

Annex 6: Class Metrics

LID	TYPE	CA	PLAND	NP	PD	LPI	TE	ED	AREA_MN
1992	cls_1	8668.08	14.4789	3670	6.1303	3.8303	2737230	45.7218	2.3619
	cls_2	2768.94	4.6252	371	0.6197	0.9573	436590	7.2927	7.4635
	cls_3	46697.4	78.0019	531	0.887	77.2785	4044420	67.5567	87.9424
	cls_4	1732.59	2.8941	2217	3.7032	0.0502	947700	15.8301	0.7815
2002	cls_1	9815.31	16.3941	4772	7.9705	4.2791	3439440	57.4475	2.0569
	cls_2	1819.89	3.0397	279	0.466	0.9606	305760	5.107	6.5229
	cls_3	47808.9	79.8532	603	1.0072	78.8115	3787350	63.2585	79.2851
	cls_4	426.87	0.713	90	0.1503	0.2265	72330	1.2081	4.743
2016	cls_1	13107.96	21.8953	4437	7.4115	5.0602	3690420	61.644	2.9542
	cls_2	2200.05	3.6749	587	0.9805	0.9244	459930	7.6826	3.748
	cls_3	44558.64	74.4298	736	1.2294	72.4916	3984930	66.5634	60.5416
2022	cls_1	9667.71	16.1509	4341	7.2521	3.6986	3096720	51.7339	2.2271
	cls_2	2555.55	4.2693	919	1.5353	0.8137	689610	11.5206	2.7808
	cls_3	46503.72	77.6892	667	1.1143	76.6556	4223190	70.5527	69.7207
	cls_4	1131.66	1.8906	1550	2.5894	0.0403	617460	10.3153	0.7301

Annex 7: Land Use Change Matrix (1992-2022)

Class Code	1992 Class	2022 Class	Pixel Sum	Area (sqm)
1	Undetermined	Undetermined	650,624	585,561,600
2	Pervious	Undetermined	56	50,400
3	Water	Undetermined	79	71,100
4	Impervious	Undetermined	120	108,000
5	Cloud	Undetermined	2	1,800
6	Undetermined	Pervious	49	44,100
10	Pervious	Pervious	45,981	41,382,900
11	Water	Pervious	4,244	3,819,600
13	Impervious	Pervious	55,856	50,270,400
16	Cloud	Pervious	1,289	1,160,100
7	Undetermined	Water	10	9,000
12	Pervious	Water	1,950	1,755,000
14	Water	Water	15,245	13,720,500
17	Impervious	Water	10,907	9,816,300
20	Cloud	Water	283	254,700
8	Undetermined	Impervious	104	93,600
15	Pervious	Impervious	47,175	42,457,500
18	Water	Impervious	10,685	9,616,500
21	Impervious	Impervious	443,056	398,750,400
23	Cloud	Impervious	15,688	14,119,200
9	Undetermined	Cloud	1	900
19	Pervious	Cloud	1,150	1,035,000
22	Water	Cloud	513	461,700

24	Impervious	Cloud	8,921	8,028,900
25	Cloud	Cloud	1,989	1,790,100

Annex 8: NDVI and LTS Min-Max Table

Year	NDVI			LST (°C)		
	Min	Max	Ave	Min	Max	Ave
1992	-0.2027	28.3893	24.0622	19.7352	28.3893	24.0622
2002	-0.2762	68.9131	50.1231	31.3332	68.9131	50.1231
2016	-0.3509	51.2478	37.2484	23.2491	51.2478	37.2484
2022	-0.3593	34.9147	25.7069	16.4991	34.9147	25.7069