Assessing Urban Heat Islands Using GIS and Remote Sensing for Sustainable Urban Planning in the Philippines

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Abstract- Growing urbanization and a tropical climate intensify the known environmental challenges of urban heat islands (UHIs) in the Philippines. UHIs are formed by human activity, infrastructure, and decreased vegetation, resulting in elevated temperatures in urban areas compared to their rural surroundings. This tendency exacerbates energy consumption, air pollution, and health concerns, posing significant issues for urban planners and policymakers. Geographic Information Systems (GIS) and remote sensing technologies provide efficient methods for evaluating and reducing UHIs. GIS enables the merging and examination of geographical data, providing a comprehensive understanding of urban settings. Remote sensing uses thermal data from satellites to provide a comprehensive understanding of land surface temperatures and heat distribution patterns. In the Philippines, these technologies are essential for detecting areas with high temperatures, assessing the elements that contribute to this, and creating specific policies for sustainable urban development. By utilizing GIS and remote sensing, urban planners can strategically create geographically accurate green spaces, optimize construction materials, and apply cooling measures, ultimately fostering a healthier and more resilient urban environment. This paper shows the significant utilization of these technologies to facilitate data-driven decision-making, which is crucial for mitigating the detrimental impacts of UHIs. This research can guide environmental planners on how to utilize GIS and remote sensing for a more scientific approach as urban areas continue to grow and science-based sustainable urban planning becomes more and more apparent. Evaluating UHIs using GIS and remote sensing is an essential step in the development of habitable, sustainable, and climate-resilient cities in the Philippines.

Keywords: Urban Heat Islands, GIS, Remote Sensing, Sustainable Urban Planning, Climate Change, Global Warming, Land Surface Temperature

I. Introduction

Urban planning has undergone significant transformations, especially in response to the growing challenges posed by climate change and urban heat islands (UHIs). The correlation between climate change and the UHI is a critical consideration in urban planning and development. Urban areas tend to be warmer than rural areas due to the UHI effect. The phenomenon, characterized by higher temperatures in urban areas compared to their rural surroundings, results from human activities and the modification of land surfaces.

The UHI is caused by factors such as concrete and asphalt surfaces, reduced vegetation, and heat generated from human activities. Climate change exacerbates the UHI effect by increasing baseline temperatures. This means that urban areas, already warmer due to UHI, become even hotter, leading to increased heat stress and energy consumption. Thus, UHIs are a significant environmental challenge for rapidly urbanizing regions around the world. For a country experiencing swift urban growth, like the Philippines, UHIs pose a critical threat to sustainable urban development, public health, and overall quality of life.

The assessment of UHIs is crucial for developing effective mitigation strategies. Geographic Information Systems (GIS) and remote sensing (RS) technologies offer powerful tools for this purpose. These technologies enable the collection, analysis, and visualization of spatial data, providing insights into the spatial distribution and intensity of UHIs. By leveraging satellite imagery and ground-based observations, researchers can monitor temperature variations, identify hotspots, and evaluate the impact of urbanization on local climates.

Understanding UHIs is essential for sustainable urban planning in the Philippines, where cities like Manila, Cebu, and Davao are rapidly expanding. The integration of GIS and RS in urban planning processes can help policymakers design greener, more resilient cities. This approach supports the development of urban areas that not only accommodate population growth but also enhance environmental sustainability and residents' well-being.

Urban planning and development must integrate strategies to mitigate the impacts of climate change and the UHI effect. This includes designing heat-resilient infrastructure, increasing green spaces, improving energy efficiency, and managing urban density through desirable, accurate, timely, accessible, comprehensive, reliable, and affordable spatial information. By doing so, cities can become more sustainable and livable in the face of rising temperatures.

This study aims to assess the extent and impact of UHIs in some areas in the Philippines using GIS and RS technology. The increasing number of publications on the impact of UHI typically use sophisticated methodologies, discouraging urban planners from conducting UHI mapping and assessment. This discouragement inspired the author to prepare this paper, which not only reflects the scientific community's interest in disseminating UHI information but also provides simple and easy-to-follow methods for assessing local UHI and generating UHI maps for better land use and urban planning. Furthermore, the findings will provide valuable insights for urban planners, environmentalists, and policymakers in guiding the creation of more sustainable and livable urban environments in the Philippines with consideration for local UHI. Also, this capstone project will serve as a public tutorial on how to build UHI maps for land use and urban planning.

Significance of the Study

Climate change and UHI requires a more scientific approach and a faster response to counteract its detrimental impact on the environment; hence, more GIS and remote sensing approaches to urban planning and development are necessary. Geographic Information Systems (GIS) and remote sensing technologies have become essential tools in urban planning, particularly for encouraging sustainability. These technologies allow for the collection, processing, and presentation of geographical data, which is critical for making educated decisions about urban development.

Given the growing urbanization and climate change challenges, this is an extremely timely topic. UHIs are becoming a growing concern in rapidly urbanizing areas, including the Philippines, which worsens the effects of climate change. In these areas, human activity and infrastructure cause much higher temperatures than in rural settings. GIS and remote sensing can help urban planners get useful insights into temperature changes, identify hotspots, and design strategies for sustainable urban development in real-time and with greater accuracy. This strategy not only serves to mitigate the negative effects of UHIs, but also promotes a healthier and more resilient urban environment in the future.

Determining UHIs using a simple GIS and remote sensing-based model with minimal requirements to generate timely and realistic recommendations is crucial. This provides information that was not previously available without sacrificing effectiveness and efficiency. Decision-makers can utilize this to tackle and simultaneously address emerging socio-economic and environmental issues, as GIS serves as a valuable tool for obtaining essential information for specific purposes. Additionally, because this model is based on GIS and remote sensing, it is subject to periodic modifications, sharing, or changes based on community preferences and government objectives. This will serve as a template for achieving a balanced ecosystem by providing spatial solutions to address UHIs.

Objectives

The main goal of the study is to employ GIS and remote sensing techniques to gather data, analyze UHIs in a particular area, and use the results to understand the UHI effects in urban planning and development. In the hope that urban planners will use these techniques to scientifically address UHIs that are significantly impacted by climate change and formulate adaptation and mitigation strategies for planning policy.

Specifically, the objectives of the study are:

a. Showcase the application of Geographic Information System (GIS) and remote sensing techniques in pinpointing, evaluating, and creating Urban Heat Islands (UHIs) maps using Landsat 8 within specific urban areas in the Philippines.
b. Offer practical guidance to urban planners and policymakers, encouraging them to integrate UHI's data and information into sustainable urban development practices.

Limitations and Duration of the Study

The study presents various constraints beyond its exclusive focus on surface temperature for calculating UHI:

a. Data Availability: The study relies on the availability and accuracy of geospatial data from USGS Earth Explored captured on June 3, 2024, which may vary in quality and completeness.
b. Technological Constraints: Compared with commercial software, the use of open-source QGIS may limit the application of GIS and remote sensing technologies.
c. Temporal Scope: The study is limited to a specific time frame, which might miss long-term trends and changes.
d. Geographical Scope: The research is confined to a particular urban area, limiting the generalizability of the findings to other regions.
e. Methodological Limitations: The chosen methodologies for data collection and analysis may have inherent biases and limitations.
f. Resource Constraints: Insufficient funds and resources may affect the study's comprehensiveness and scope.
g. Human Factors: The researcher's expertise and experience may have an impact on the study's accuracy.

II. Review of Related Literature

Urban Heat Islands (UHIs)

Global warming is a widely acknowledged phenomenon affecting our planet. The ongoing increase in Earth's temperatures, combined with the additional heat generated by the Urban Heat Islands (UHIs) effect, will significantly impact urban residents. Furthermore, the interconnectedness of UHI, urbanization, and climate change will exacerbate this issue. As the average global

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temperature rises, countries such as the Philippines will likely experience more extreme temperatures and heat waves in the coming decades. Vergara & Blanco (2023) observed that urban areas in the Philippines are experiencing higher temperatures compared to rural areas. They noted that the impact of the temperature differential, also known as the UHI, intensifies in Metro Manila, home to millions of Filipinos, during March, April, and the hot dry season. In other parts of the world, based on the research conducted by Tapper et al. (1981), Tāmaki Makaurau, Auckland, New Zealand, is projected to experience an additional 70 hot days (exceeding 25°C) year by the year 2100. This type of heat can significantly affect infants, the elderly, and anyone with chronic illnesses. During heat waves, the increased utilization of cooling systems contributes additional waste heat to the already elevated temperatures of urban areas (Lewellen, 2023).

More than in natural settings like forests and water bodies, buildings, roads, and other infrastructure absorb and re-emit the heat from the sun. Urban areas, where these buildings are extremely concentrated and vegetation is scarce, become "islands" with higher temperatures than outlying environments. These heated spots are called "heat islands." Heat islands can develop under a variety of circumstances—day or night, in small or large cities, in suburban regions, in northern or southern climates, and every season (US EPA, 2014).

Sharman et al. (2024) assert that Luke Howard first observed the phenomenon in 1818, which explains the temperature differential between urban centers and their rural environs, primarily caused by human activity and natural landscape modification. UHI occurs when an urban area has significantly higher temperatures than adjacent rural areas (NASA, 2019; National Geographic, 2022). According to Arrau (2021), the UHI is defined as the rise in temperature of any man-made area, resulting in a well-defined, distinct "warm island" among the "cool sea" represented by the lower temperature of the area's nearby natural landscape. UCAR (2021) simply describes heat islands as the local temperature differences, generally between urban and rural areas (Figure 1).

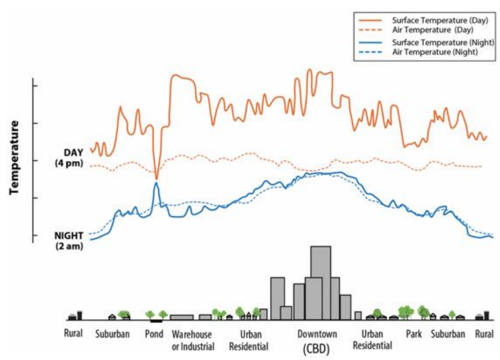

Figure 1. An illustration of an urban heat islands profile was adopted from the US EPA in 2014

According to the definition, "U" in UHIs denotes "built-up areas," as heat islands can develop in both rural and urban settings at various spatial scales; nonetheless, cities are particularly susceptible due to their surfaces' tendency to emit substantial amounts of heat. UHIs effect adversely affect not only urban people but also individuals and their ecosystems situated at considerable distances from cities (Arrau, 2021).

It is obvious that utilizing climatic data is crucial to mitigate the impacts of climate change, especially heat. According to Buchholz (2021), heat is considered a lethal weather-related occurrence across a significant portion of the inhabited globe. In her research, she asserted that extreme heat events significantly affect human health by elevating heat-related morbidity and death among the elderly, individuals with pre-existing conditions, young children, and the impoverished. In a future warmer climate, extended and severe heat waves are increasingly probable. She also noted that the UHI effect exacerbates heat events in the city.

Nowadays, UHIs have been the subject of extensive research due to the impact of climate change on urban areas, given their significant influence on urban ecosystems and the health of those residing in these areas. UHIs indirectly exacerbate climate change by affecting the greenhouse effect, subsequently resulting in global warming (Arrau, 2021). The rising demand for air conditioning during heat waves requires energy derived from fossil fuel combustion, leading to the release of heat-trapping greenhouse gases and compromising human health, lifestyle, and comfort. (Akbari et al., 2015; UCAR, 2021; M, 2024). The interconnection of UHI, urbanization, and climate change is growing, leading to various environmental consequences at both local and regional levels, including heat stress, biodiversity loss, fire risk, warming water due to runoff, and reduced air quality (Shi et al., 2021).

The US EPA (2014) and Bhargava et al. (2017), identified two categories of urban heat islands: (1) surface heat islands and (2) atmospheric heat islands. Surface heat islands are often more pronounced during daylight hours when solar radiation is at its peak. In rural areas, it exposed a greater portion of the surface to sunlight than shaded parts. It arises because urban surfaces, including roadways and rooftops, absorb and emit heat more significantly than most natural surfaces. On a warm day with a temperature of 91°F (32.78°C), traditional roofing materials can attain temperatures up to 60°F (15.56°C) above normal air temperatures (Simmons et al., 2008). The Surface Urban Heat Island phenomenon occurs continuously, with its intensity reaching a maximum

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during daylight hours. Atmospheric heat islands develop due to increased air temperatures in urban areas relative to the colder air in surrounding areas; however, they exhibit significantly less variation in severity than surface heat islands. Bhargava et al. (2017) and Favretto, A. (2018), categorize an atmospheric urban heat island into two subdivisions: a canopy layer urban heat island and a boundary layer urban heat island. The canopy layer of an urban heat island stretches from the ground to just beneath the tops of trees or roofs, whereas the boundary layer begins at the rooftop or tree top level and reaches the altitude where the urban environment ceases to affect the atmosphere. Nevertheless, owing to the closeness of the surface and canopy layers, surface urban heat islands frequently encounter the effects of intensified atmospheric urban heat islands. Table 1 shows the fundamental attributes of surface and atmospheric urban heat islands.

Table 1. Bhargava, A. et al., 2017 provided the fundamental attributes of surface and atmospheric UHIs.

Feature	Surface Urban Heat Island	Atmospheric Urban Heat Island
Temporal Development	• Present at all time of the day and night. • Most intense during the day and in the summer.	• May be Smaller or non-exist during the day time. • Most intense at night or predawn and in the winter.
Peak Intensity (most intense UHI conditions)	**More spatial and temporal variation:** • Day: 18-27°F (10-15°C). • Night: 9-18°F (5-10°C).	**Less variation:** • Day: 1.8-5.4°F (-1-3°C). • Night: 12.6-21.6°F (7-12°C).
Typical Identification Method	**Indirect measurement** • Remote sensing.	**Direct measurement** • Fixed weather statins. • Mobile traverses.
Typical Depiction	Thermal images	• Isotherm maps. • Temperature graph.

If planners understand the UHI spatially, they can devise urban designs that promote cooling while preserving material quality and integrity in a specific location. Incorporating sustainable materials and evidence-based urban planning from a bird's-eye perspective can significantly mitigate the impacts of urban heat islands. Urban planners can mitigate urban heat by creating green spaces in high-temperature zones, strategically positioning buildings for optimal natural ventilation, and employing reflective materials to diminish heat absorption.

Jack Lien’s (2024) study demonstrates that urban planning is essential in alleviating the UHI effect. His study indicates that effective urban planning strategies, including the augmentation of green spaces, the installation of green roofs and walls for insulation and heat absorption, and the promotion of urban forestry through the strategic planting of trees in streets and public areas, can significantly mitigate UHI effects. Moreover, he asserted that these solutions, when integrated, foster a more robust urban environment capable of addressing the difficulties presented by increasing temperatures and climate change. Finally, he emphasized that urban planning is crucial for developing sustainable cities that focus on mitigating UHI effects, thereby enhancing the quality of life and public health for urban inhabitants.

The study of Arifwidodo, et al. (2018), that uses GIS and remote sensing to understand UHI effect and its implications to climate change adaptation strategies in major Southeast Asian cities, shows that indeed this technology is essential in determining Land Surface Temperature (LST) to measure understand different patterns and characteristics of UHI in Southeast Asian cities, to determine the built environment found to intensify UHI magnitude, to know the significant association between health outcomes and UHI, to understand the positive association between UHI magnitude and household energy consumption, and to assess the existing policy measures to mitigate UHI which they found out are still scarce at the city level like in Bangkok, Thailand the existing policy on UHI mitigation and adaptation are scattered in different urban development plans. Integrating UHI into urban planning via a data-driven modeling approach employing GIS and remote sensing will enable the development of a decision-support tool for UHI concerns in urban design (Pena Acosta et al. 2021).

As stated in numerous studies, alterations in thermal properties represent a significant consequence of urbanization and city growth. It is indeed encouraging to note that enhancements in thermal properties contribute to the development of new green spaces, subsequently fostering the advancement of green technology. Government officials, urban planners, and other professionals will accomplish this by understanding the process of generating local UHI, enabling them to analyze the specific UHI characteristics or patterns of the particular site.

Geographic Information System (GIS) and Remote Sensing

The concept is akin to the typical comparisons of maps created on various dates. The notion of GIS was employed when maps on the same subject created on different dates were analyzed concurrently to discern changes, and when maps depicting various types of information for the same region were superimposed to ascertain linkages.

GIS essentially resembles a large panel of uniformly formed open boxes, each representing a designated area on the Earth's surface. After identifying each informational element regarding a specific attribute (e.g., soil, rainfall, population) relevant to the area, we can assign it to the appropriate box. Theoretically, we can systematically gather vast quantities of data, given the unrestricted input of information into each field. By adding a few attributes to the box system, it becomes evident that a collection of map data was created, which can then layer on top of each other to illustrate the spatial connections between various attributes such as temperature, land cover, natural resources, socio-economic phenomena, and dangerous events (Tatlonghari, 2002).

Similar to GIS technology, digital data continuity, and topological precision provide the prompt and precise information necessary for decision-making. People currently regard geographic information systems (GIS) as an essential science within the field of information technology. According to Tatlonghari (2002), it is a systematic collection of hardware, software, geographic data, and personnel that efficiently captures, stores, updates, modifies, analyzes, and presents various forms of spatially connected data and information for specific purposes. Geographic Information Systems (GIS) are computer systems that capture, store, verify, and visualize data related to locations on the Earth's surface (National Geographic, 2023). Remote sensing collects data worldwide through satellites, locally through planes, and, more recently, via small unmanned aerial vehicles (UAVs, often known as drones) and portable devices (van der Linden et al., 2018). It is the process of acquiring information from a distance (NASA, 2023).

In essence, GIS refers to a computer system that includes software for data analysis and hardware for the software's operation, whereas remote sensing refers to surveying and collecting data about an object (Innocent, 2022). People frequently confuse the terms GIS and remote sensing, as GIS software nowadays also serves as remote sensing software. Furthermore, generally, people who are proficient in GIS are also competent in remote sensing, and vice versa.

The use of GIS and remote sensing is highly extensive. Numerous disciplines in planning currently use GIS and remote sensing technology. Geographic Information Systems (GIS) and remote sensing have progressively emerged as invaluable tools in the investigation of environmental impacts. Various fields can utilize GIS and remote sensing due to the spatial aspect of the data. Criminal justice uses GIS and remote sensing to investigate crime patterns; marketing uses technology to enhance target marketing; public health institutions monitor disease proliferation; hydrologists chart the dispersion of toxins in subsurface water; foresters manage their resources more efficiently; and urban planners design the community sustainably by synthesizing spatial information from spatial query and mapping to analyze existing city layouts with the aid of various spatial data sources to explore potential solutions. GIS and remote sensing enable urban growth by accommodating more people in a smaller area while taking into account their health, lifestyle, and comfort. In forestry and environmental planning, GIS and remote sensing technologies are extensively employed for land use planning, rapid impact assessment, resource inventory, hydrologic modeling, fire management, timber harvesting, pest and disease detection, monitoring, and evaluation, among other applications.

GIS and remote sensing have vast application. Only the quantity of accessible information and the user's creativity constrain the applications of GIS and remote sensing in urban development and planning. Information about natural events (like records of past disasters), scientific literature (like papers, articles, newsletters, etc.), and hazard mapping (showing where earthquake faults, volcanoes, floodplains, erosion patterns, and other risks are located) is usually enough to do a preliminary GIS and remote sensing assessment of natural hazard conditions and plan channel development. To gain a thorough understanding of the site, simulation modeling through GIS and remote sensing are essential. This methodology will produce previously inaccessible information, resulting in enhanced site design and planning.

Combining different types of simulation models such as statistical models, socioeconomic models, and/or physics-based modeling with GIS and remote sensing can produce very useful analytical tools for examining various policy and management scenarios at all levels of decision-making. These technologies can be beneficial for developing national and international policies. GIS and remote sensing-assisted spatial planning may contribute to environmentally acceptable development and help resolve conflicts that would otherwise arise (Babu, 2000). People widely use GIS and remote sensing to assess the environment and scenarios. This technology facilitates the simple organization and easy graphic presentation of geographic data, both spatially and temporally (Tripathy, 2000).

For several decades, GIS and remote sensing technologies have offered continuous data capture, integrity, and real-time monitoring, thereby addressing the limitations of conventional approaches. It facilitates the quantification of urban heat island intensity and the detection of thermal anomalies inside urban environments. Thermal satellite data and statistical analysis can assess the influence of climate change and the severity of the UHI. GIS platforms, such as QGIS, are utilized to process and analyze remote sensing data, pinpoint urban sprawl, and assess landscape metrics related to UHI effects. These methodologies provide essential data for urban planning, ecological preservation, and alleviation of the UHI phenomenon.

Sustainable urban planning is one of GIS and remote sensing's primary applications. Urban planners utilize GIS as a spatial database and tool for conducting research and presenting their findings, while they use remote sensing to obtain a bird's-eye view of spatial information. Different stages, levels, sectors, and parts of urban planning can utilize GIS and remote sensing in different ways. As the ease of use and features of GIS and remote sensing software continue to improve, and the price of these tools continues to drop, GIS and remote sensing have emerged as valuable and cost-effective spatial information systems for planning. It's becoming more important to plan networks that will help people perform their jobs well. The increasing integration of GIS and remote sensing with planning models, representations, and the Web will enhance its utility in town planning. Today, the main problems with using GIS and remote sensing in urban planning are not technical ones but rather the accessibility of information (spatial and non-spatial); rules are changing quickly, and there aren't enough staff to utilize GIS (Rudrawar, 2020).

Often a challenge is the availability of useful information that can assist planning decisions; various studies have underlined the importance of environmental evaluations offering spatially explicit data in a timely, cost-effective, and repeatable manner. One such element influences urban planning. Using remote sensing (RS) and a geographic information system (GIS) to extract important data could be one way to help overcome the challenges mentioned above since GIS and RS in land use planning for identifying suitable sites require desirable, accurate, timely, accessible, comprehensive, reliable, and affordable spatial information. Hence, the use of geographic information systems to provide such information is imperative (Tatlonghari, 2002; Wellman et al., 2020).

Some of the most popular spatial information technologies, such as GIS and remote sensing, provide planners, both national and local, with information about the overall land and water conditions. It provides ideas for identifying areas that need additional

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attention and evaluation, such as natural hazards for natural resource management and development potential. GIS and remote sensing have unique abilities to manipulate, manage, and analyze geographic and spatial-related data sets. Furthermore, the visualization capabilities of GIS and remote sensing are more persuasive than written text pages. Visualization and graphical representation of information are critical for decision-making analysts, as well as non-experts who need to understand the context as a whole.

Many fields, from archeology to zoology, have acknowledged GIS and remote sensing as valuable spatial data analysis tools capable of providing useful information for planning and management. It offers substantial advantages like increasing quantity of output, high quality, and more timely output, which are vital in any decision-making system. Syam et al. (1999) asserted that GIS and remote sensing could save significant amounts of money by creating maps that show where and when to pick crops, thereby improving the extremely laborious and time-consuming logistics of moving people and equipment at night. Therefore, it is considered a cost-effective information technology. The advantage of using this technology in any field is that it makes the work faster, allows for frequent low-cost examination of large areas, and provides an increasing amount of data. As a result, this information technology necessitates appropriate expertise as it deals with technical procedures and discipline.

III. Methodology

The Study Area

The study site for Land Surface Temperature (LST) is a portion of the Luzon Islands, specifically the entire provinces of Laguna, Batangas, Cavite, Rizal, Bulacan, Pampanga, Bataan, and Metro Manila, along with a segment of Tarlac, Zambales, Nueva Ecija, Aurora, Occidental Mindoro, and Quezon.

The primary reason for selecting only 14 study sites was the constraint of time. Simple random sampling techniques were employed to guarantee an impartial selection of study sites. With the help of a digital orthophoto from Google Map, the author carefully recorded all the towns with the complete boundary feature encompassed by the downloaded Landsat 8 within LST coverage and allocated a distinct number to each town. The author utilized the generated random numbers in Excel (=RAND) to select the numbers corresponding to the study site (town).

Materials

The researcher downloaded the Landsat 8 Level 2 from USGS Earth Explorer captured on June 3, 2024, with the following Landsat Collection Information (Table 2):

Table 2. Landsat Collection Information (source: USGS Earth Explorer, 2021)

Geometry	
Geometric Registration Base	Global Land Survey (GLS) 2000
Map Projection	Albers
Resampling	Cubic Convolution
Pixel Size (Reflective) (MSS / TM, ETM+, OLI)	60m / 30m
Pixel Size (Thermal) (TM / ETM+ / TIRS)	0m/30m/30m
Datum	WGS84
Precision Correction Methodology	Baseline
Radiometry	
Per-Pixel Solar Angle Corrections	Full Per-Pixel Correction Applied
Solar/Sensor Viewing Angle Information	None (Per-Pixel Correction Already Applied)
Atmospheric Correction/Level-2 Processing	
Surface Reflectance Algorithm Version	LEDAPS v3.2.1 (TM/ETM+) LasSRC v1.3.0 (OLI/TIRS)
Surface Temperature Algorithm Version	Landsat Single-Channel Surface Temperature v1.3.0
Data Type/Scaling Factor (Surface Reflectance)	Signed 16-bit integer 0.0001 (no offset)
Data Type / Scaling Factor (Surface Temperature)	Signed 16-bit integer 0.1 (no offset)
Water Vapor Source	NCEP Grid (TM / ETM+) / MODIS CMA (OLI/TIRS)
Aerosol Source	Internally Calculated (TM/ETM+)/MODIS CMA (OLI/TIRS)
Ozone Source	OMI/TOMS ETM+) / MODIS CMG (OLI/TIRS)
Air Temperature Source	NCEP Grid (TM / ETM+) / MODIS CMA (OLI/TIRS)
Atmospheric Elevation Model	
Atmospheric Reanalysis Source (Surface Temperature)	North American Regional Reanalysis (NARR)
Emissivity Source	ASTER GED
Surface Temperature Retrieval Method	Single-Channel (Landsat 4-8)

The author's experience, combined with prior similar studies, indicates that employing the current Landsat 8 for UHI evaluation can provide enough insight into the existing UHI pattern in the area, which is advantageous for planning initiatives. The concept is akin to utilizing a soil test kit to promptly ascertain the pH of the soil, which is crucial for farmers in deciding which crops to plant. However, if farmers require more in-depth details such as soil organic matter and nutrients, they require additional samples for laboratory analysis. The same principle applies to UHI mapping: to obtain more detailed information, additional spatial data series and historical data are required. Having a general understanding of local UHI is more beneficial than having no knowledge at all.

Additionally, the current Landsat 8 at a specific location functions as a crucial instrument for analyzing the correlation between urban characteristics and the factors that delineate thermal variations across spatial and temporal dimensions. A number of important factors support the use of Landsat 8 for estimating land surface temperature (LST), which plays a crucial role in assessing urban heat islands (UHI). According to the data regarding the collection of Landsat information, Table 2 indicates that Landsat 8 comprises two thermal infrared bands, designated as TIRS 1 and TIRS 2. Table 2 shows that the spatial resolution of these bands is now 30 meters. The elevated resolution facilitates comprehensive thermal mapping. The sensor's revisit time is 16 days, which enables the collection of valuable data for tracking variations in land surface temperature over time.

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Researchers and practitioners worldwide can easily access Landsat 8 data through the USGS Earth Explorer platform. There are established algorithms and methodologies for retrieving LST from Landsat 8 data, including the Split-Window Algorithm and the Single Channel Algorithm. A multitude of studies have confirmed the effectiveness of these strong methods. Ultimately, it maintains the legacy of previous Landsat missions, providing a dependable and durable data record crucial for trend analysis and historical comparisons. Finally, because of the aforementioned factors, it is considered a dependable and widely used option for LST estimation across multiple applications, such as urban planning, agriculture, and climate studies.

Data Gathering and Analysis

Generally, the methodology for this study consists of three stages: (1) data acquisition; (2) data engineering; and (3) product creation.

Initially, satellite images are acquired through USGS Earth Explorer (https://earthexplorer.usgs.gov) for the demonstration of assessing UHI using GIS and remote sensing for urban planning. An account is necessary to download any type of satellite image. Landsat 8 with atmospheric corrected data that has urbanity and rural areas in the Philippines was downloaded and stored. Additional secondary data were acquired through the compilation of prior research on UHI and pertinent climate information.

In the second stage, data engineering consists of geoprocessing, manipulation, analysis, and storage. All the gathered maps were digitized, edited, labeled, manipulated, and analyzed using QGIS 3.34, an open-source GIS and remote sensing software. The raster analysis in QGIS, particularly the raster calculator, was used for algorithm application of Landsat 8 and raster study site extraction. Vector processing for site boundaries and profiling were also done using QGIS, specifically using Geoprocessing and Profile Tools.

The study utilized both qualitative and quantitative data analysis. Qualitative analysis was employed to provide descriptions, particularly in assessing UHI and understanding the spatial perspectives and importance of LST in urban planning. Quantitative analysis was employed to examine numerical data generated by GIS and remote sensing for UHI and its effects on urban environments.

The algorithms of Rahman et al. (2022) and Blueie (2023) on how to compute NDVI, ToA, BT, LSE, PVI, Ec, LST, and UHI were adopted for this study.

Normalized Difference Vegetation Index (NDVI):

The Normalized Differential Vegetation Index (NDVI) is a standardized vegetation index which Calculated using Near Infra-red (Band 5) and Red (Band 4) bands.

NDVI = (NIR – RED) / (NIR + RED)

NDVI = (Band 5-Band 4)/ (Band 5+Band 4)

NDVI = ("B5.TIF" - "B4.TIF")/("B5.TIF" + "B4.TIF")

Where:

RED = DN values from the RED Band

NIR = DN values from Near-Infrared Band

B5.TIF = Band 5 in TIF

B4.TIF = Band 4 in TIF

Conversion to Top of Atmosphere (ToA) Radiance:

Using the radiance rescaling factor, Thermal Infra-Red Digital Numbers can be converted to TOA spectral radiance.

*ToA = ML * Qcal + AL-Oi*

*ToA = 0.0003342 * "B10.TIF" +0.1 -0.29*

Where:

ToA = Top of Atmosphere spectral radiance (Watts/ (m2 * sr * μm))

ML = Radiance multiplicative Band number

AL = Radiance Add Band (No.)

Qcal = Quantized and calibrated standard product pixel values (DN)

Oi = Correction value for band 10 is 0.29

B10.TIF = Band 10 in TIF

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Conversion to Top of Atmosphere (TOA) to Brightness Temperature (BT):

The thermal constant values in the metadata file can convert spectral radiance data from the top-of-atmosphere to brightness temperature.

Kelvin (K) to Celsius (0C) Degrees BT = (K2 / In ((k1 / Lλ) + 1)) - 273.15

BT= (1321.0789/ Ln((774.8853/ToA)+1)) - 273.15

Where:

BT = Top of atmosphere brightness temperature (°C)

ToA = Top of Atmosphere spectral radiance (Watts/ (m2 * sr * µm))

K1 = K1 Constant Band (No.)

K2 = K2 Constant Band (No.)

Land Surface Emissivity (LSE):

Land surface emissivity (LSE) is the average emissivity of an element of the surface of the Earth Calculated (Ec) from NDVI values.

PVI = Square ((“NDVI" - NDVI Min)/ (NDVI Max - NDVI Min))

Where:

PVI= Proportion of Vegetation Index

NDVI = DN values from NDVI Image

NDVI min = Minimum DN values from NDVI Image

NDVI max = Maximum DN values from NDVI Image

*Ec = 0.004 * PVI + 0.986*

Where:

Ec = Land Surface Emissivity

PVi = Proportion of Vegetation Index

0.986 = Corresponds to a correction value of the equation

Land Surface Temperature (LST):

The Land Surface Temperature (LST) is the radiative temperature Which calculated using Top of atmosphere brightness temperature, Wavelength of emitted radiance, Land Surface Emissivity.

*LST = BT/ (1 + (λ * BT / c2) * ln(Ec))*

Here, *c2= 14388 µm K*

The Values of λ for Landsat 8: For Band 10 is 10.8 and for Band 11 is 12.0

Therefore:

LST = ("BT"/(1+(0.00115"BT"/1.4388) * Ln ("Ec")))*

Where:

BT = Top of atmosphere brightness temperature (°C)

λ = Wavelength of emitted radiance

Ec = Land Surface Emissivity

c2 = h*c/s=1.4388*10-2 mK =14388 mK

h = Planck’s Constant =6.626*10-34 J s

s = Boltzmann constant =1.38*10-23 JK

c = velocity of light =2.998*108 m/s

Urban Heat Island (UHI):

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024

UHI = LST – LSTmean / SD

Where:

UHI = Urban Heat Islands

LST = Land Surface Temperature

LSTmean =Average temperature of the land surface temperature in the study area

SD = Standard deviation of temperature

In the last stage, upon derivation of UHI map, all layers were put together including diagram to create a decision map for urban planner to consider in their design and planning. And for the contributions to society, this paper will be published online once it was accepted by peer review for publication.

IV. Results and Discussions

Methodological Approach

The findings of the study highlight the methodological approach used in the study, from data gathering to algorithm application to encourage urban planners to utilize open-source GIS and remote sensing technology to be able to generate UHI for effective and efficient urban planning. This entails implementing necessary spatial mitigation strategies that promote a balanced ecosystem, incorporating them into the decision-making process for environmental and natural resource management, and developing a geospatial process for improved policy formulation. These strategies aim to counteract the various effects of UHIs, such as heightened energy consumption, negative health consequences, and contamination of air and water, among others.

The models employed are physics-based model and statistical model that utilizes scientific rules, to elucidate system behaviors, including weather patterns and climate change. It offers high-fidelity simulations that accurately replicate real-world behavior. It can forecast the behavior of systems under diverse conditions, which is essential for urban planning and optimization. Although the preferred paradigm is complex, the actions outlined in this paper are straightforward and comprehensible. The results show actions that can be undertaken with minimal knowledge of GIS and remote sensing, which is one of the primary purposes of this paper.

The findings demonstrate how simple it is to obtain satellite imagery via the USGS Earth Explorer website at no cost, especially since there are video tutorials available on YouTube for guidance on the download process. Moreover, raster analysis and raster calculators for the UHI algorithm using open-source GIS and remote sensing applications are simple to understand, and there are video lessons available on YouTube for the raster calculation process.

Upon inputting the requisite information on a specific area of interest, the USGS Earth Explorer website presents the accessible satellite imagery of the designated area. For demonstration reasons, the author chose the satellite exhibiting minimal cloud cover from the image preview of the USGS Earth Explorer interface, which presents the catalog of accessible satellite images. The author chose the June Landsat imagery because it has less cloudiness, which is essential for LST computation demonstration.

The following were obtained from USGS Earth Explorer that are needed for UHI map generation (Figure 2-4):

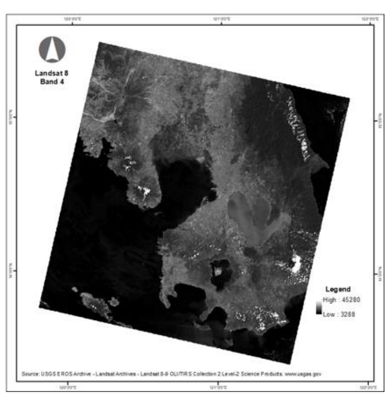


Figure 1. Landsat 8 Band 4

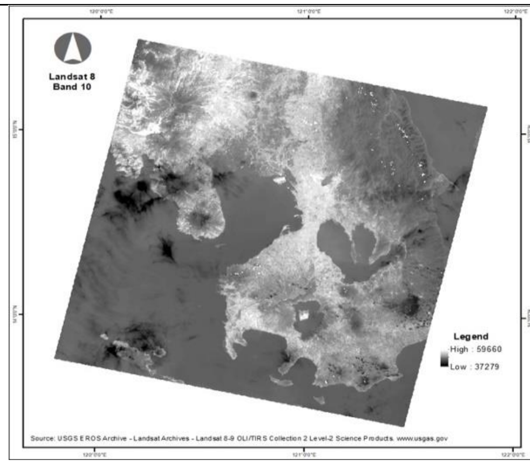


Figure 3. Landsat 8 Band 5

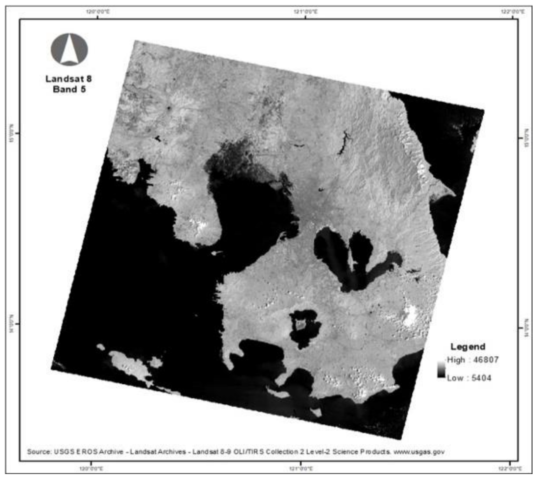


Figure 4. Landsat 8 Band 10

Upon loading of downloaded satellite images in QGIS, the files were rename accordingly for more manageable name based on their band (e.g., B4.TIF for Band 4, B5.TIF for Band 5 and B10.TIF for Bad 10). This was made for easy identification during map calculations using Raster Calculator.

Figure 5 summarizes the application stage of the algorithm and framework. Each stage plays an important role in the subsequent calculation of LST for UHI generation. The following stages demonstrate the application of the algorithm used in the study using GIS and remote sensing technology.

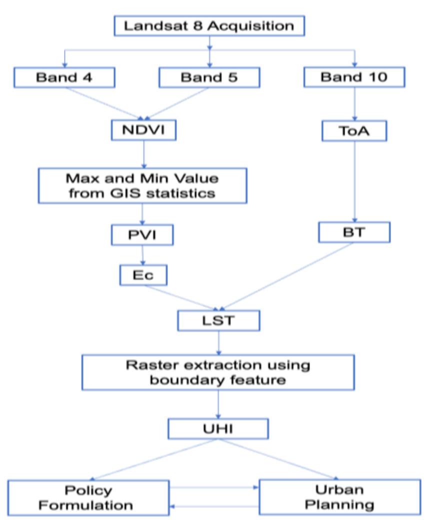


Figure 5. Summary of the application stage of the algorithm and framework.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024

The calculated NDVI is shown in Figure 6, which was generated from a raster calculator using the following formula: NDVI = ("B5.TIF"-"B4.TIF")/ ("B5.TIF" + "B4.TIF").

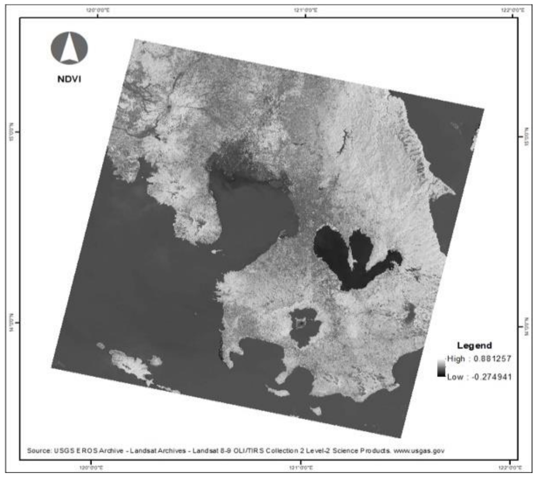


Figure 6. Generated Normalized Difference Vegetation Index (NDVI)

The calculation of the Top of Atmosphere (ToA) was performed using the equation: ToA = 0.0003342* B10.TIF + 0.1 - 0.29. Figure 7 illustrates the results.

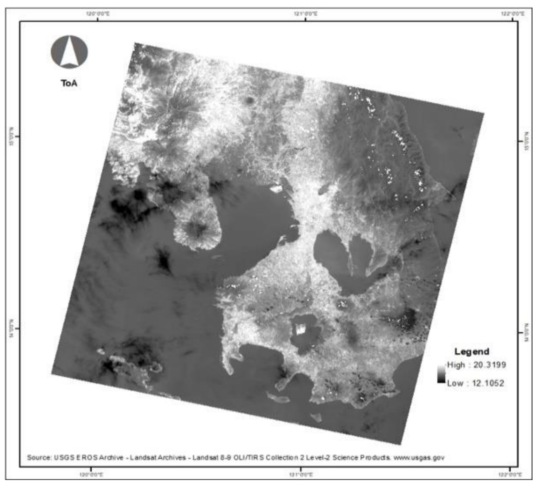


Figure 7. Generated Top of Atmosphere (ToA) Radiance

Figure 8 shows the results of the calculated Brightness Temperature (BT) derived from the following equation: BT = (1321.0789 / Ln((774.8853 / "ToA") + 1)) - 273.15.

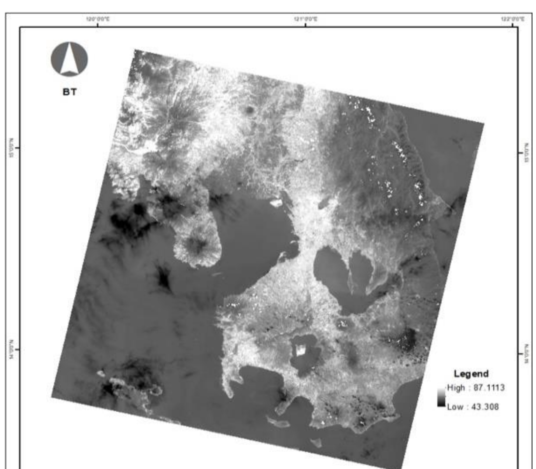


Figure 8. Generated Brightness Temperature (BT)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024

The Land Surface Emissivity (LSE) was determined using the Proportional Vegetation Index (PVI), derived from the maximum (0.8812572956085205) and minimum (-0.2749408483505249) statistical values of the NDVI through the equation: PVI = Square (("NDVI" - 0.2749408483505249) / (0.8812572956085205 - 0.2749408483505249)). Following the generation of the PVI, it was adjusted using the equation: Ec = 0.004 * "PVI" + 0.986. The results are shown in Figures 9 and 10, respectively.

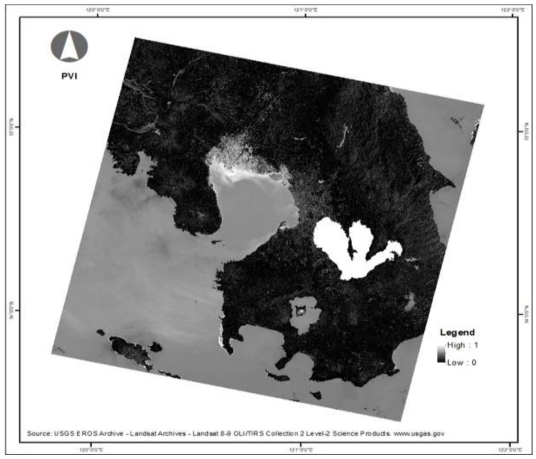


Figure 9. Generated Proportional Vegetation Index (PVI)

The proportion of vegetation index (PVI) usually ranges from 0 to 1, where: 0 The proportion of vegetation index (PVI) typically varies between 0 and 1, with 0 representing a complete absence of vegetation cover and 1 signifying total vegetation cover.

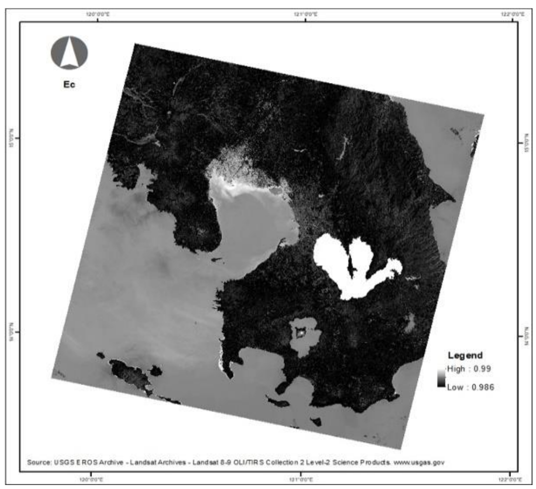


Figure 10. Generated Land Surface Emissivity (LSE)

The generated Land Surface Temperature (LST) is a product of the combined calculated BT and the corrected LSE (Ec) using the following equation: LST=("BT"/(1+(0.00115*"BT"/1.4388)*Ln("Ec"))). Figure 11 reveals the calculation's results.

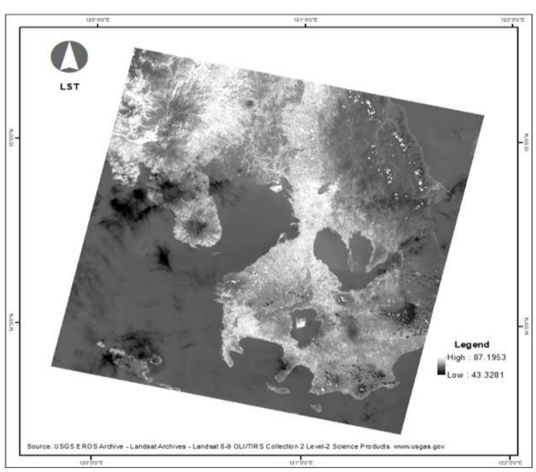


Figure 11. Generated Land Surface Temperature (LST)

For this demonstration, the author used the following boundary feature (*.shp) to extract by mask to compute the UHI of the following study sites in alphabetical order:

1. Antipolo City, Rizal
2. Candaba, Pampanga
3. Dinalupihan, Bataan
4. Hagonoy, Bulacan
5. Infanta, Quezon
6. Laurel, Batangas
7. Lucban, Quezon
8. Mataasnakahoy, Batangas
9. Metro Manila, NCR
10. Norzagaray, Bulacan
11. Pila, Laguna
12. Porac, Pampanga
13. Sant Rosa City, Laguna
14. Tiaong, Quezon

The boundary features (*.shp) were projected uniformly the same with the projection of satellite images which is WGS_1984_UTM_Zone_51N. Study sites extraction were done since UHI is site dependent for urban planning. Thus, study site boundaries were delineated first before UHI calculation of study sites.

The calculated UHI for study sites were calculated using the following equation: UHI=LST-LSTmean /Std Dev from LST Statistics. The following statistical data were generated using GIS software (Table 3):

Table 3. The Mean and Standard Deviation of Study Sites.

Study Site	Mean (°C)	Standard Deviation
Antipolo City, Rizal	61.643541	2.422732
Candaba, Pampanga	63.967765	2.342665
Dinalupihan, Bataan	61.659548	3.030579
Hagonoy, Bulacan	60.020963	1.728284
Infanta, Quezon	59.164756	1.687795
Laurel, Batangas	61.864093	1.556839
Lucban, Quezon	57.624242	2.414684
Mataasnakahoy, Batangas	60.466497	1.698497
Metro Manila, NCR	67.864160	2.396514
Norzagaray, Bulacan	60.803668	2.692663
Pila, Laguna	61.859689	1.773077
Porac, Pampanga	64.630302	4.153545
Sant Rosa City, Laguna	66.367653	1.910957
Tiaong, Quezon	61.396982	2.307056

The UHI of the Study Sites

Table 3 reveals the descriptive statistics of the study sites. The overall mean is 62.184 °C; Metro Manila has the highest mean temperature (67.864160 °C); and the lowest mean is Lucban (57.624242 °C). Overall standard deviation is 2.26°C, the highest standard deviation is Porac (4.153545°C), and the lowest standard deviation is Laurel (1.556839°C). GIS produced these statistical data of average temperature in degrees Celsius and standard deviation, which were used to calculate the Urban Heat Island (UHI) effect of selected study sites using the formula: UHI = LST – LSTmean / SD. Figures 12–25 and Graphs 1–14 present the results of these calculations.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024

A low standard deviation indicates a close clustering of values around the mean, while a high standard deviation indicates a wider dispersion of values. Typically, a standard deviation below 10% of the mean is regarded as low, whereas a standard deviation exceeding 20% of the mean is viewed as high.

Based on the results, Metro Manila has the highest mean temperature, indicating it might be the warmest among the study sites. Lucban has the lowest mean temperature, suggesting it might be cooler compared to other sites. Porac shows the highest variability in temperature, as indicated by its standard deviation.

Laurel has the lowest variability in temperature, suggesting more consistent temperatures.

To enhance visualization, the author modified the symbology from default black and white to a color gradient, employing green for low temperatures, yellow for moderate temperatures, and red for high temperatures.

The data presented in Table 4 illustrates the range of maximum and minimum temperatures obtained from profiling conducted in both urban and rural settings using GIS.

Table 4. The Maximum and Minimum Temperature Difference of Urban and Rural Areas

Study Site	Maximum (°C)	Minimum (°C)
Antipolo City, Rizal	6.17731	-2.42273
Candaba, Pampanga	4.05040	-1.84041
Dinalupihan, Bataan	3.37266	-3.27147
Hagonoy, Bulacan	4.87029	-2.88205
Infanta, Quezon	4.44682	-4.67482
Laurel, Batangas	5.75671	-1.92723
Lucban, Quezon	4.46001	-2.15677
Mataasnakahoy, Batangas	3.57141	-1.96730
Metro Manila, NCR	8.06636	-3.89859
Norzagaray, Bulacan	4.64940	-1.84314
Pila, Laguna	3.90013	-2.17629
Porac, Pampanga	2.53028	-2.13854
Sant Rosa City, Laguna	9.97409	-2.79773
Tiaong, Quezon	2.88090	-2.54865

The results show that UHI is site-specific based on the unique physical characteristics of each site. The findings indicate that the UHI effect can differ markedly across various urban areas due to a range of contributing factors. Multiple factors, including geographical location, climate, topography, urbanization patterns, industrial activities, urban planning and policies, green spaces, and urban density and infrastructure, influence the variations observed among study sites.

The preliminary investigative analysis of the 14 study sites (Figure 12-25, Graph 1-14)), utilizing digital orthophoto from Google Map, indicates that the characteristics of UHI differ based on the interplay between land use, precipitation, population density, and urban density (Figure 26).

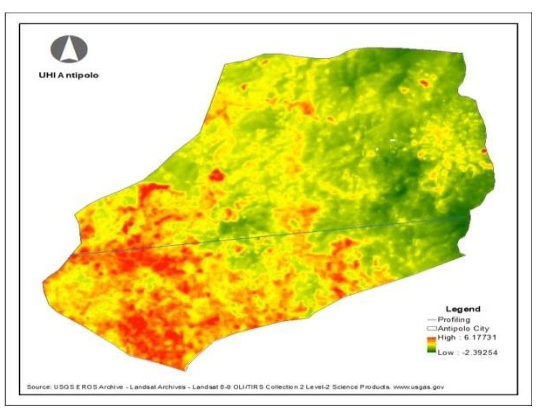
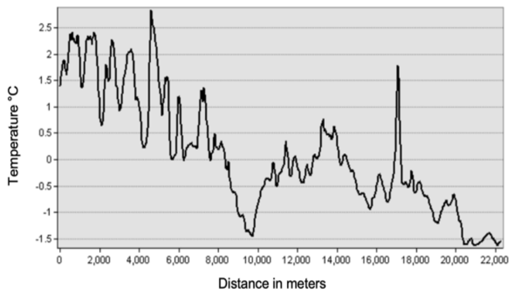


Figure 2. Generated UHI of Antipolo City, Rizal (June 2024)

INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024



Graph 2. Generated UHI Profile of Antipolo City, Rizal (June 2024)

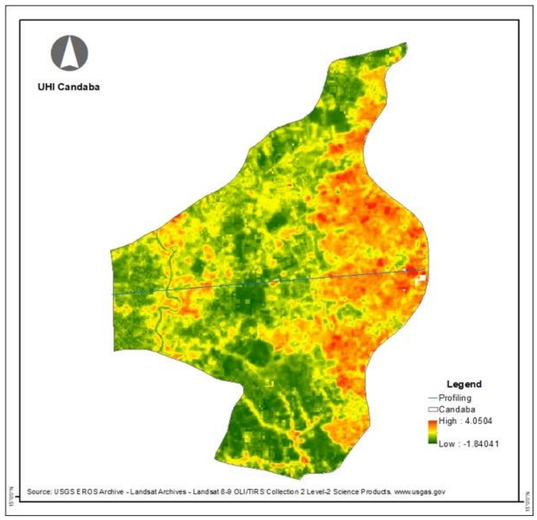
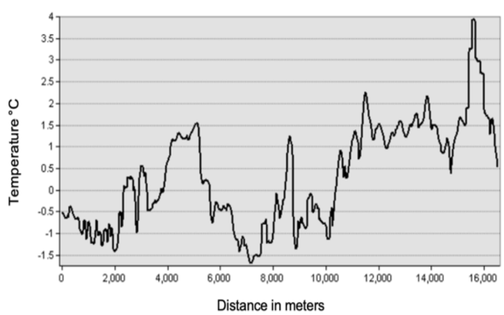


Figure 3. Generated UHI of Candaba, Pampanga (June 2024)



Graph 2. Generated UHI Profile of Candaba, Pampanga (June 2024)

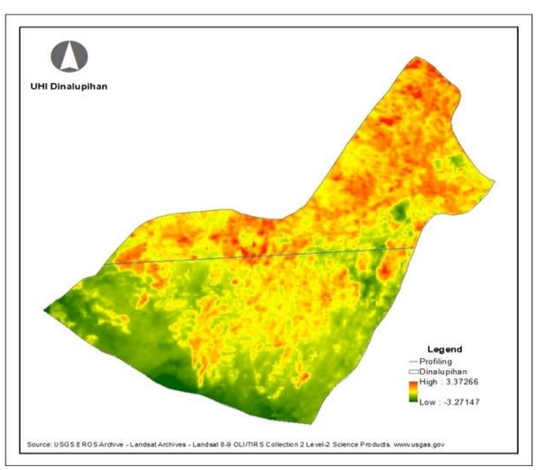
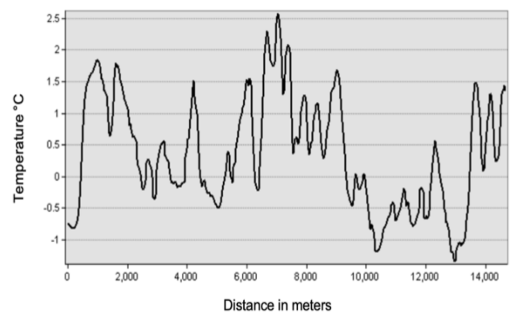


Figure 3. Generated UHI of Dinalupihan, Bataan (June 2024)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024



Graph 4. Generated UHI Profile of Dinalupihan, Bataan (June 2024)

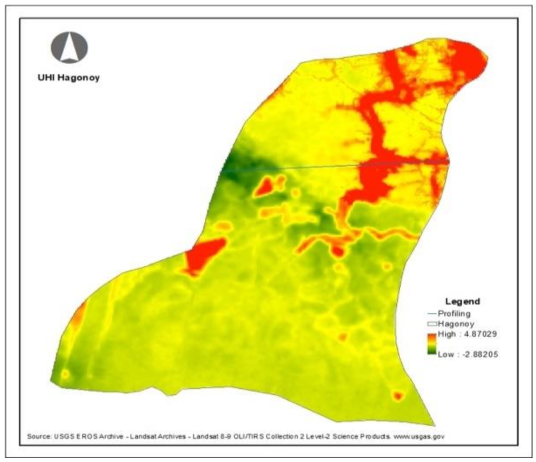
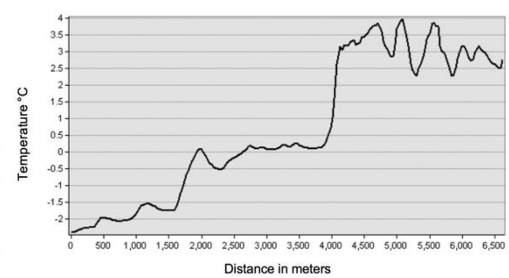


Figure 5. Generated UHI of Hagonoy, Bulacan (June 2024)



Graph 4. Generated UHI Profile of Hagonoy, Bulacan (June 2024)

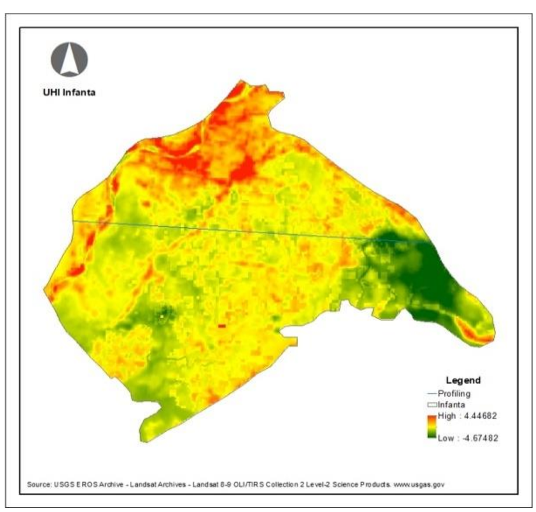
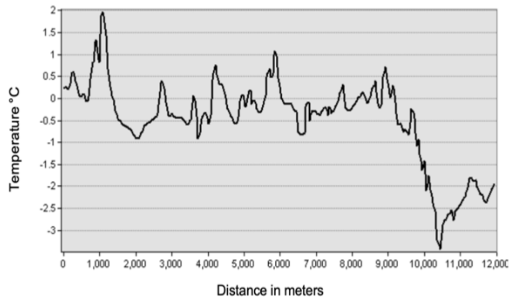


Figure 5. Generated UHI of Infanta, Quezon (June 2024)



Graph 6. Generated UHI Profile of Infanta, Quezon (June 2024)

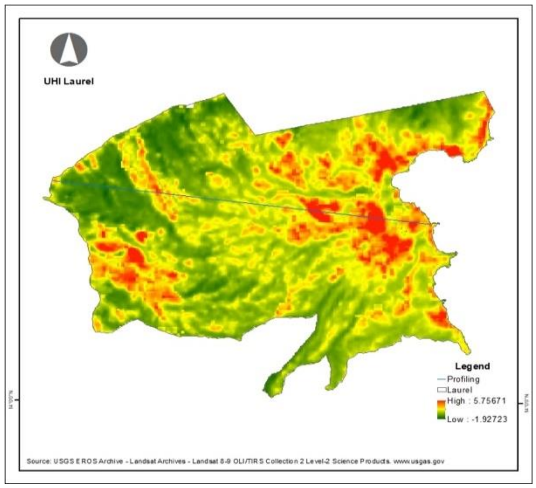
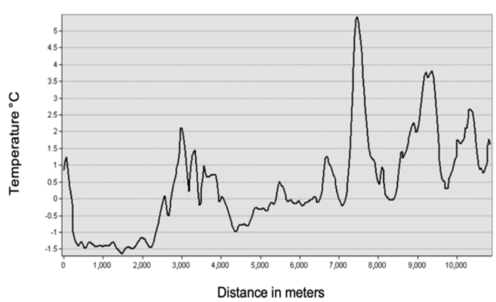


Figure 7. Generated UHI of Laurel, Batangas (June 2024)



Graph 6. Generated UHI Profile of Laurel, Batangas (June 2024)

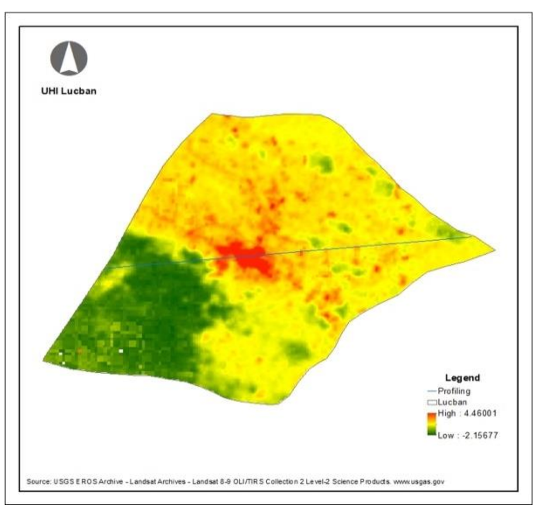
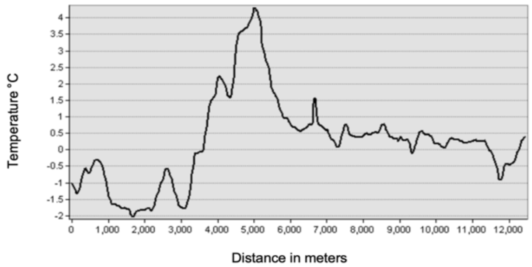


Figure 7. Generated UHI of Lucban, Quezon (June 2024)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024



Graph 8. Generated UHI Profile of Lucban, Quezon (June 2024)

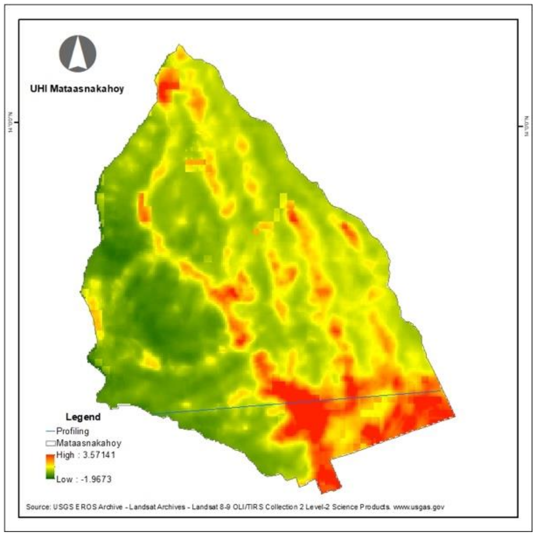
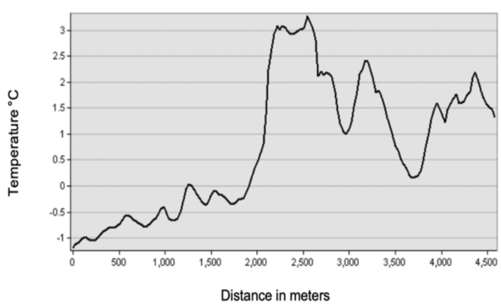


Figure 9. Generated UHI of Mataasnakahoy, Batangas (June 2024)



Graph 8. Generated UHI Profile of Mataasnakahoy, Batangas (June 2024)

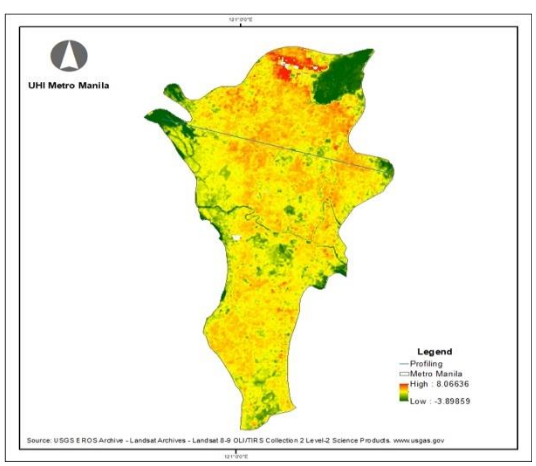
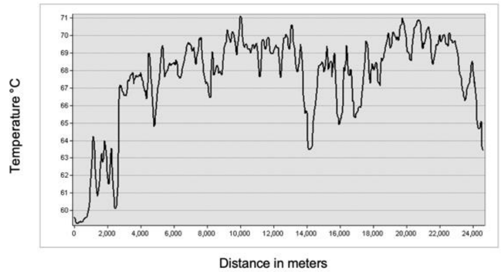


Figure 9. Generated UHI of Metro Manila, NCR (June 2024)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024



Graph 10. Generated UHI Profile of Metro Manila, NCR (June 2024)

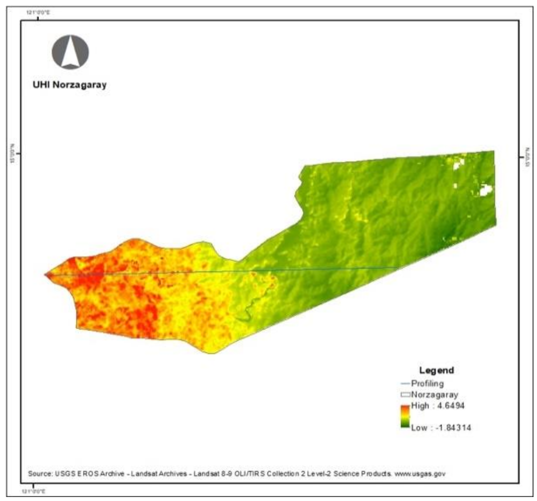
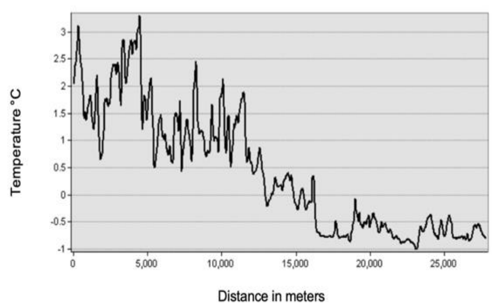


Figure 11. Generated UHI of Norzagaray, Bulacan (June 2024)



Graph 10. Generated UHI Profile of Norzagaray, Bulacan (June 2024)

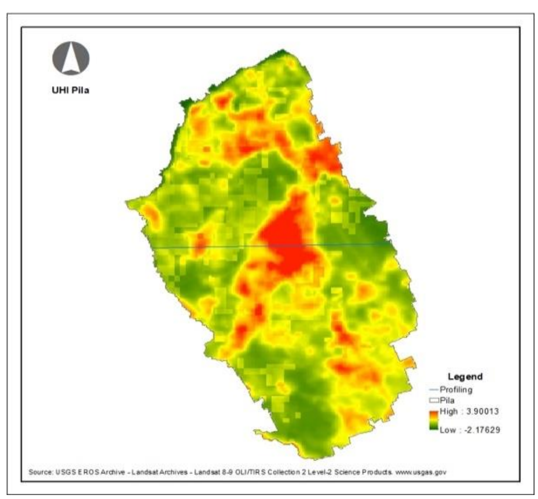
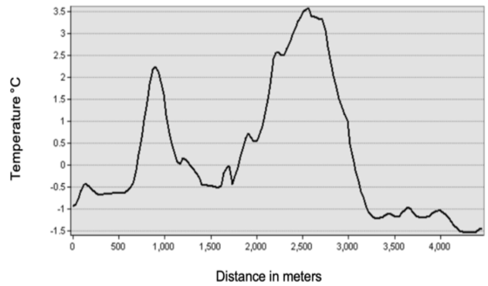


Figure 11. Generated UHI of Pila, Laguna (June 2024)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024



Graph 12. Generated UHI Profile of Pila, Laguna (June 2024)

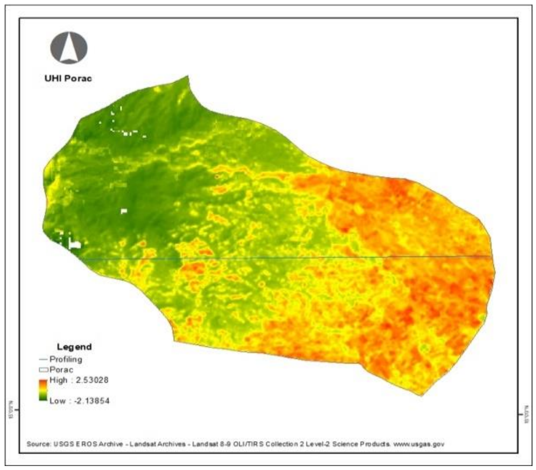
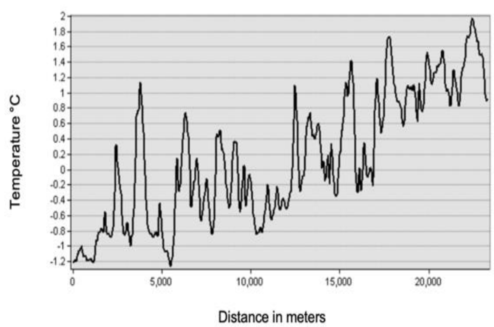


Figure 13. Generated UHI of Porac, Pampanga (June 2024)



Graph 12. Generated UHI Profile of Porac, Pampanga (June 2024)

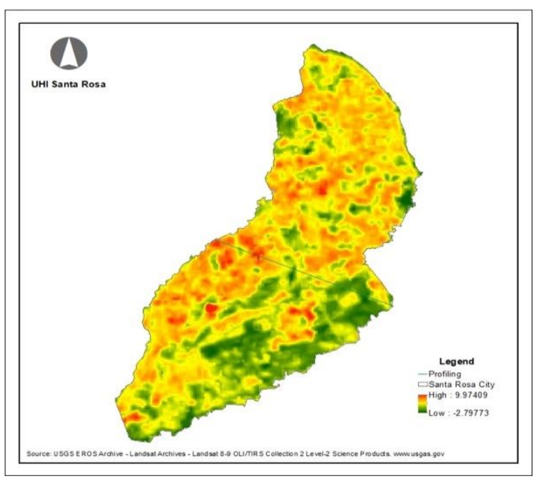
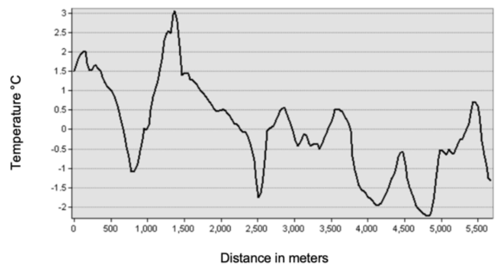


Figure 13. Generated UHI of Santa Rosa City, Laguna (June 2024)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024



Graph 14. Generated UHI Profile of Santa Rosa City, Laguna (June 2024)

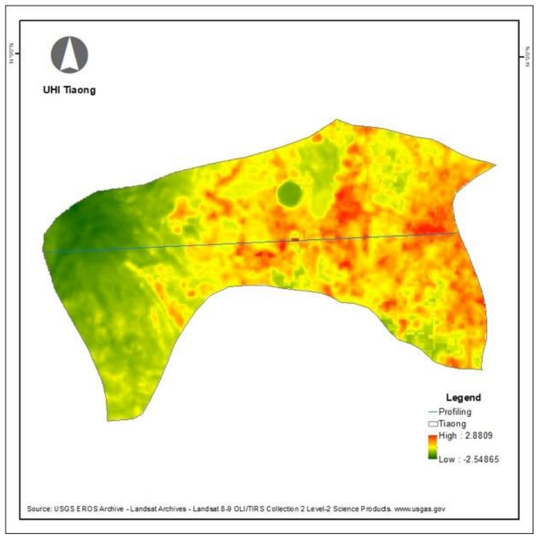
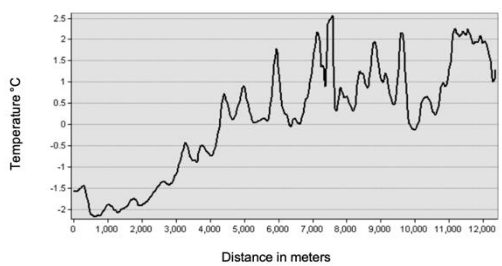


Figure 15. Generated UHI of Tiaong, Quezon (June 2024)



Graph 14. Generated UHI Profile of Tiaong, Quezon (June 2024)

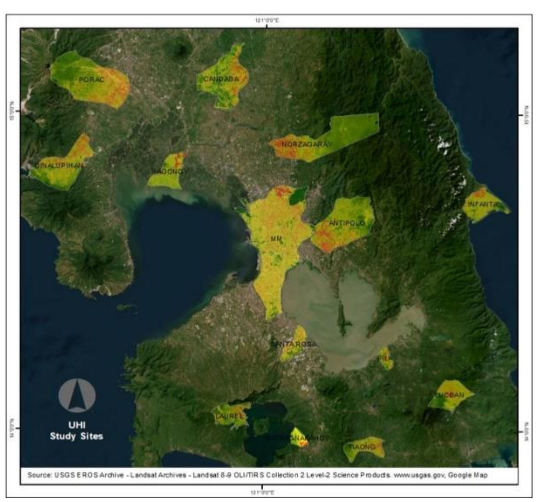


Figure 15. Investigative Analysis using Google Map

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The UHI map overlay on Google Map emphasizes the significance of UHI maps in developing decision area maps for urban planning. Multiple studies indicate a direct correlation between land use patterns, urban design, and the intensity of UHI. Consequently, integrating the UHI map into the creation of decision area maps is essential for thorough land use or urban planning. In the case of Rahaman et al.'s (2022) study, it shows a strong link ($R2 > 0.79$, $p < 0.001$) between carbon emissions and both LST and UHI effects. This means that carbon emissions played a big role in both the rise in LST and the effects of UHI. Assessing UHI will be advantageous to reduce carbon emissions by designing sustainable urban plans.

The line graph for each study site was derived from the profile tool. A profile tool is a valuable tool in geographic information systems (GIS) for analyzing and visualizing the elevation profile of a line feature across various surfaces, including multipath, raster, TIN (Triangulated Irregular Network), and terrain surfaces. These graphs illustrate the variation in maximum and minimum temperatures between urban and rural regions. The proximity to urban areas correlates with a notable rise in temperature, and the opposite is also true.

The derived profiling using the GIS profile tool for each study site aids in understanding the elevation changes along a specific path, which can influence temperature variations in urban areas. Some generated UHI maps, such as those for Lucban, Antipolo, Laurel, Norzagaray, Porac, and Dinalupihan, clearly demonstrate how elevation can influence heat absorption and retention, thereby impacting UHI intensity. The profile tool provides a visual representation of temperature changes along a line; it helps in identifying hotspots and cooler areas within a specific location. This profile can be crucial for urban planning and implementing cooling strategies. Furthermore, the author analyzed the relationship between land surface temperature (LST), vegetation (NDVI), and built-up areas (NDBI) using this generated profile. Profiling helps the author understand how different land cover types contribute to UHI effects. Finally, urban planning and policy decisions aimed at mitigating UHI effects can benefit from the insights gained from the profiling. For instance, pinpointing regions that would profit from heightened vegetation or modifications in construction materials is crucial.

The generated UHI maps and profiles present the increases in urban temperature shown in Figures 12-25 and Graphs 1-14. The findings reveal the different LST characteristics of 14 sites, and it is noticeable that Metro Manila has lower UHI data than Santa Rosa City, a city known for its industrial zones, which include manufacturing plants and economic zones. According to Vergara & Blanco (2023), these areas can contribute to higher local temperatures due to the heat generated by industrial processes, and carbon emissions emitted played a big role in both the rise in LST and the effects of UHI (Rahaman et al., 2022). Vergara & Blanco (2023) assert that Santa Rosa's proximity to natural bodies of water and its slightly more suburban layout might contribute to different heat retention and dissipation patterns compared to Metro Manila. Further, effective urban planning and policies play a role in reducing heat. Metro Manila has been implementing various measures to combat the UHI effect, such as increasing green roofs and urban forestry (Renz Palalimpa, 2024).

The findings demonstrate that the UHI effect is observable even in less urbanized or more rural areas, including Tiaong, Porac, Pila, Dinalupihan, and Mataasnakahoy. As noted by MAPFRE (2023), a rise of just one degree Celsius would result in an increased incidence of extreme heat waves, leading to both more frequent and longer-lasting events. They also claimed that it would subsequently raise the risk of heat-related illnesses, particularly in the most vulnerable populations.

Numerous studies indicate that rising temperatures will impact our natural environment, particularly forest ecosystems. For example, forests may face greater risks from more intense and frequent wildfires, resulting in substantial alterations to the composition and structure of terrestrial ecosystems.

According to Utah State University (2024), the ground surface temperature is now a significant meteorological factor. They stated that on a sunny day, the ground surface's temperature can be more than 10 °C above air temperature; on clear nights, when the surface loses heat by radiation to the frigid vastness of outer space, the temperature can be up to 10 °C below air temperature.

Generated UHI maps can serve as valuable tools for both the strategic management of land use over time and the formulation of impactful policies in urban planning and building regulations aimed at mitigating UHI intensity. Understanding the intensity of UHI allows urban planners to recommend cool roofs and pavements, as well as materials that reflect more sunlight and absorb less heat, thereby reducing temperatures.

Evaluating the UHI effect using GIS and remote sensing techniques with Landsat 8 is crucial for informed decision-making. This approach is essential to mitigate the adverse impacts of UHI and guides environmental planners toward a more empirical methodology as urban areas expand and the principles of science-based sustainable urban planning become increasingly evident.

Moreover, the results demonstrate that assessing UHI through GIS and remote sensing can be considered an essential process in creating livable, sustainable, and climate-resilient cities in the Philippines.

Challenges

The author faced challenges with data availability and the utilization of open-source tools such as QGIS, which may affect the study's accuracy and applicability. Addressing these challenges and broadening its scope will enable the study to produce more accurate and generalizable insights on urban heat islands, promoting more effective and sustainable urban development in the Philippines.

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Despite QGIS's capabilities, non-technical users might encounter a challenging learning curve. This may adversely affect the efficiency and accuracy of the analysis, especially if the user is unfamiliar with the technical components of QGIS. Moreover, the integration of QGIS with other remote sensing and data processing technologies presents challenges, potentially constraining the study's scope. The strong user community of QGIS facilitated the author's timely execution of the required spatial analysis to finalize the study. This issue may complicate the process for non-technical people, hindering their ability to recognize it and implement sophisticated techniques. Nevertheless, this study is crucial for non-technical users due to its systematic approach, which is its primary objective. This may facilitate non-technical users in identifying UHI hotspots, assessing their intensity and spatial distribution, and formulating effective policies and measures to mitigate the impacts of UHI.

The author executed the study within a brief timeframe to illustrate the efficacy of GIS and remote sensing in evaluating UHIs, which may be promptly applied for urban planning. To improve the generalizability of the findings, it is essential to integrate diverse data sources, cross-validate results, broaden geographic coverage, and engage with local authorities.

The integration of satellite imaging, ground-based observations, and crowd-sourced data will improve data coverage and precision, therefore reinforcing the outcomes. Verifying conclusions through several datasets and procedures to guarantee robustness and dependability is highly beneficial. Finally, collaboration with local governments to obtain supplementary data and insights that can augment the study's relevance and applicability is very beneficial.

V. Conclusion

The overall findings are practical for policymaking, particularly in developing an effective policy for reducing high UHI intensity, planning long-term land use management, and sustainable urban planning. As urban areas rapidly grow, they face increasing environmental challenges—such as air pollution, water contamination, and land subsidence—that exacerbate UHI intensity. Understanding the dynamics of UHI is essential for urban planners and policymakers, as it provides valuable insights into how to mitigate heat impacts in both urban and rural settings.

Understanding land surface temperatures and their physical characteristics is key to addressing UHI. This understanding enables the development of strategies aimed at cooling urban areas and improving overall livability. By recognizing the primary causes of temperature differentials—largely attributed to human activities and the built environment—planners can utilize UHI mapping to devise actionable plans that target the root causes of heat accumulation.

Advanced technologies like Geographic Information Systems (GIS) and remote sensing are invaluable tools in this effort. In addition to facilitating the collection of essential spatial data, these advanced technologies can also provide previously unavailable spatial information, which can enhance decision-making processes and enable timely and effective environmental planning. Continuous digital coverage of environmental planning supports not just urban planners but also local, provincial, and national governments, fostering a collaborative approach to addressing UHI challenges. UHI maps can assist in addressing temperature issues by utilizing UHI spatial data to create an actionable plan that reduces the causes.

Incorporating UHI considerations into decision area maps marks a significant step toward combating climate change and global warming. As geographical conditions vary, the UHI effect is distinct across urban environments, necessitating tailored strategies that reflect local contexts. Ultimately, by prioritizing the understanding and mitigation of UHI effects, communities can work toward creating sustainable, resilient urban landscapes that benefit both current and future generations.

Recommendation

The study's findings have led to the development of the following recommendations:

a. Integrate UHI mapping into the development of decision area maps to manage urban sprawl, evaluate landscape metrics concerning UHI phenomena, and deliver essential insights for urban planning, ecological preservation, and the reduction of the UHI effect in the locality.

b. Evaluate the effects of local UHI on energy consumption, air pollution, and social issues. A comparison with ground-based temperature readings is necessary. Use ground-based temperature observations to cross-validate and check the correctness of satellite-derived data. This can help discover differences and increase the findings' dependability. Furthermore, ground-based data can give higher spatial resolution in certain areas, supplementing the broader coverage of satellite data and allowing for a more complete investigation of UHI impacts. Examine how UHIs affect vulnerable groups, such as the impoverished, the elderly, and those with pre-existing medical issues. This might emphasize the social components of UHIs and identify specific areas that require targeted attention. Consider the economic consequences of UHIs, such as increased cooling energy costs, healthcare expenses, and potential productivity losses. Understanding these effects can help with a cost-benefit analysis of mitigating solutions. By incorporating social and economic factors, the study can provide a more comprehensive understanding of UHIs. This can inform the creation of inclusive policies that address both environmental and socioeconomic issues. By applying these recommendations, the study can provide a more thorough understanding of UHIs and contribute to the development of more effective and equitable urban planning strategies in the Philippines.

c. Using GIS and remote sensing to create green spaces that are accurate in terms of geography, improve building materials, and put cooling plans into action based on UHI assessment results will help make cities healthier and more resilient.

d. Conduct GIS-based policy implementation assessments with regard to UHI effects. This will geospatially outline the reduction in temperature, the growth of green spaces, the reduction in energy consumption, the decline in heat-related illnesses and mortality rates, the reduction of air pollutants and greenhouse gas emissions due to lower temperatures, the increased public participation and support for UHI mitigation initiatives, the successful integration of UHI mitigation strategies into urban planning, the enhancement of infrastructure resilience, and the continuous maintenance and effectiveness of UHI mitigation measures.

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