SPATIOTEMPORAL ANALYSIS OF LAND SURFACE TEMPERATURE IN THE PHILIPPINES FROM 2019 TO 2021

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ABSTRACT: Transitions brought by the COVID pandemic had significant impact in the anthropogenic activities, environment, and infrastructure projects in the Philippines. Quantifying these impacts is challenging but with the availability of satellite datasets, it is possible to investigate environmental parameters that significantly changed over the years. Land Surface Temperature (LST) plays a crucial role in understanding and monitoring the Earth's climate system, land-atmosphere interactions, and environmental changes. This study aims to assess the changes in LST in the country from 2019 to 2021 using aggregated monthly values from MODIS data. Significant clusters of hotspots and coldspots of monthly mean LST were identified using Emerging Hot Spot Analysis (EHSA). Results reveal that 67.31% of the Philippines' land surface area from 2019 to 2021 was classified as hotspots while 28.40% as coldspots. The majority of hot spot classes consisted of oscillating hotspots (57.27%), followed by oscillating coldspots (16.50%) and persistent hotspots (13.33%). Several parameters including the presence of highly urbanized areas, elevation, land cover, proximity to water bodies, and climate zones were visually examined to provide more context on the result of EHSA. The occurrence of the "Intensifying Hot Spot" phenomenon was also evident, as seen in the National Capital Region, which may be further quantitatively assessed considering high density of built-up areas. Elevation played a crucial role in determining temperature patterns, with high elevation areas, such as mountainous regions experiencing persistent coldspots, while low elevation regions showed persistent hotspots. Land cover types also influenced temperature distribution, with areas with dense vegetation exhibiting coldspots, and non-vegetated regions showing hotspots. Proximity to water bodies, such as river basins and coastal areas, contributed to the formation of coldspots. Different climate zones also showed varying hot and cold spot patterns, with dry seasons contributing to hotspots, and consistently distributed rainfall leading to coldspots. The paper also identified "New Hot Spots" in certain areas in Romblon and Palawan, necessitating further investigation to understand the underlying drivers and potential implications for the local communities. The results underscore the need for more extensive and detailed investigations into these and other influencing factors to gain a comprehensive understanding of the drivers behind hotspot patterns and develop targeted climate adaptation and mitigation strategies for the Philippines. The study highlights the significance of emerging hotspot analysis in the Philippines. The understanding of temperature patterns and their influencing factors can aid in formulating effective land management and conservation strategies and ultimately contribute to building a more resilient and sustainable future.

1. INTRODUCTION

1.1 Background

The rapid urbanization witnessed in many Southeast Asian developing countries has brought significant economic growth but also contributed to climate change (Almadrones-Reyes & Dagamac, 2022). Urban growth in major cities like the Philippines and other Southeast Asian developing countries has led to economic progress but also has significant consequences, particularly in terms of climate change, as infrastructure buildup, vegetation loss, and surface properties increase Land Surface Temperature (LST) and exacerbate urban heat islands.

Land surface temperature (LST) is the Earth's surface temperature, measured by remote sensing or ground-based sensors. It represents thermal energy emitted by the land surface, influenced by factors like solar radiation, air temperature, soil moisture, vegetation cover, and urbanization. LST is crucial for understanding climate systems, land-atmosphere interactions, and environmental changes, providing insights into surface energy balance, heat fluxes, and thermal characteristics of different land cover types. Land surface temperature (LST) serves as a significant indicator of the urban climate, providing valuable insights into the thermal characteristics of urban areas (Sathianarayanan & Dr. Hsu, 2019).

Satellite systems equipped with thermal infrared sensors, such as the Moderate Resolution Imaging Spectroradiometer (MODIS), are commonly used to measure LST on a global scale. These sensors detect thermal emissions from the Earth's surface and convert them into temperature values. Emerging Hot Spot Analysis (EHSA), an invaluable spatial analysis technique utilized in Geographic Information Systems (GIS) and remote sensing, was carried out to examine several geospatial phenomena including LST. Hot Spot Analysis is a spatial analysis technique that helps in understanding local climate conditions and tracking environmental changes. It is particularly useful in evaluating the effects of climate change and the prevalence of urban heat islands, as it helps visualize areas with consistently high or low LST values.

The COVID-19 pandemic in the Philippines, which began in early 2020 and continued into subsequent years, had a significant impact on the atmospheric environment similar to the observations in other countries. Lockdown measures and travel restrictions led to changes in human activity patterns, resulting in localized decreases in waste heat emissions and slightly lower LST in urban areas, specifically Metro Manila. Understanding the impact of urbanization on LST is crucial as it helps guide urban planning efforts, improve human health and comfort, and develop climate change adaptation strategies.

1.2 Research Objectives and Significance

This study aims to analyze the spatio-temporal monthly variations of Land Surface Temperature in the Philippines from 2019 to 2021. Specifically, it seeks to determine areas of different patterns of hot spots and cold spots, with emphasis on intensifying and new hot spots. This study further seeks to examine these hot spots and cold spots by overlaying them with explanatory variables such as Normalized Difference Built-up Index (NDBI), land cover, climate type, elevation, and proximity to water bodies using major river basins boundaries.

The study period focuses before and during the highest surge of COVID-19 pandemic in the Philippines that led to transitions that have significantly affected the entire country's status and activities. The identification of different hot spots and cold spots along with how the aforementioned explanatory variables relate to them will help the concerned administrations in focusing which areas contribute more to the rapid temperature changes given their spatial context. This spatio-temporal analysis will be essential to the crafting of targeted strategies, actions, and policies for climate challenges specifically in periods of pandemic or events with great changes in the anthropogenic and entire activities of the county.

2. REVIEW OF RELATED LITERATURE

2.1 Land Surface Temperature during COVID-19 Pandemic

Land surface temperature in Europe and North America decreased the aerosol and land surface temperature by 1–2°C during the course of COVID-19 pandemic (Parida et.al, 2021). There was a large decrease in LST during nighttime, mostly found in urban areas, yet a large increase in LST during daytime was also found in Europe. Although this study further noted changes in LST might be temporary, this has still significance for environmental studies and policies. These observations were also consistent in other countries of which restrictions due to COVID-19 were imposed. Decrease in LST was observed during lockdown periods in Ho Chi Minh City, reaching up to reduction of 1°C to 1.8 °C, and an intensifying LST before and after these periods (Veettil & Van, 2023). However, only those in non-impervious surfaces had a significant decrease in LST.

2.2 Land Surface Temperature and its Predictors

Rapid urbanization has expanded the UHI effect, necessitating innovative solutions and recognizing the importance of understanding, adapting to, and mitigating climate change's complexities for the sustainability and vitality of our urban landscapes. A study on the spatial distribution and driving factors of the Urban Heat Island effect in Fuzhou Central Area, China was conducted using remote sensing technology to analyze temperature variations over large areas, highlighting the importance of understanding spatial variations and factors affecting Land Surface Temperature to effectively address and alleviate the UHI effect (You et al., 2021). The study found hotspots in industrial zones, sub-hotspots in densely populated residential and commercial areas, and cold spots in urban green spaces and bodies of water. Urban functions significantly impact Land Surface Temperature (LST), and stratification analysis reveals the connection between urban development and Urban Heat Island (UHI) phenomenon.

Urban environments present multifaceted challenges rooted in the intricate interplay of dynamic and thermal attributes within the built landscape. The Urban Heat Island (UHI) effect, caused by human activity, transportation, and buildings, can significantly increase temperatures. Thermal remote sensing data is more commonly used for land surface temperature retrieval due to its high spatial density, derived from air radiances from thermal infrared sensors (Mathew et al., 2016). Maithani et al. (2020) study investigates the impact of COVID-19 lockdown on Dehradun city's land surface temperature (LST) patterns. The study found that hot spots were primarily in the city core, while cold spots were concentrated in the southern and northern parts. The northern parts remained cooler due to open spaces and less crowded buildings, while the core became hotter due to tall buildings and less greenery. These results were also found in the Guangdong-Hong Kong-Macao greater bay area during 2000 to 2020, where emerging hot spot analysis observed the study area's center to have distributed intensifying hot spots, persistent hot spots, and sporadic hot spots (Deng et al., 2023). These intensifying hot spots were found at connections of cities where there is high urbanization.

Spatial-temporal trends of land surface temperature in the Dhaka Metropolitan Area using Landsat images, in consideration with its Normalized Difference Vegetation Index (NDVI), were analyzed to identify hotspot zones for immediate examination between these locations (Begum et al., 2021). Increased vegetation activity can help mitigate climate change effects in metropolitan areas by keeping hot, humid air out. Hot spot zones are found in developed areas with lower vegetation coverage than growing and developing areas. As developed areas are more susceptible to climate change, hotspot regions must adopt adaptation strategies or enhance vegetation to mitigate LST increases. Subsequently, another study was conducted to analyze the predictors behind the temperature in Florence, Tuscany. There was 11.5% and 6.5% hot spot and cold spot observed with mean LST variation of 10 °C (Guerri et al., 2021). Tree cover, NDVI, and mean spatial albedo were observed as the most significant parameters for 99%-significance cool spots, and NDVI, mean population density, mean spatial albedo, and sky view factor were determined as most significant parameters of 99%-significance hot spots.

2. METHODOLOGY

2.1 Data Sets and Instrumentation

Primary spatial data for this study is LST from MODIS data obtained from 2019 to 2021 with a spatial coverage of the entire Philippines. The acquired satellite images have a spatial resolution of 1x1 km after they are reprojected to WGS84 UTM Zone 51N – a projected reference system suited for the study area. These satellite images were then clipped only to the land areas of the Philippines. Due to gaps in the acquired daily satellite images, a monthly spatiotemporal analysis was done to have a better analysis for the entire study area and period. Hence, the daily data was aggregated to the monthly mean LST per cell. A mosaic raster dataset was created for building the multidimensional raster layer to be used for the Emerging Hot Spot Analysis (EHSA).

To give more context to the results of EHSA, it was visually compared to their Normalized Difference Built-up Index (NDBI) using Sentinel-2 NIR and SWIR satellite images, 2020 land cover, climate type, elevation derived from Interferometric Synthetic Aperture Radar (IFSAR) Digital Elevation Model (DEM), from National Mapping and Resource Information Authority (NAMRIA), and proximity to water bodies using major basins boundaries from Department of Environment and Natural Resources (DENR).

2.2 Emerging Hot Spot Analysis (EHSA)

Hot Spot analysis is a method used to describe the spatial properties of location-dependent measures, identifying data or measurement clusters surrounded by high or low values. It determines if these clusters are statistically significant or follow a random distribution pattern. Moran's I and Getis-Ord Gi* statistics, along with other global and regional variables, are used to establish patterns. Getis-Ord Gi* identifies statistically significant groupings of high values (hotspots) or low values (coldspots), while Moran's I detects geographical anomalies (Recto et al., 2023).

To assess the clustering of data both in space and time, a space-time cube through a multidimensional raster layer was created and analyzed using ArcGIS Pro, representing space horizontally and time vertically (Figure 1). This space-time cube was used for performing EHSA with a time step of 1 month, fixed distance as concept of spatial relationship, default neighborhood distance, and missing values filled using their temporal trend. From the archipelagic nature of the Philippines, the default neighborhood distance computed by the tool was 34178.215423 m. The EHSA employed an individual time step as its global window for the analysis. Individual time step analyzes each neighborhood only in comparison to other bins in the same time step, a more appropriate global window in understanding how monthly mean LST varies individually in the study period.

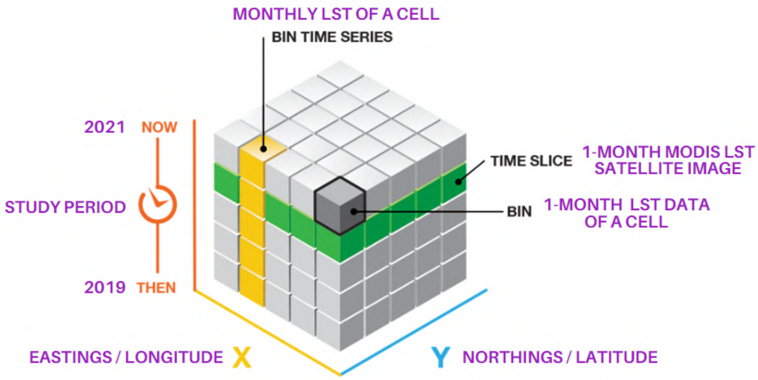

Figure 1. Elements of a space-time cube © ESRI ArcGIS Pro 3.1 Image Copyright 2015

In this analysis, Getis-Ord Gi* was utilized with False Discovery Rate (FDR) correction to assess the degree of spatial clustering and was further analyzed through the Man-Kendall statistic for the trend in their temporal aspect. After the EHSA, each bin has a computed z-score and p-value from the aforementioned statistics, where their pattern type is based from. There are 17 pattern types that could be present after the analysis: no pattern detected, new hot spot, consecutive hot spot, intensifying hot spot, persistent hot spot, diminishing hot spot, sporadic hot spot, oscillating hot spot, historical hot spot, new cold spot, consecutive cold spot, intensifying cold spot, persistent cold spot, diminishing cold spot, sporadic cold spot, oscillating cold spot, and historical cold spot (How Emerging Hot Spot Analysis works—ArcGIS Pro | Documentation, 2015). New hot spots are statistically significant hot spots only for the final time step. Consecutive hot spots are single uninterrupted runs of at least two statistically significant hot spot bins in the final time-step intervals and less than 90 percent of all bins are statistically significant hot spots. Intensifying hot spots are statistically significant hot spots for 90 percent of the time-step intervals and increasing statistically significant in the overall intensity of clustering of high counts. Persistent hot spots are statistically significant hot spots for 90 percent of the time-step intervals with no discernible trend in the intensity of clustering over time. Diminishing hot spots are statistically significant hot spots for 90 percent of the time-step intervals and decreasing statistically significant in the overall intensity of clustering of high counts. Sporadic hot spots are statistically significant hot spots for the final time-step interval with a history of also being an on-again and off-again hot spot. Oscillating hot spots are statistically significant hot spots for the final time-step interval that have a history of also being a statistically significant cold spot during a prior time step. Historical hot spots result when the most recent time period is not hot, but at least 90 percent of the time-step intervals have been statistically significant hot spots. These criteria apply vice versa for the cold spots pattern detected, and in cases which none of these are met, no pattern detected will be the resulting pattern type.

3. RESULTS AND DISCUSSION

3.1 Emerging Hot Spot Analysis (EHSA)

From 2019 to 2021, the distribution of hot and cold spots exhibited diverse patterns across the country (Table 1). The majority of the analyzed areas in the Philippines were classified as hot spots, covering approximately 67.31% of the total land surface area. In contrast, cold spots accounted for around 28.40% of the total area. Additionally, approximately 4.28% of the total area did not exhibit any distinct pattern of hot or cold spots.

Table 1. Hot Spot and Cold Spot area coverage in the Philippines

Classification	Area (ha)	Percentage (%)
Total Hot Spot	18,823,838.97	67.31
Total Cold Spot	7,943,237.98	28.40
No Pattern Detected	1,197,851.13	4.28
Total	27,964,928.08	100

Table 2 presents the total area coverage and percentage distribution of emerging hot spot classes in the Philippines from 2019 to 2022. The majority of the hot spot classes consist of oscillating hot spots, accounting for 52.27% of the total land surface area, followed by oscillating cold spots (16.50%) and persistent hot spots (13.33%). Persistent cold spots cover 9.91% of the total area. Additionally, a small percentage of the land surface area is classified as having no distinct pattern detected (4.28%), diminishing cold spots (1.55%), diminishing hot spots (0.75%), intensifying hot spots (0.74%), historical cold spots (0.32%), new hot spots (0.13%), intensifying cold spots (0.11%), sporadic hot spots

(0.08%), and sporadic cold spots (0.01%). Understanding the distribution of these emerging hot spot classes can provide valuable insights for climate adaptation and land management strategies in the Philippines

Table 2. Total area coverage of emerging hot spot classes.

Pattern Type	Hotspot Area (ha)	Hotspot %	Coldspot Area (ha)	Coldspot %
Oscillating	14,616,394.93	52.27	4,615,572.57	16.50
Persistent	3,728,798.91	13.33	2,771,028.93	9.91
Diminishing	211,030.75	0.75	432,893.87	1.55
Intensifying	207,415.40	0.74	31,330.76	0.11
Historical	-	-	90,409.63	0.32
New	36,498.11	0.13	-	-
Sporadic	23,700.86	0.08	2,002.23	0.01
No patterns detected*	1,197,851.13 ha	4.28%		
Total	27,964,928.08 ha	100%		

The absence of patterns detected indicates that it is neither a hotspot or coldspot area.

3.1.1 Mean Land Surface Temperature (LST)

The average land surface temperature in the Philippines varied between 20.2°C and 38.7°C from 2019 to 2021 (Figure 2). The National Capital Region (NCR) experienced an intensifying hot spot pattern with temperatures ranging from 33.4°C to 38.7°C. Similarly, in Nueva Ecija, there was a clustering of the same hot spot pattern, with temperatures between 30.0°C and 33.4°C, which was consistent with the majority of persistent hot spots observed. Conversely, most of the persistent cold spots exhibited a mean land surface temperature between 20.2°C and 25.2°C.

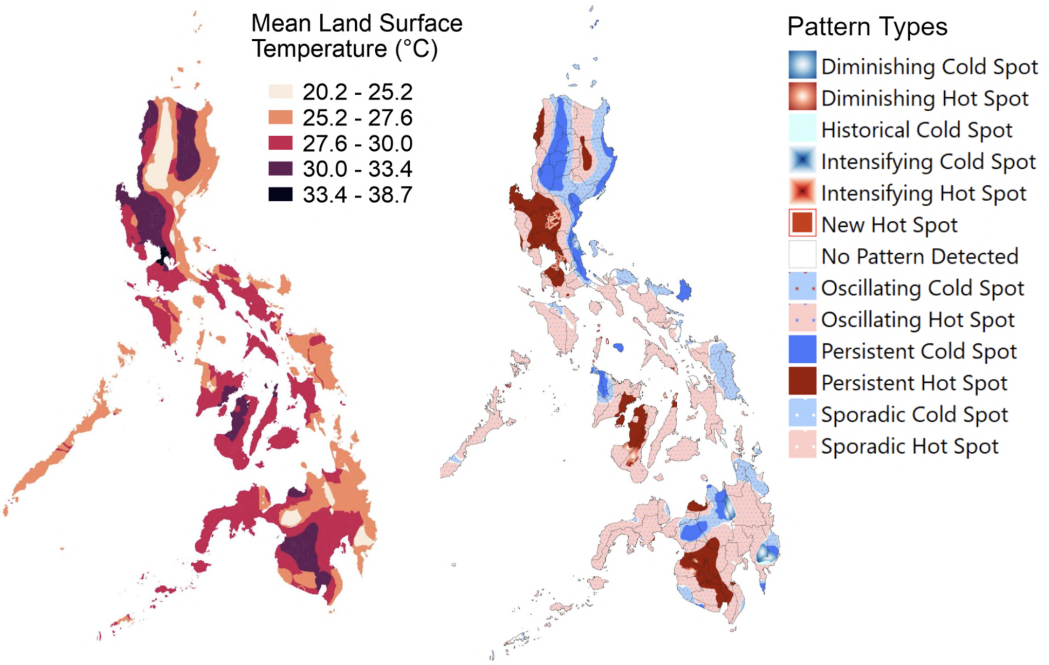

Figure 2. Mean land surface temperature from 2019-2021 (left) and Emerging Hot Spot Analysis Result (right).

3.1.2 Emergence of New Hot Spots

New Hot Spots emerged in certain areas in the Philippines such as in Romblon and Palawan (Figure 3). The identification of new hot spots signifies a noteworthy shift in land surface temperature patterns. This may be a result of the reopening of tourism in these areas and can be examined in future work. Further investigation is needed to ascertain the drivers behind this emergence and assess its potential implications for the local environment and communities.

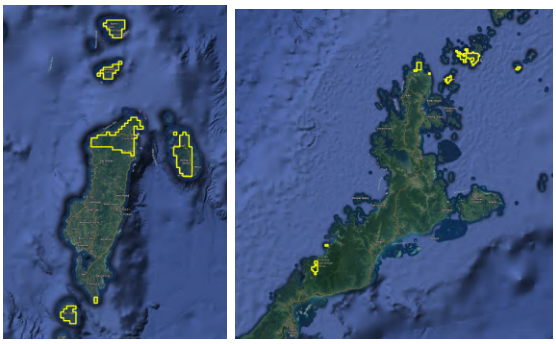

Figure 3. New hot spots found in Romblon (left) and upper area of Palawan (right).

3.2 Parameters that Influence Temperature Patterns

3.2.1 Intensifying Hot Spot In NCR And NDBI

One of the most critical findings of our study was the identification of "Intensifying Hot Spot" covering 207,415.40 hectares (Figure 4). Intensifying hotspots demands immediate attention due to the escalating land surface temperatures and potential environmental stress it indicates, posing heightened risks for local communities. This intensification was predominantly observed in urban areas, with a notable concentration in the National Capital Region (NCR). The phenomenon can be linked to the dominant land cover of built-up areas in the region.

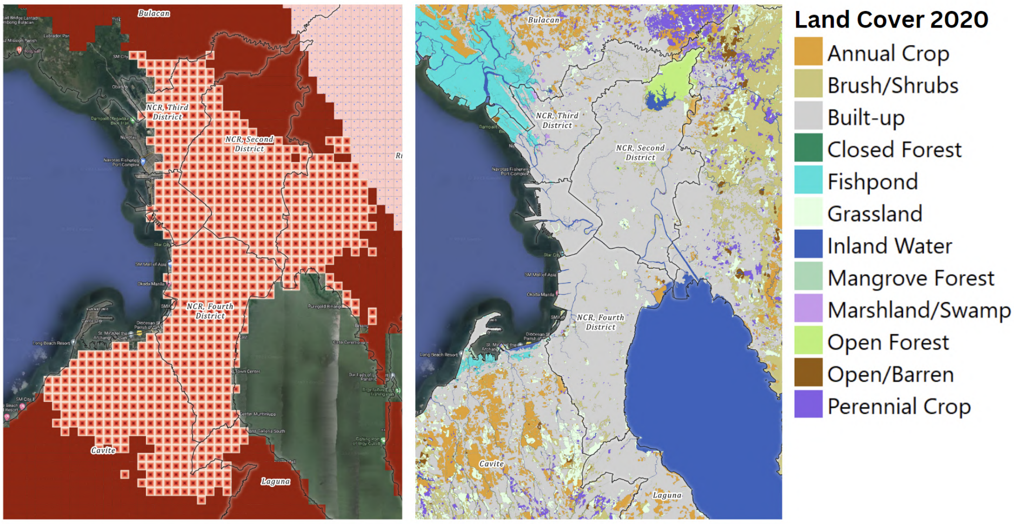

Figure 4. Intensifying hotspot in NCR (left) in comparison with the 2020 land cover for NCR (right).

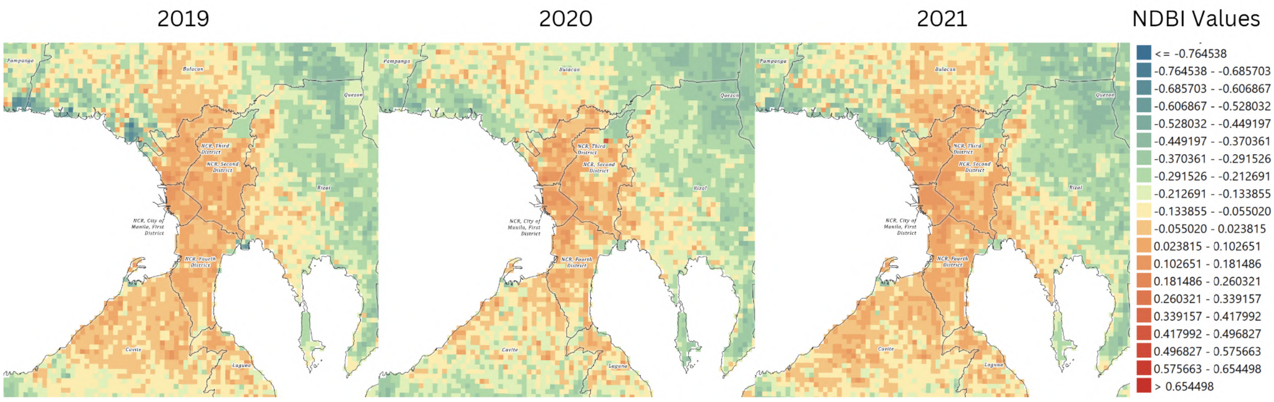

Figure 5. Consistent built-up areas.

By utilizing the Normalized Difference Built-up Index (NDBI), calculated as (SWIR - NIR) / (SWIR + NIR), a consistent trend in 2019, 2020, and 2021 was observed indicating that these years all exhibited a high percentage of built-up areas (Figure 5). The intensification of the hot spot observed during the study period is likely the result of a combination of increased human activities and the relaxation of movement restrictions (ECQ). To better understand this phenomenon, additional research should be conducted.

3.2.2 Elevation

A notable pattern of mostly persistent cold spots in high elevation areas (244 meters and above) and persistent hot spots in low elevation regions (below 244 meters) across the Philippines was observed (Figure 6). This phenomenon can be attributed to the influence of elevation on temperature variations. In high elevation areas, such as mountainous regions and elevated plateaus, temperatures tend to be lower due to the decrease in atmospheric pressure and the subsequent adiabatic cooling of air as it rises. These conditions create a favorable environment for the persistence of cold spots throughout the study period. In contrast, persistent hot spots in low elevation regions can be explained by various factors. One significant contributor is the heat-retaining capacity of low-lying areas, where warm air tends to accumulate and get trapped, leading to higher temperatures. Additionally, lowland regions often experience less wind movement and reduced cloud cover, which further exacerbates heat retention. Further studies on the effect of elevation and its correlation with hot spot patterns is highly recommended.

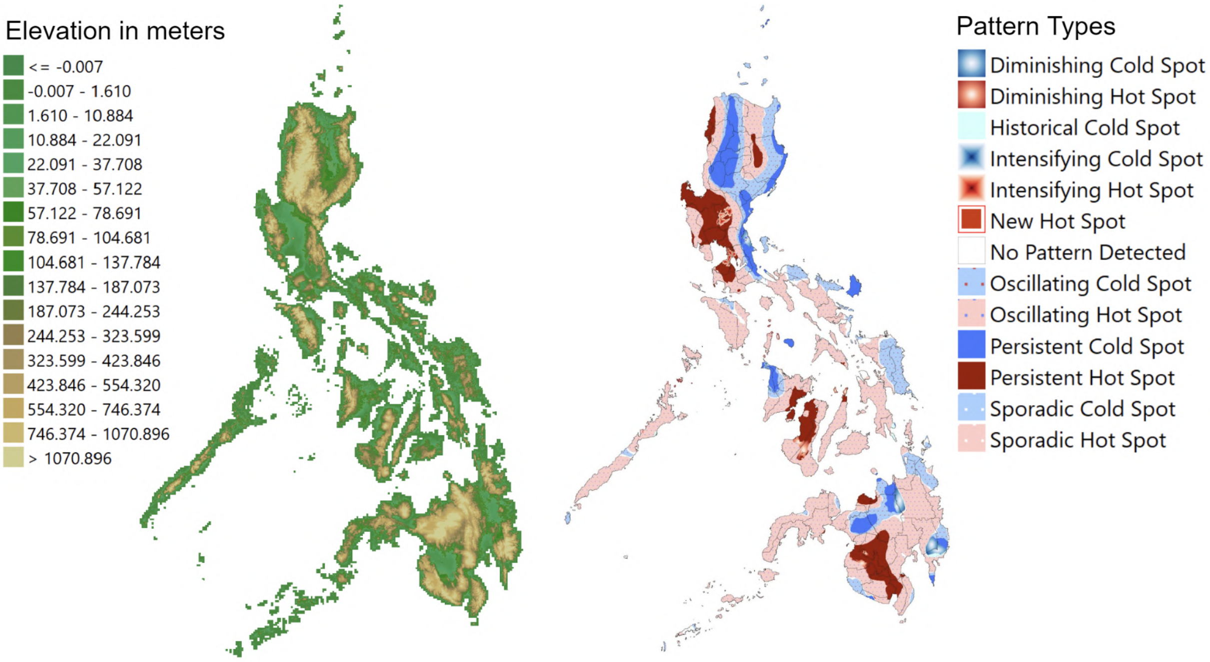

Figure 6. Comparison of elevation (left) with the clustering result (right).

3.2.3 Land Cover

Areas characterized by lush vegetation and thick canopy, such as most forests and mangroves, predominantly exhibited a significant occurrence of persistent and oscillating cold spots (Figure 7). The presence of dense vegetation and a well-developed canopy in these areas contributes to a cooling effect on the land surface, as vegetation provides shade and evaporative cooling. This leads to the formation of cold spots. Specifically, persistent cold spots were observed more frequently in or near areas with closed canopy forests. Closed canopy forests have a continuous cover of foliage, allowing for greater shade and temperature regulation. On the other hand, built-up areas, open or barren lands, brush or shrubs, grasslands, and other areas without significant vegetation were found to be usually hotspots. These regions are more susceptible to heat absorption and retention due to the lack of vegetation's cooling effect allowing land surface temperatures to rise, leading to the formation of hotspots.

Understanding the relationship between land cover types and the distribution of hot and cold spots is vital for comprehending regional climate dynamics and guiding land management and conservation efforts. The observed pattern of cold spots in areas with lush vegetation highlights the importance of preserving and restoring forested landscapes to enhance climate resilience and mitigate the impacts of rising land surface temperatures. Likewise, addressing the factors contributing to hotspots in non-vegetated areas is crucial for implementing targeted measures to alleviate heat stress and enhance the overall sustainability of the affected regions.

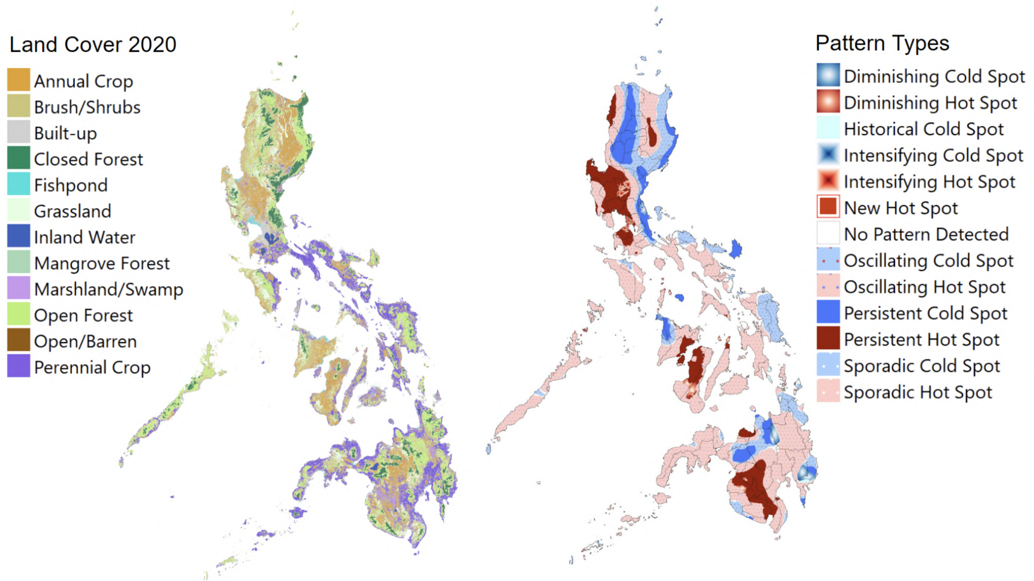

Figure 7. Comparison of 2020 land cover with the clustering result.

3.2.4 Proximity to Water Bodies

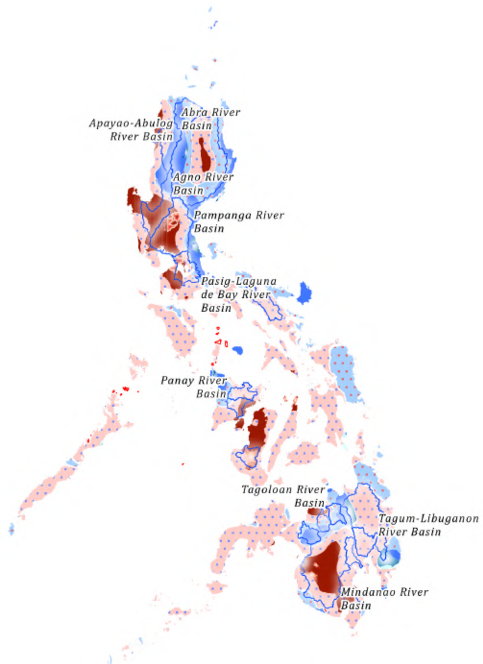

Figure 8. Eight major river basins overlaid on the clustering result.

Areas near bodies of water like major river basins and those adjacent to the Pacific Ocean are observed to be usually cold spots, with predominantly oscillating or persistent patterns (Figure 8). The proximity to large water bodies, such as the Pacific Ocean, can influence temperature variations in these regions. Water bodies have a moderating effect on temperatures, leading to milder and more stable climate conditions compared to inland areas. As a result, these areas experience relatively cooler land surface temperatures, particularly during specific seasons or periods.

3.2.5 Climate Zones

The Philippines is divided into four distinct climate zones, each with its own unique weather patterns (Figure 9). Climate Type I experiences a distinct dry period from November to April, followed by a wet season for the remainder of the year. In Climate Type II, rainfall is evenly distributed throughout the year, with the least amount of rain falling either from December to February or from March to May. Climate Type III regions have a shorter dry season, lasting only one to three months, either from December to February or from March to May. Meanwhile, Climate Type IV sees consistent, evenly distributed rainfall throughout the year (PAGASA, 2014).

In regions with Climate Type I, hot spots are prevalent due to their distinct dry seasons, which often display persistent and oscillating patterns. Climate Type II areas, conversely, tend to feature cold spots, primarily in the form of persistent and oscillating cold spots. This occurrence is likely a consequence of the consistent low rainfall leading to cooler land temperatures. Climate Type III regions exhibit a mixed pattern of both hot and cold spots, driven by a shorter dry season and localized climatic conditions. Lastly, in Climate Type IV regions, hot spots are dominant, primarily attributed to the consistent rainfall that retains heat in the land surface.

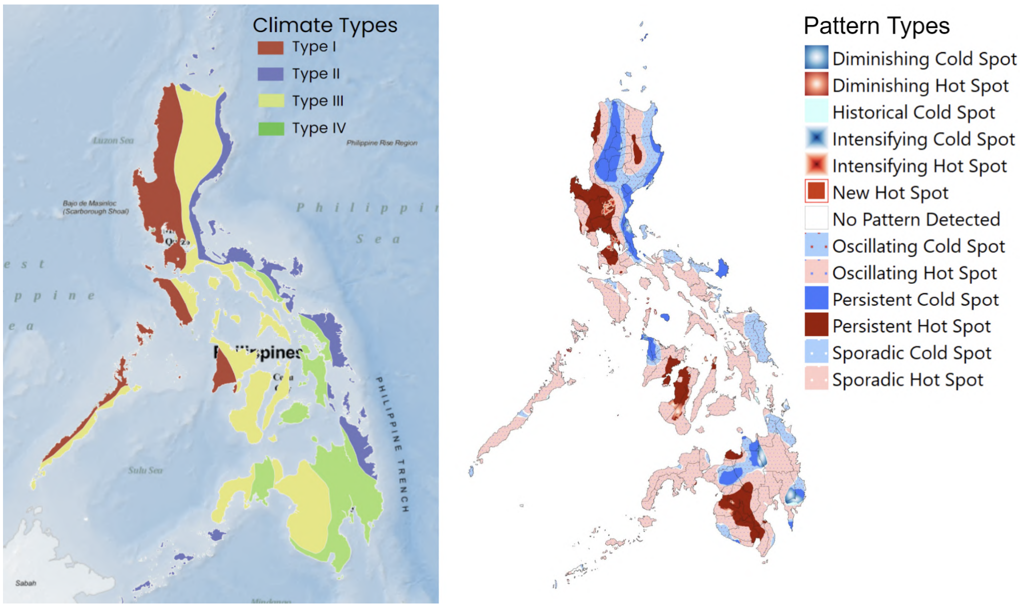

Figure 9. Comparison of the Philippine climate types with the clustering result © PAGASA Image Copyright 2014

4. CONCLUSION AND RECOMMENDATIONS

In light of the findings from this study, it is highly recommended to further investigate the factors mentioned, as well as additional aspects that can influence local temperature variations. Weather patterns, including prevailing wind direction, monsoons, and weather systems like El Niño or La Niña, should be analyzed in conjunction with temperature data to understand their impact on land surface temperatures. Albedo, which refers to the reflectivity of the Earth's surface, should also be considered, as different surfaces reflect and absorb solar radiation differently, affecting local temperatures. Areas with low albedo, such as dark surfaces, may experience higher temperatures. Additionally, topography, beyond elevation, should be explored, including aspects like aspect (the direction the slope faces) and slope angle, as they can influence temperature patterns. Human activities, such as deforestation, land use changes, and industrial emissions, can significantly impact local temperatures, and data on human activities should be analyzed in relation to hot spot locations. Furthermore, incorporating the normalized difference vegetation index (NDVI) or other vegetation indices can provide insights into the amount of green vegetation in an area, which influences local temperature through the cooling effect of evapotranspiration. A negative correlation between NDVI and land surface temperature may indicate areas with higher vegetation cooling. By examining these factors comprehensively, a more understanding of the drivers behind the observed hot spot patterns can be gained and targeted climate adaptation and mitigation strategies for the Philippines can be developed.

Land Surface Temperature (LST) emerging hot spot analysis can be invaluable in the Philippines, as it identifies regions with rapid temperature changes, allowing for targeted climate adaptation and mitigation strategies, efficient resource allocation, and early detection of temperature anomalies, ultimately fostering a more resilient response to climate challenges. As the Philippines grapples with the intensifying consequences of climate change, including the inexorable rise in temperatures, understanding which regions are experiencing rapid temperature changes becomes paramount. This granular knowledge empowers policymakers, environmental agencies, and local governments to tailor their strategies to address climate challenges. Through LST emerging hot spot analysis, efficient resource allocation—often a problem in poor countries—can also be considerably improved. The government can make the most of scarce resources while strengthening the resilience of affected communities by wisely allocating financial investments and relief efforts to regions dealing with extreme heat events or emerging temperature anomalies that may portend future droughts, water shortages, or heat-induced health crises. These perceptions are essential for understanding local climate conditions. Utilizing Hot Spot Analysis for LST analysis makes it easier to keep track of environmental changes and identify areas with unusual temperature variations. When considering the effects of climate change and the presence of urban heat islands, this becomes increasingly pertinent.

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