Spatiotemporal Patterns of COVID-19 Cases in Quezon City, Philippines

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ABSTRACT

Various studies have been undertaken to explore the spatial characteristics of the COVID-19 pandemic. However, only a few have considered the pandemic's temporal characteristics to assess space-time dynamics. This study focuses on COVID-19 spatiotemporal patterns in Quezon City, Philippines from November 2020 to October 2021. Spatial clustering and spatiotemporal patterns were analyzed based on a space-time cube (STC). Results showed that hot spots and cold spots were found in the city's northern and southern parts, respectively. Also, a significant increasing pattern was revealed throughout the study period. Moreover, STC analysis demonstrated that intensifying hot spots or locations that were statistically significant hot spots for 90% of the study period and the intensity of clustering of high counts of COVID-19 cases is significantly increasing overall, was primarily concentrated in the center and northern regions of Quezon City, where the majority of the barangays in Districts 2, 5, and 6 are located. Barangays identified with this pattern were Bagong Silangan, Batasan Hills, Commonwealth, Holy Spirit, Payatas, Matandang Balara, Pasong Putik Proper, Fairview, Pasong Tamo, and Sauyo. As there is a possible resurgence in COVID-19 cases, identifying spatiotemporal trends and clustering patterns is vital for regulating and controlling COVID-19's spread. Thus, the study's findings and methods can be utilized to predict and manage epidemics and help decision-makers control existing and future outbreaks.

Keywords: spatial clustering, spatiotemporal analysis, space-time cube, coronavirus

I. INTRODUCTION

The World Health Organization (WHO) has proclaimed a new public health crisis with the emergence of coronavirus or COVID-19 in March 2020 (WHO, 2020). According to Liu, et al. (2020), COVID-19 has now been identified as the fifth recorded pandemic since the onset of the 1918 influenza pandemic, as well as the first known coronavirus outbreak in history. It was first identified in Wuhan, China in December 2019. Globally, there have been 246,472,724 confirmed cases of COVID-19 with 5,012,227 fatalities reported to WHO as of November 2, 2021.

In the Philippines, the first confirmed case was on January 30, 2020 (Endrada, et al., 2020). Due to the country's weak healthcare infrastructure, the Philippines experienced one of the worst outbreaks in the world in July 2020. Among Southeast Asian countries, it ranked second in terms of COVID-19 cases and fatalities (De Vero, et al., 2021). As of November 4, 2021, the Department of Health (DOH) has already recorded a total of 2,793,898 cases which includes 2,712,298 recoveries and 43,586 deaths in the country. Out of these reported cases, the region and city with the most cases of COVID-19 are the National Capital Region (NCR),

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and Quezon City, respectively (DOH, 2021[a]). Despite strict social distancing measures and vaccination programs, COVID-19 continues to spread in the country. This highlights the need for further exploration of the coronavirus.

According to Giuliani, et al. (2020), there are three risk factors contributing to the spread of COVID-19. These include disease transmission within a province, disease transmission across neighboring provinces, and the evolution of the disease over time. It was found that provinces that are adjacent to one another and are currently affected by severe contagions have a high prevalence of disease when spatial proximity is considered. This may indicate that COVID-19 possesses spatial and temporal properties. In line with this, Müller and Louwsma (2021) indicated that an infectious disease like COVID-19 spreads at varying rates across space and time and can result in local outbreaks, and such diseases necessitate new insights. Spatiotemporal analysis can assist in gaining such new insights. Thus, this study investigated the COVID-19 spatiotemporal patterns in the country. Specifically, Quezon City was the chosen area of interest for the study since it is the largest and most populous city in the NCR which also has the highest number of COVID-19 cases as of December 10, 2021 (DOH, 2021[a]).

The findings in this study will be useful in implementing targeted intervention strategies based on the heterogeneity of the COVID-19 patterns and the optimal allocation of limited resources in Quezon City. It can also assist government officials and decision-makers in developing law enforcement strategies that are effective at preventing the spread of the virus at the right time and in the right place. To future researchers, this can serve as a basis for studying COVID-19 spatiotemporal patterns in other areas in the Philippines. Likewise, this can also serve as a foundation for investigating spatiotemporal patterns of various illnesses that may also emerge in the city. Moreover, results can also reveal barangays that need government attention when such diseases spread in the city because they can also be at greater risk.

II. METHODOLOGY

Data Source

The data on COVID-19 cases and the predictors of the clustering patterns used in the study were requested from the Quezon City Government, while the population size and the average household size of Quezon City barangays were obtained from the 2020 Census of Population from the Philippine Statistics Authority (PSA). For the mapping, the vector map of Quezon City was acquired from PSA while the geographic coordinates were collected from Google Maps.

Data Analyses

In describing how quickly COVID-19 occurs in a population, the COVID-19 incidence rates (per 10,000) per barangay. Incidence rates were computed to allow easier comparison of the number of COVID-19 cases across barangays having different populations.

Preliminary exploratory spatial data analysis was used to investigate the spatial distribution of COVID-19 cases and incidence in Quezon city. According to Anselin (1998), ESDA is a collection of techniques for describing spatial distributions, identifying spatial outliers, analyzing spatial autocorrelation, and analyzing spatial clusters. To show the progression of COVID-19 cases and incidence among barangays in Quezon city, data visualizations such as line charts and heatmaps were created using Microsoft Excel.

Additionally, thematic maps were produced using GeoDa to easily observe the spatiotemporal pattern of COVID-19 intensity.

In testing the spatial autocorrelation among barangays in Quezon City, global spatial autocorrelation was used. It measures how the COVID-19 case in a barangay is similar to other barangays surrounding it. It ranges from -1 to +1, wherein a positive spatial autocorrelation means nearby barangays tend to have similar values (high-high location or hot spot or low-low location or cold spot) of cases; while a negative spatial autocorrelation implies that barangays have dissimilar values (high-low location or low-high location) of cases. The study utilized two spatial weights, the Queen contiguity weight, and the Distance-based weight, that express the degree of spatial proximity between pairs of locations. To identify the optimal spatial weight, Global Moran's I was computed as:

$$I = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}\left(y_i - \bar{y}\right)\left(y_j - \bar{y}\right)}{\frac{1}{N}\sum_{i=1}^{N}\left(y_i - \bar{y}\right)^2 \sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}} \tag{1}$$

where N is the number of barangays, w_{ij} is the spatial weight between barangay i and barangay j, and y_i is the COVID-19 cases in the i^{th} barangay. The spatial weight that resulted in the highest significant value of Moran's I was chosen as the better weight, which was also used in this study.

After identifying significant spatial clusters of COVID-19 cases among the barangays in Quezon City, the Local Moran's Index of Spatial Autocorrelation (LISA) was considered to identify specific clusters and their type of clustering. Specifically, high-high spatial clusters, low-low spatial clusters, low-high spatial outliers, high-low spatial outliers, and not significant spatial clusters were identified in the spatial maps that were generated using GeoDa. In essence, high-high clusters are groups that have high risks and are surrounded by areas that also have high risks. The local Moran's I was computed as:

$$I_i = \sum_{j=1}^{N} w_{ij}^{std}\left(\frac{y_i - \bar{y}}{\sigma_y}\right)\left(\frac{y_j - \bar{y}}{\sigma_y}\right) \tag{2}$$

where σ_y is the standard deviation of the COVID-19 cases in Quezon city, w_{ij}^{std} is the row standardized spatial weights matrix for the i^{th} and j^{th} barangay, and y_i is the COVID-19 cases in the i^{th} barangay.

Local spatial clustering was also determined using the Local Getis and Ord Statistics (Gi*). However, in contrast to LISA, Gi* detects high-risk clusters (hot spots) and low-risk clusters (cold spots). The computed Getis-Ord Gi* statistics were also used in emerging hot spot analysis (EHSA) to incorporate the temporal dimension of data (ESRI, 2020). It is the ratio of the number of observations within a given range to the total count of points which is given below:

$$G_i^* = \frac{\sum_j w_{ij} x_j}{\sum_i x_j} \tag{3}$$

A Gi* statistic having a positive standard z-value indicates a hot spot (high-high clusters), while a Gi* statistic having a negative standard z-value tells a cold spot (low-low clusters). Using GeoDa, significance maps and cluster maps were generated to visualize the clusters based on the calculated index and p-values.

In this study, to show how COVID-19 cases change over time in each barangay in Quezon City, a space-time cube (STC), a three-dimensional (3-D) cube that aggregates spatiotemporal data into bins, was constructed using ArcGIS Pro. Each bin is identified by a unique location ID and contains summary statistics for the specified attribute (i.e., COVID-19 weekly cases). These bins were used to create a new data structure called Network Common Data Form which has two dimensions: space (x and y) and time (t) as shown in Figure 1. Bins that are in the same (x, y) region, share the same column and location ID, generating a bin time series. On the other hand, bins with identical t regions share a common time slice that represents the values of locations at time t.

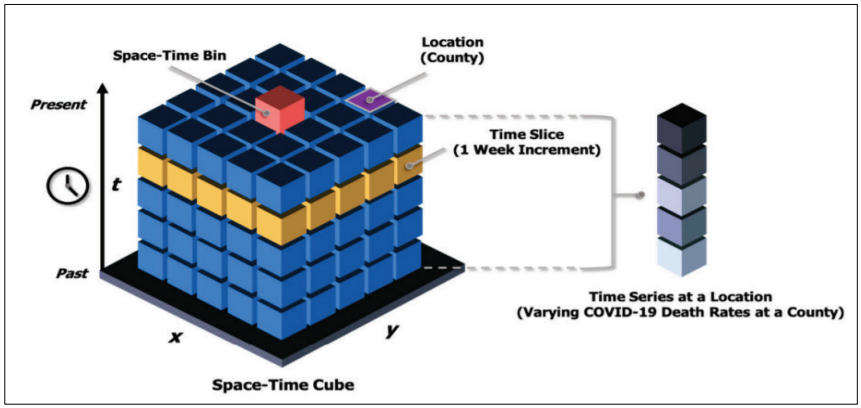

Figure 1. Structure of a Space-time cube as explained by Park, et al. (2021)

To further investigate data clustering and outliers, a local outlier analysis, an implementation of *Local Moran's I* statistics in space and time dimensions, was conducted using ArcGIS Pro. It distinguishes statistically significant locations between a certain barangay and its neighborhood by using neighborhood distance and time step neighborhood parameters to estimate *Local Moran's I* statistics for each bin. The output consisted of six types of patterns: only high-high cluster, only high-low outlier, only low-high outlier, only low-low cluster, multiple types, and never significant, and it can be visualized on a two-dimensional plane, as shown in Figure 2 (ESRI, n.d.).

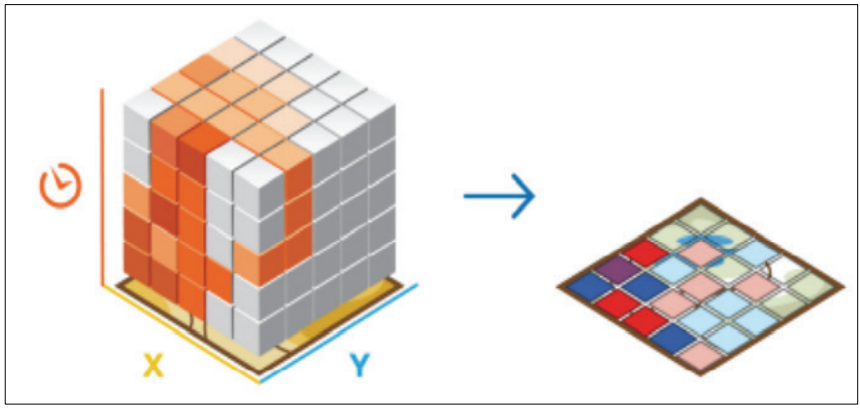

Figure 2. Space-time cube shrunk into 2D cluster map (*https//pro.arcgis.com*).

An emerging hot spot analysis (EHSA) was also performed to determine the patterns or trends of COVID-19 hot spots on the created STC. It conceptualizes the spatial relationships based on the calculated Getis-Ord Gi* statistics. After the completion of EHSA, each bin in the STC output will have the corresponding *z*-score, p-value, and hot spot classification. Using the Mann-Kendall trend test, the hot and cold spot trends were evaluated, and with the hot spot *z*-score and p-value for each bin, EHSA shrunk the STC into a 2D visualized hot spot trend map which is shown in Figure 3 (ESRI, n.d.). Moreover, the Mann-Kendall trend test was considered to determine if the weekly COVID-19 cases are either consistently increasing or decreasing.

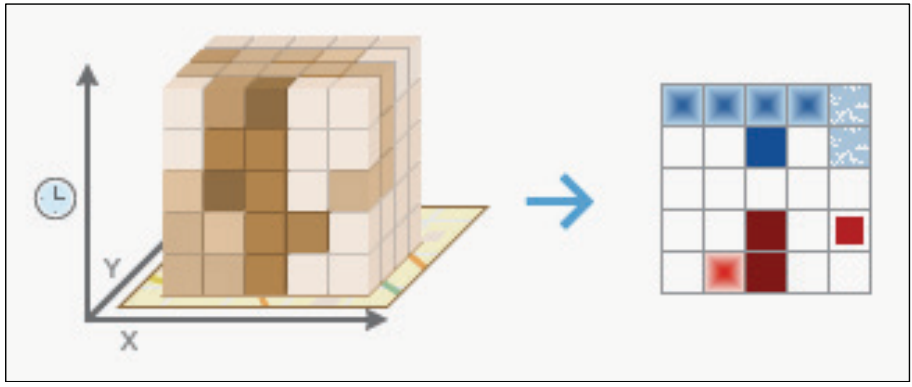

Figure 3. Space-time cube shrunk into a 2D cluster map (*https//pro.arcgis.com*).

The EHSA tool categorized the barangays into the patterns shown in Table 1, which was provided by ESRI.

Table 1. Patterns and definition of patterns from emerging hot spot analysis.

Pattern	Pattern Name	Definition
	No Pattern Detected	Does not fall into any of the hot or cold spot patterns defined below.
	New Hot Spot	A location that is a statistically significant hot spot for the final time step and has never been a statistically significant hot spot before.
	Consecutive Hot Spot	A location with a single uninterrupted run of statistically significant hot spot bins in the final time-step intervals. The location has never been a statistically significant hot spot prior to the final hot spot run and less than 90% of all bins are statistically significant hot spots.
	Intensifying Hot Spot	A location that has been a statistically significant hot spot for 90% of the time-step intervals, including the final time step. In addition, the intensity of clustering of high counts in each time step is increasing overall and that increase is statistically significant.
	Persistent Hot Spot	A location that has been a statistically significant hot spot for 90% of the time-step intervals with no discernible trend indicating an increase or decrease in the intensity of clustering over time.
	Diminishing Hot Spot	A location that has been a statistically significant hot spot for 90% of the time-step intervals, including the final time step. In addition, the intensity of clustering in each time step is decreasing overall and that decrease is statistically significant.
	Sporadic Hot Spot	A location that is an on-again then off-again hot spot. Less than 90% of the time-step intervals have been statistically significant hot spots and none of the time-step intervals have been statistically significant cold spots.
	Oscillating Hot Spot	A statistically significant hot spot for the final time-step interval that has a history of also being a statistically significant cold spot during a prior time step. Less than 90% of the time-step intervals have been statistically significant hot spots.
	Historical Hot Spot	The most recent period is not hot, but at least 90% of the time-step intervals have been statistically significant hot spots.
	New Cold Spot	A location that is a statistically significant cold spot for the final time step and has never been a statistically significant cold spot before.
	Consecutive Cold Spot	A location with a single uninterrupted run of statistically significant cold spot bins in the final time-step intervals. The location has never been a statistically significant cold spot prior to the final cold spot run and less than 90% of all bins are statistically significant cold spots.
	Intensifying Cold Spot	A location that has been a statistically significant cold spot for 90% of the time-step intervals, including the final time step. In addition, the intensity of clustering of low counts in each time step is increasing overall and that increase is statistically significant.
	Persistent Cold Spot	A location that has been a statistically significant cold spot for 90% of the time-step intervals with no discernible trend, indicating an increase or decrease in the intensity of clustering of counts over time.
	Diminishing Cold Spot	A location that has been a statistically significant cold spot for 90% of the time-step intervals, including the final time step. In addition, the intensity of clustering of low counts in each time step is decreasing overall and that decrease is statistically significant.
	Sporadic Cold Spot	A location that is an on-again then off-again cold spot. Less than 90% of the time-step intervals have been statistically significant cold spots and none of the time-step intervals have been statistically significant hot spots.
	Oscillating Cold Spot	A statistically significant cold spot for the final time-step interval that has a history of also being a statistically significant hot spot during a prior time step. Less than 90% of the time-step intervals have been statistically significant cold spots.
	Historical Cold Spot	The most recent period is not cold, but at least 90% of the time-step intervals have been statistically significant cold spots.

III. Results and Discussion

Exploratory Spatial Data Analysis

Figure 4 presents the growth of the total COVID-19 cases from November 2020 to October 2021 in Quezon City. The graph shows that the growth of COVID-19 cases was initially slow until the end of February 2021. At the start of the Early Vaccination Period or March 2021, there was a rapid increase in the growth of the number of cases, with 8,855 new cases in the last week of March. Haseltine (2021) stated that in January 2021, the Philippines had reported 1,500 per day, but during March 2021, the rate became 10,000 cases per day. He mentioned that this resurgence coincides with the discovery of a new Philippine variant, B.1.1.28.3, which originated from the Brazilian B.1.1.28 strain. The same trend can be observed from July 2021 to October 2021, wherein cases started to increase again in September 2021. According to DOH (2021), this upsurge in the daily reported cases, including hundreds of daily fatalities, was due to the Delta variant. This variant is twice as transmissible as the original virus. The highest number of cases in the study period was recorded during the Delta Variant Spread Period, specifically in the first week of September 2021, with 10,432 new cases. After the B.1.1.28.3 and Delta variants were identified in the country, the outbreak spread rapidly across Quezon City within two months, from March 2021 to April 2021 and from August 2021 to September 2021, but also decreased after these periods.

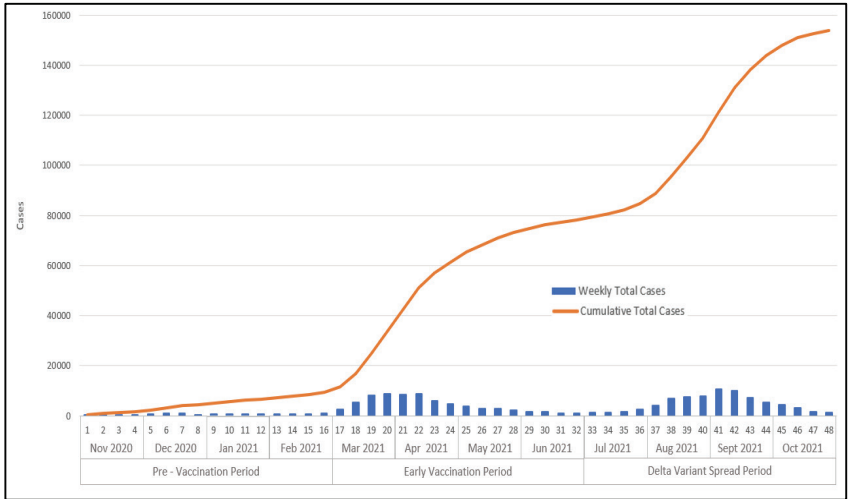

Figure 4. The trend of COVID-19 cases in Quezon City, Philippines from Nov 1, 2020, to Oct 31, 2021.

A heat map was also constructed to further visualize the growth of COVID-19 cases and incidence in the 142 barangays in Quezon City from November 1, 2020 to October 31, 2021. The colors from green to yellow, and then to red indicate an increase in the intensity of the values, namely the COVID-19 cases and the cumulative cases. Figure 5 shows that high cases of COVID-19 happened from March 2021 to April 2021 and August 2021 to September 2021. Moreover, the highest number of cases were recorded in District 2 and District 6. Specifically, it is observed that Brgy. Batasan Hills in District 2 had the highest number of cases with a total of 546 cases in a week that occurred on the 1st week of September 2021.

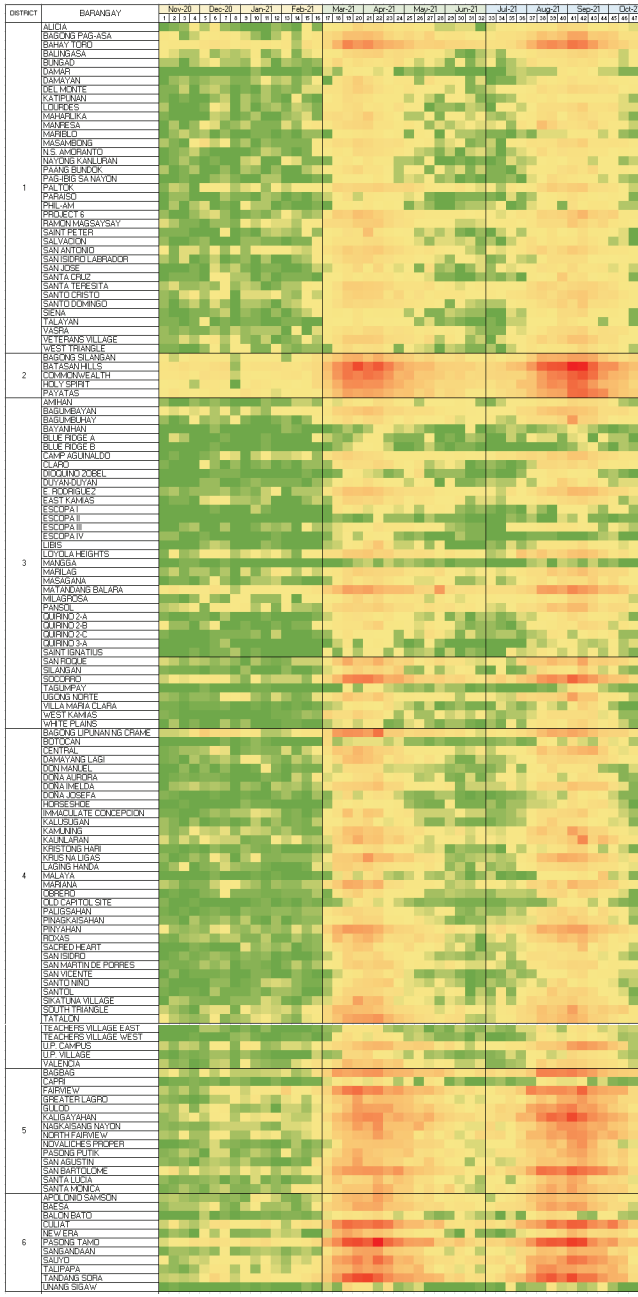

Figure 5. Heat map of COVID-19 daily cases in Barangays of Quezon City.

The map of Quezon City, which is divided into six legislative districts, is shown in Figure 6. This map will be useful in identifying and visualizing where each district is located.

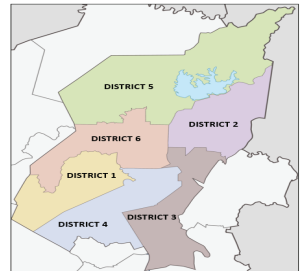

Figure 6. Quezon City District Map.

Figures 7A and 7B show the cumulative number of COVID-19 cases and the cumulative incidence per 10,000 in each barangay in Quezon City, Philippines. As shown in Figure 7A, most of the cases, particularly from July to October 2021, lie in the middle part of Quezon City or in Districts 2 and 5 starting from Barangay Commonwealth and spreading to adjacent barangays. On the other hand, Figure 7B shows that a large number of cases per 10,000 residents started in the southern part of Quezon City, specifically in UP Campus in District 4, wherein it continued to spread downwards the city. Furthermore, it can be seen that COVID-19 incidence in barangays located in the Southern part of Quezon City or in Districts 1, 3 and 4, such as UP Campus, Project 6, Camp Aguinaldo, Socorro, and South Triangle, worsen rapidly. Alternatively, barangays located in the Northern part increased at a slower rate.

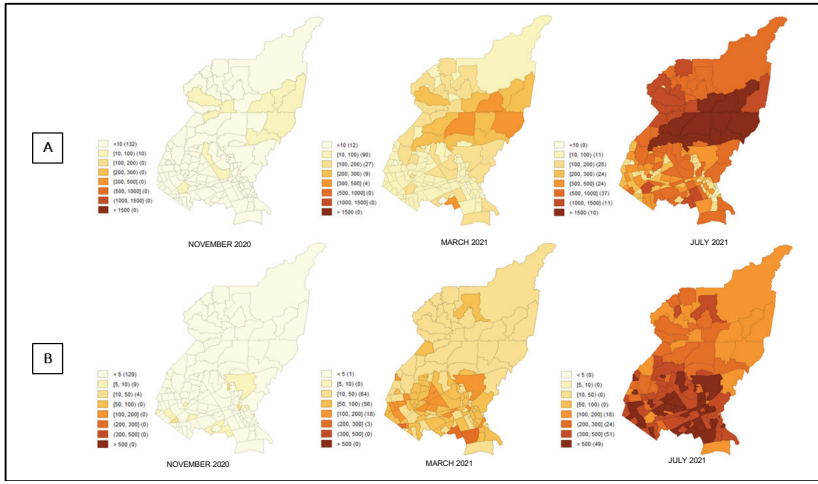

Figure 7. Thematic maps showing the movement of COVID-19 cases (A) and incidence per 10,000 (B) in Quezon City in Week 1, Week 17, and Week 33.

Spatial Analysis of COVID-19 Cases

For the spatial analysis of COVID-19 cases, the cumulative cases for the three-time points namely, November 2020 (Week 1), March 2021 (Week 17), and July 2021 (Week 33), the first

weeks of the three-time periods, were also used to have at least one time point for each period: (1) from November 2020 to February 2021 as the pre-vaccination period, (2) from March 2021 to June 2021 as the early vaccination period, and (3) from July 2021 to October 2021 as the start of the Delta variant spread period. The results of the Global Moran's I statistics are shown in Figure 8.

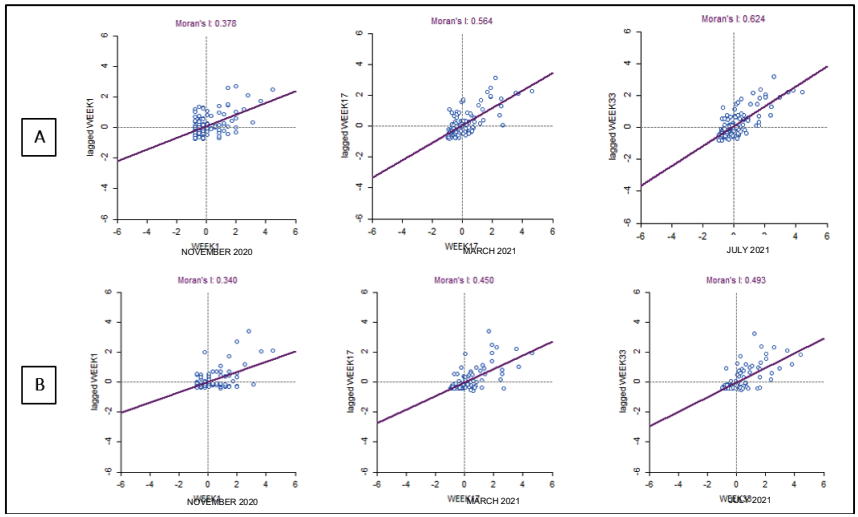

Figure 8. Global Moran's I scatterplot of COVID-19 cases in Quezon City on selected time points using Queen Contiguity Weight Matrix (A) and Distance Weight Matrix (B).

To further summarize the results of the Global Moran's I, Table 2 is provided. Since the Queen Contiguity revealed a higher significant Moran's I, it was then selected for spatial weight. Based on the analysis, all the time points had a positive spatial autocorrelation implying that neighboring barangays with high risks of COVID-19 have a tendency to be close to other areas with similarly high COVID-19 risks. In addition, it can also be observed that the results of Moran's I for both weights increase over time. This demonstrates that the areas surrounding a hot spot are prone to becoming a hot spot at some point.

Table 2. Global Moran's I result of COVID-19 cases in Quezon City on the selected time points.

Spatial Weight		**Nov 2020 (Week 1)**	**March 2021 (Week 17)**	**July 2021 (Week 33)**
Queen	Moran's I	**0.378**	**0.564**	**0.624**
	P-value	0.0010	0.0010	0.0010
Distance	Moran's I	0.340	0.450	0.493
	P-value	0.0010	0.0010	0.0010

Figure 9 shows the resulting significance maps and cluster maps of COVID-19 cases. Based on Figure 9B, hot spots of COVID-19 can be found at the center and northern part of Quezon City or in Districts 2 and 5, specifically Pasong Putik Proper, Commonwealth, and Holy Spirit. Meanwhile, some cold spots can be found in the southern part of Quezon City, such as Brgy. St. Ignatius, spreading around adjacent barangays.

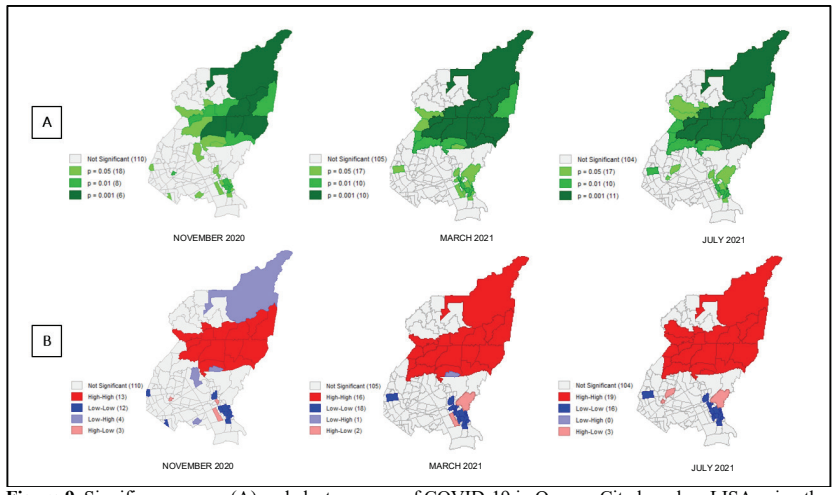

Figure 9. Significance maps (A) and clusters maps of COVID-19 in Quezon City based on LISA using the Queen Contiguity weight matrix.

As shown in Table 3, at week 33, 19 barangays had high-high clusters, 19 barangays had high-high clusters, 16 had low-low clusters, and three (3) had high-low clusters. The significant high-high spatial clusters indicate that these locations have high risks and are surrounded by other high-prevalence areas. These clusters were mostly found in Districts 2, 5, and 6, which are the most populated districts in Quezon City according to the 2020 Census of Population and Housing. In contrast, District 3 had mostly low-low clusters, wherein Brgy. Matandang Balara, which is located beside Districts 2 and 6, was the only barangay in District 3 with a high-high cluster. This aligns with the findings of a study by Oster et al. (2022) that smaller population sizes are less likely to be identified as hot spots. Additionally, it is notable that hot spots and cold spots in Quezon City may change over time, for example, Brgy. Pasong Putik in District 5 had a low-high cluster in week 1, but for the succeeding time points, it became a high-high cluster or a hot spot. Similarly, Brgy. New Era in District 6 had a low-high cluster for week 1 and week 17, but it became a high-high cluster for week 33.

Table 3. Results of LISA (using Queen Contiguity weight matrix) of COVID-19 cases in Quezon City, Philippines.

DISTRICT	BARANGAY	Nov 2020 (Week 1)		Mar 2021 (Week 17)		July 2021 (Week 33)	
		Index	P-value	Index	P-value	Index	P-value
1	ALICIA	-0.543	0.113	-0.344	0.084	-0.321	0.122
	BAGONG PAG-ASA	0.919	0.172	0.229	0.184	0.106	0.269
	BAHAY TORO	0.707	0.075	1.735	0.008	1.803	0.002
	BALINGASA	-0.321	0.186	-0.035	0.243	0.069	0.143
	BUNGAD	0.013	0.237	-0.012	0.381	0.036	0.479
	DAMAR	0.176	0.417	0.204	0.407	0.403	0.225
	DAMAYAN	0.133	0.357	0.128	0.294	0.173	0.134
	DEL MONTE	0.062	0.417	0.049	0.393	0.108	0.259
	KATIPUNAN	-0.360	0.065	-0.346	0.097	-0.345	0.122
	LOURDES	0.003	0.386	0.113	0.211	0.154	0.254
	MAHARLIKA	0.253	0.104	0.153	0.123	0.227	0.052
	MANRESA	0.296	0.096	0.010	0.048	0.216	0.008
	MARIBLO	-0.626	0.008	-0.138	0.065	-0.138	0.031
	MASAMBONG	-0.011	0.299	-0.029	0.313	0.109	0.186
	N.S. AMORANTO	0.284	0.279	0.295	0.098	0.314	0.081
	NAYONG KANLURAN	0.464	0.136	0.161	0.354	0.321	0.213

DISTRICT	BARANGAY	Nov 2020 (Week 1)		Mar 2021 (Week 17)		July 2021 (Week 33)	
		Index	P-value	Index	P-value	Index	P-value
	PAANG BUNDOK	-0.026	0.217	0.312	0.228	0.344	0.212
	PAG-IBIG SA NAYON	0.284	0.290	0.290	0.243	0.413	0.122
	PALTOK	0.201	0.093	-0.055	0.108	-0.018	0.020
	PARAISO	0.263	0.255	0.143	0.396	0.195	0.336
	PHIL-AM	-0.299	0.204	-0.054	0.369	0.077	0.484
	PROJECT 6	-0.274	0.014	-0.236	0.063	0.056	0.081
	RAMON MAGSAYSAY	-0.003	0.453	0.068	0.228	-0.020	0.262
	SAINT PETER	0.197	0.220	0.148	0.252	0.249	0.096
	SALVACION	0.051	0.347	0.235	0.129	0.276	0.089
	SAN ANTONIO	-0.159	0.343	-0.049	0.451	-0.013	0.397
	SAN ISIDRO LABRADOR	-0.002	0.474	0.163	0.296	0.142	0.266
	SAN JOSE	0.554	0.032	0.294	0.197	0.329	0.103
	SANTA CRUZ	0.000	0.476	0.076	0.359	0.144	0.258
	SANTA TERESITA	-0.011	0.342	0.106	0.105	0.026	0.064
	SANTO DOMINGO	0.020	0.447	0.120	0.162	0.135	0.119
	SIENNA	0.197	0.202	0.143	0.304	0.339	0.128
	STO. CRISTO	-0.119	0.094	0.023	0.168	-0.008	0.299
	TALAYAN	0.166	0.189	0.162	0.267	0.308	0.109
	VASRA	-0.047	0.255	-0.194	0.098	-0.182	0.108
	VETERANS VILLAGE	-0.037	0.312	0.000	0.426	0.005	0.369
	WEST TRIANGLE	-0.182	0.147	-0.003	0.446	0.080	0.384
2	BAGONG SILANGAN	5.868	0.006	3.612	0.005	2.586	0.007
	BATASAN HILLS	11.145	0.001	10.396	0.001	9.722	0.001
	COMMONWEALTH	6.249	0.001	7.612	0.001	7.722	0.001
	HOLY SPIRIT	3.728	0.001	6.929	0.001	8.072	0.001
	PAYATAS	5.332	0.001	4.690	0.001	4.065	0.001
3	AMIHAN	0.135	0.171	0.222	0.309	0.212	0.326
	BAGUMBAYAN	-0.260	0.295	-0.228	0.233	-0.138	0.178
	BAGUMBUHAY	0.150	0.014	0.310	0.002	0.293	0.003
	BAYANIHAN	0.300	0.148	0.419	0.066	0.437	0.058
	BLUE RIDGE A	0.572	0.005	0.556	0.002	0.695	0.002
	BLUE RIDGE B	0.608	0.033	0.735	0.013	0.725	0.006
	CAMP AGUINALDO	-0.286	0.149	-0.029	0.182	-0.051	0.289
	CLARO	0.173	0.170	0.405	0.023	0.282	0.024
	DIOQUINO ZOBEL	0.032	0.436	0.470	0.163	0.321	0.304
	DUYAN-DUYAN	0.392	0.094	0.382	0.070	0.345	0.076
	E. RODRIGUEZ	-0.018	0.371	0.036	0.384	-0.006	0.500
	EAST KAMIAS	0.032	0.467	0.209	0.064	0.086	0.194
	ESCOPA I	0.608	0.028	0.691	0.020	0.609	0.014
	ESCOPA II	0.522	0.026	0.747	0.002	0.763	0.001
	ESCOPA III	0.479	0.043	0.374	0.033	0.439	0.022
	ESCOPA IV	0.176	0.099	0.699	0.027	0.739	0.019
	LIBIS	0.176	0.432	0.313	0.268	0.304	0.177
	LOYOLA HEIGHTS	0.222	0.088	-0.202	0.044	-0.089	0.023
	MANGGA	0.090	0.447	0.538	0.037	0.437	0.107
	MARILAG	0.500	0.008	0.381	0.035	0.417	0.023
	MASAGANA	0.248	0.235	0.399	0.023	0.314	0.040
	MATANDANG BALARA	3.045	0.002	3.669	0.001	3.851	0.001
	MILAGROSA	0.333	0.005	0.146	0.002	0.251	0.002
	PANSOL	0.040	0.106	0.255	0.101	0.050	0.131
	QUIRINO 2-A	0.142	0.295	0.535	0.015	0.360	0.087
	QUIRINO 2-B	-0.541	0.028	0.360	0.004	0.309	0.045
	QUIRINO 2-C	0.207	0.136	0.273	0.194	0.240	0.208
	QUIRINO 3-A	0.238	0.201	0.631	0.003	0.527	0.017
	SAN ROQUE	-0.642	0.049	-0.019	0.026	-0.103	0.111
	SILANGAN	0.020	0.455	0.219	0.179	0.057	0.412
	SOCORRO	0.105	0.359	0.174	0.296	0.167	0.355
	ST. IGNATIUS	0.423	0.046	0.416	0.040	0.512	0.015
	TAGUMPAY	0.212	0.287	0.473	0.061	0.407	0.079
	UGONG NORTE	-0.021	0.429	0.023	0.342	-0.010	0.357
	VILLA MARIA CLARA	0.079	0.458	0.334	0.211	0.286	0.265
	WEST KAMIAS	-0.049	0.264	0.025	0.493	-0.024	0.399

DISTRICT	BARANGAY	Nov 2020 (Week 1)		Mar 2021 (Week 17)		July 2021 (Week 33)	
		Index	P-value	Index	P-value	Index	P-value
	WHITE PLAINS	-0.094	0.354	-0.060	0.373	0.085	0.484
4	BAGONG LIPUNAN NG CRAME	0.187	0.297	0.103	0.372	0.143	0.338
	BOTOCAN	0.220	0.319	0.042	0.498	0.072	0.479
	CENTRAL	-0.205	0.148	-0.062	0.289	-0.008	0.353
	DAMAYANG LAGI	-0.165	0.228	0.006	0.380	0.000	0.431
	DON MANUEL	0.338	0.239	0.218	0.149	0.287	0.189
	DOÑA AURORA	0.104	0.409	0.109	0.268	0.148	0.273
	DOÑA IMELDA	-0.040	0.430	0.011	0.375	0.027	0.339
	DOÑA JOSEFA	-0.011	0.384	0.139	0.378	0.161	0.343
	HORSESHOE	-0.903	0.041	-0.943	0.059	-0.425	0.172
	IMMACULATE CONCEPCION	-0.085	0.292	0.007	0.465	-0.027	0.365
	KALUSUGAN	-0.014	0.498	0.003	0.440	-0.006	0.433
	KAMUNING	-0.035	0.425	-0.058	0.231	-0.014	0.339
	KAUNLARAN	0.073	0.411	0.086	0.240	0.003	0.423
	KRISTONG HARI	0.094	0.359	0.145	0.308	0.153	0.265
	KRUS NA LIGAS	-0.026	0.127	-0.001	0.292	-0.134	0.172
	LAGING HANDA	0.114	0.413	0.049	0.451	0.078	0.361
	MALAYA	0.068	0.491	0.213	0.375	0.063	0.492
	MARIANA	-0.043	0.296	-0.007	0.442	0.017	0.324
	OBRERO	0.284	0.192	0.161	0.253	0.135	0.297
	OLD CAPITOL SITE	0.089	0.204	0.238	0.271	0.306	0.189
	PALIGSAHAN	0.137	0.280	0.082	0.360	0.137	0.262
	PINAGKAISAHAN	0.051	0.353	0.106	0.300	0.102	0.367
	PINYAHAN	0.001	0.468	-0.087	0.327	-0.132	0.296
	ROXAS	0.015	0.471	0.038	0.214	-0.038	0.175
	SACRED HEART	-0.342	0.147	-0.062	0.323	-0.017	0.394
	SAN ISIDRO	0.464	0.146	0.256	0.225	0.269	0.141
	SAN MARTIN DE PORRES	-0.137	0.105	-0.284	0.079	-0.149	0.101
	SAN VICENTE	0.176	0.378	0.336	0.184	0.340	0.113
	SANTOL	0.253	0.331	0.158	0.463	0.117	0.459
	SIKATUNA VILLAGE	0.485	0.016	0.162	0.011	0.042	0.049
	SOUTH TRIANGLE	0.334	0.171	-0.079	0.471	-0.050	0.398
	STO. NIÑO	0.161	0.032	0.190	0.220	0.173	0.235
	TATALON	-0.695	0.127	-0.216	0.152	-0.332	0.085
	TEACHER'S VILLAGE EAST	0.306	0.214	0.231	0.251	0.204	0.304
	TEACHER'S VILLAGE WEST	0.212	0.311	0.244	0.257	0.180	0.311
	U.P. CAMPUS	-0.262	0.402	-0.047	0.430	-0.114	0.427
	U.P. VILLAGE	-0.118	0.302	0.054	0.454	0.063	0.462
	VALENCIA	0.126	0.346	-0.036	0.498	-0.011	0.430
5	BAGBAG	2.059	0.027	1.443	0.034	2.154	0.023
	CAPRI	-0.795	0.077	-0.576	0.123	-0.857	0.067
	FAIRVIEW	1.224	0.003	3.581	0.001	4.193	0.001
	GREATER LAGRO	0.010	0.292	0.430	0.079	0.398	0.067
	GULOD	0.142	0.300	0.120	0.241	0.561	0.100
	KALIGAYAHAN	-0.011	0.429	0.188	0.288	0.498	0.239
	NAGKAISANG NAYON	0.014	0.263	0.038	0.323	0.409	0.163
	NORTH FAIRVIEW	0.031	0.371	0.435	0.189	0.307	0.187
	NOVALICHES PROPER	-0.094	0.364	-0.142	0.246	0.088	0.119
	PASONG PUTIK	-0.289	0.001	0.061	0.001	0.388	0.001
	SAN AGUSTIN	-0.015	0.292	0.009	0.221	0.209	0.076
	SAN BARTOLOME	1.202	0.074	0.502	0.166	1.154	0.039
	STA. LUCIA	0.055	0.026	-0.184	0.059	0.038	0.027
	STA. MONICA	-0.006	0.463	0.090	0.275	0.213	0.094
6	APOLONIO SAMSON	0.086	0.305	0.040	0.273	0.019	0.412
	BAESA	0.014	0.243	0.395	0.077	0.484	0.062
	BALONG BATO	-0.040	0.428	-0.043	0.366	-0.094	0.342
	CULIAT	1.021	0.023	3.364	0.002	3.203	0.003
	NEW ERA	-0.676	0.028	-0.088	0.015	0.256	0.019
	PASONG TAMO	2.173	0.001	7.894	0.001	8.715	0.001
	SANGANDAAN	-0.374	0.076	0.066	0.003	0.861	0.002

DISTRICT	BARANGAY	Nov 2020 (Week 1)		Mar 2021 (Week 17)		July 2021 (Week 33)	
		Index	P-value	Index	P-value	Index	P-value
	SAUYO	1.989	0.008	2.105	0.001	3.111	0.001
	TALIPAPA	0.252	0.054	1.488	0.013	1.558	0.004
	TANDANG SORA	0.874	0.025	4.534	0.001	5.559	0.001
	UNANG SIGAW	0.356	0.112	0.348	0.108	0.380	0.067

Only Low-Low | Only Low-High | Not Significant | Only High-Low | Only High-High

Using the Queen Contiguity Matrix, significance maps and cluster maps of COVID-19 cases in Quezon City based on Getis-Ord statistics are shown in Figure 10.

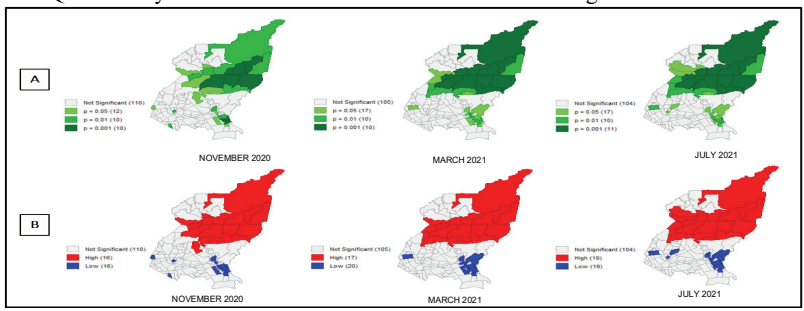

Figure 10. Significance maps (A) and clusters maps of COVID-19 in Quezon City based on Getis-Ord statistics using the Queen Contiguity weight matrix.

In Table 4, barangays that were found significantly high risk were highlighted red, while the significantly low risks were highlighted in blue. The result of Gi* was nearly identical to the result of LISA. High risks barangays were found in Districts 2, 5, and 6 while low-risk barangays were mostly in District 3, with only Brgy. Matandang Balara is high-risk in the district.

Table 4. Results of Getis-Ord (using Queen Contiguity weight matrix) of COVID-19 cases in Quezon City, Philippines.

DISTRICT	BARANGAY	Nov 2020 (Week 1)		Mar 2021 (Week 17)		July 2021 (Week 33)	
		Gi*	P-value	Gi*	P-value	Gi*	P-value
1	ALICIA	0.010	0.139	0.011	0.084	0.010	0.122
	BAGONG PAG-ASA	0.012	0.176	0.009	0.185	0.009	0.269
	BAHAY TORO	0.012	0.075	0.013	0.008	0.013	0.002
	BALINGASA	0.005	0.186	0.005	0.243	0.004	0.143
	BUNGAD	0.009	0.237	0.007	0.382	0.006	0.224
	DAMAR	0.004	0.362	0.004	0.405	0.003	0.134
	DAMAYAN	0.005	0.336	0.005	0.290	0.004	0.259
	DEL MONTE	0.006	0.403	0.006	0.392	0.005	0.122
	KATIPUNAN	0.012	0.078	0.010	0.098	0.010	0.254
	LOURDES	0.008	0.407	0.005	0.209	0.005	0.051
	MAHARLIKA	0.003	0.076	0.004	0.123	0.003	0.051
	MANRESA	0.003	0.086	0.004	0.046	0.003	0.031
	MARIBLO	0.004	0.008	0.004	0.065	0.004	0.031
	MASAMBONG	0.005	0.289	0.006	0.312	0.005	0.186
	N.S. AMORANTO	0.003	0.225	0.003	0.095	0.003	0.081
	NAYONG KANLURAN	0.001	0.078	0.004	0.353	0.003	0.213
	PAANG BUNDOK	0.004	0.217	0.003	0.224	0.003	0.209
	PAG-IBIG SA NAYON	0.003	0.233	0.004	0.240	0.003	0.122
	PALTOK	0.003	0.080	0.005	0.108	0.004	0.020
	PARAISO	0.003	0.229	0.005	0.394	0.005	0.335
	PHIL-AM	0.009	0.205	0.007	0.369	0.006	0.484
	PROJECT 6	0.016	0.019	0.011	0.064	0.011	0.081
	RAMON MAGSAYSAY	0.008	0.468	0.009	0.228	0.008	0.262

DISTRICT	BARANGAY	Nov 2020 (Week 1)		Mar 2021 (Week 17)		July 2021 (Week 33)	
		Gi*	P-value	Gi*	P-value	Gi*	P-value
	SAINT PETER	0.003	0.182	0.005	0.250	0.004	0.095
	SALVACION	0.005	0.304	0.004	0.126	0.003	0.089
	SAN ANTONIO	0.007	0.343	0.007	0.451	0.006	0.397
	SAN ISIDRO LABRADOR	0.007	0.497	0.004	0.295	0.004	0.266
	SAN JOSE	0.001	0.012	0.004	0.195	0.003	0.103
	SANTA CRUZ	0.006	0.487	0.006	0.358	0.005	0.258
	SANTA TERESITA	0.006	0.342	0.004	0.103	0.004	0.064
	SANTO DOMINGO	0.006	0.444	0.004	0.161	0.004	0.119
	SIENNA	0.003	0.169	0.005	0.302	0.003	0.127
	STO. CRISTO	0.011	0.100	0.009	0.168	0.008	0.299
	TALAYAN	0.004	0.154	0.005	0.267	0.004	0.109
	VASRA	0.008	0.283	0.010	0.098	0.010	0.108
	VETERANS VILLAGE	0.008	0.335	0.007	0.426	0.006	0.368
	WEST TRIANGLE	0.009	0.164	0.007	0.446	0.006	0.384
2	BAGONG SILANGAN	0.028	0.006	0.022	0.005	0.020	0.007
	BATASAN HILLS	0.033	0.001	0.026	0.001	0.025	0.001
	COMMONWEALTH	0.025	0.001	0.024	0.001	0.024	0.001
	HOLY SPIRIT	0.029	0.001	0.029	0.001	0.029	0.001
	PAYATAS	0.030	0.001	0.024	0.001	0.023	0.001
3	AMIHAN	0.003	0.087	0.004	0.309	0.004	0.326
	BAGUMBAYAN	0.007	0.295	0.006	0.233	0.005	0.178
	BAGUMBUHAY	0.002	0.007	0.002	0.002	0.002	0.003
	BAYANIHAN	0.003	0.119	0.003	0.065	0.003	0.058
	BLUE RIDGE A	0.000	0.001	0.002	0.002	0.001	0.002
	BLUE RIDGE B	0.000	0.001	0.001	0.013	0.001	0.006
	CAMP AGUINALDO	0.009	0.164	0.009	0.183	0.008	0.289
	CLARO	0.004	0.154	0.003	0.023	0.003	0.024
	DIOQUINO ZOBEL	0.005	0.500	0.003	0.159	0.004	0.303
	DUYAN-DUYAN	0.002	0.062	0.003	0.069	0.003	0.075
	E. RODRIGUEZ	0.008	0.393	0.006	0.379	0.007	0.500
	EAST KAMIAS	0.006	0.446	0.004	0.064	0.005	0.194
	ESCOPA I	0.000	0.001	0.001	0.019	0.002	0.014
	ESCOPA II	0.001	0.014	0.001	0.002	0.001	0.001
	ESCOPA III	0.001	0.019	0.003	0.033	0.003	0.022
	ESCOPA IV	0.002	0.001	0.001	0.025	0.001	0.018
	LIBIS	0.004	0.397	0.003	0.266	0.003	0.175
	LOYOLA HEIGHTS	0.003	0.065	0.004	0.044	0.004	0.023
	MANGGA	0.005	0.411	0.002	0.035	0.003	0.107
	MARILAG	0.001	0.003	0.003	0.035	0.003	0.023
	MASAGANA	0.004	0.196	0.003	0.023	0.003	0.040
	MATANDANG BALARA	0.019	0.003	0.021	0.001	0.021	0.001
	MILAGROSA	0.001	0.001	0.002	0.002	0.002	0.002
	PANSOL	0.013	0.106	0.012	0.101	0.011	0.131
	QUIRINO 2-A	0.004	0.271	0.002	0.014	0.003	0.087
	QUIRINO 2-B	0.004	0.028	0.002	0.004	0.003	0.045
	QUIRINO 2-C	0.003	0.104	0.004	0.192	0.004	0.207
	QUIRINO 3-A	0.004	0.192	0.002	0.002	0.003	0.017
	SAN ROQUE	0.005	0.049	0.004	0.026	0.005	0.111
	SILANGAN	0.006	0.434	0.004	0.177	0.006	0.412
	SOCORRO	0.009	0.381	0.009	0.296	0.009	0.355
	ST. IGNATIUS	0.002	0.024	0.003	0.039	0.003	0.015
	TAGUMPAY	0.004	0.243	0.003	0.059	0.003	0.079
	UGONG NORTE	0.008	0.402	0.008	0.434	0.006	0.426
	VILLA MARIA CLARA	0.005	0.401	0.003	0.210	0.004	0.265
	WEST KAMIAS	0.008	0.295	0.006	0.493	0.007	0.399
	WHITE PLAINS	0.007	0.395	0.007	0.374	0.005	0.483
4	BAGONG LIPUNAN NG CRAME	0.010	0.309	0.011	0.373	0.009	0.338
	BOTOCAN	0.004	0.271	0.006	0.497	0.006	0.479
	CENTRAL	0.010	0.150	0.006	0.289	0.006	0.353
	DAMAYANG LAGI	0.009	0.269	0.008	0.381	0.007	0.431
	DON MANUEL	0.003	0.192	0.004	0.148	0.004	0.189

DISTRICT	BARANGAY	Nov 2020 (Week 1)		Mar 2021 (Week 17)		July 2021 (Week 33)	
		Gi*	P-value	Gi*	P-value	Gi*	P-value
	DOÑA AURORA	0.005	0.364	0.005	0.263	0.005	0.272
	DOÑA IMELDA	0.006	0.443	0.006	0.375	0.006	0.339
	DOÑA JOSEFA	0.007	0.419	0.005	0.378	0.005	0.343
	HORSESHOE	0.013	0.054	0.011	0.059	0.009	0.173
	IMMACULATE CONCEPCION	0.008	0.319	0.007	0.467	0.007	0.365
	KALUSUGAN	0.007	0.495	0.007	0.440	0.006	0.433
	KAMUNING	0.007	0.399	0.005	0.231	0.006	0.338
	KAUNLARAN	0.009	0.427	0.009	0.242	0.007	0.423
	KRISTONG HARI	0.005	0.330	0.005	0.307	0.005	0.265
	KRUS NA LIGAS	0.004	0.127	0.005	0.291	0.005	0.172
	LAGING HANDA	0.005	0.361	0.006	0.451	0.005	0.360
	MALAYA	0.005	0.444	0.004	0.374	0.006	0.492
	MARIANA	0.008	0.330	0.006	0.441	0.006	0.324
	OBRERO	0.003	0.167	0.005	0.251	0.005	0.297
	OLD CAPITOL SITE	0.004	0.173	0.004	0.270	0.004	0.188
	PALIGSAHAN	0.004	0.234	0.005	0.357	0.005	0.262
	PINAGKAISAHAN	0.005	0.315	0.005	0.299	0.005	0.366
	PINYAHAN	0.009	0.472	0.006	0.327	0.006	0.296
	ROXAS	0.006	0.460	0.005	0.214	0.005	0.175
	SACRED HEART	0.009	0.176	0.007	0.324	0.007	0.394
	SAN ISIDRO	0.007	0.497	0.004	0.295	0.004	0.266
	SAN MARTIN DE PORRES	0.011	0.117	0.011	0.079	0.010	0.101
	SAN VICENTE	0.004	0.340	0.003	0.180	0.003	0.111
	SANTOL	0.003	0.221	0.004	0.460	0.005	0.458
	SIKATUNA VILLAGE	0.001	0.009	0.003	0.011	0.004	0.049
	SOUTH TRIANGLE	0.011	0.171	0.007	0.471	0.006	0.398
	STO. NIÑO	0.002	0.006	0.004	0.215	0.004	0.234
	TATALON	0.006	0.117	0.005	0.151	0.005	0.085
	TEACHER'S VILLAGE EAST	0.003	0.174	0.004	0.249	0.005	0.303
	TEACHER'S VILLAGE WEST	0.004	0.261	0.004	0.254	0.005	0.311
	U.P. CAMPUS	0.007	0.405	0.008	0.342	0.008	0.357
	U.P. VILLAGE	0.003	0.084	0.004	0.107	0.003	0.067
	VALENCIA	0.010	0.374	0.007	0.500	0.006	0.430
5	BAGBAG	0.020	0.027	0.016	0.034	0.017	0.023
	CAPRI	0.011	0.103	0.009	0.125	0.011	0.067
	FAIRVIEW	0.019	0.003	0.021	0.001	0.021	0.001
	GREATER LAGRO	0.009	0.299	0.012	0.079	0.012	0.067
	GULOD	0.010	0.322	0.009	0.243	0.012	0.100
	KALIGAYAHAN	0.006	0.429	0.010	0.290	0.012	0.239
	NAGKAISANG NAYON	0.009	0.268	0.008	0.325	0.011	0.163
	NORTH FAIRVIEW	0.010	0.371	0.012	0.189	0.011	0.187
	NOVALICHES PROPER	0.007	0.373	0.008	0.246	0.011	0.119
	PASONG PUTIK	0.017	0.002	0.017	0.001	0.017	0.001
	SAN AGUSTIN	0.005	0.292	0.009	0.221	0.012	0.076
	SAN BARTOLOME	0.014	0.077	0.011	0.167	0.013	0.039
	STA. LUCIA	0.015	0.030	0.012	0.060	0.014	0.027
	STA. MONICA	0.007	0.478	0.009	0.275	0.011	0.094
6	APOLONIO SAMSON	0.009	0.307	0.008	0.273	0.008	0.412
	BAESA	0.009	0.248	0.012	0.077	0.012	0.062
	BALONG BATO	0.006	0.450	0.006	0.367	0.007	0.343
	CULIAT	0.015	0.028	0.018	0.002	0.017	0.003
	NEW ERA	0.015	0.030	0.015	0.015	0.015	0.019
	PASONG TAMO	0.021	0.001	0.024	0.001	0.024	0.001
	SANGANDAAN	0.012	0.092	0.017	0.003	0.018	0.002
	SAUYO	0.017	0.008	0.019	0.001	0.020	0.001
	TALIPAPA	0.013	0.060	0.015	0.013	0.017	0.004
	TANDANG SORA	0.016	0.029	0.021	0.001	0.022	0.001
	UNANG SIGAW	0.008	0.311	0.005	0.459	0.005	0.462

Spatiotemporal Analysis of COVID-19 Cases

Using the weekly COVID-19 cases, a total of 142 spatial locations were generated in the space-time cube of COVID-19, with a time step interval of one week (48 weeks in total). Figure 11 shows the space-time cube on a three-dimensional map. After the model was established, the nonparametric Mann-Kendall analysis resulted in a positive test statistic of $Z = 4.3996$ with a p-value = <0.0001, which indicates an increasing trend in the overall COVID-19 cases in Quezon City for the study period. The figure also shows the value of COVID-19 cases of a bin with its corresponding color intensity, which was divided by the method of natural breakpoint.

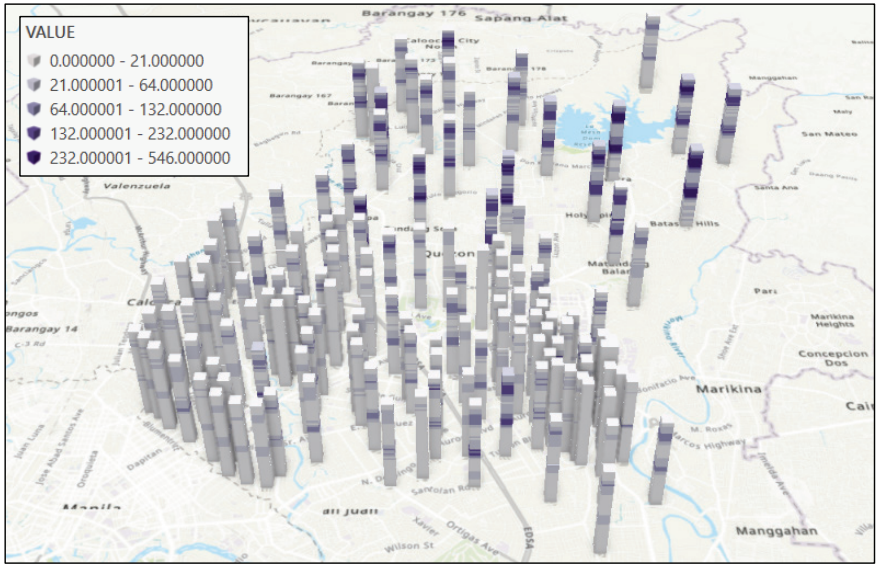

Figure 11. Space-time cube of COVID-19 weekly COVID-19 cases in Quezon City, Philippines from November 2020 to October 2021

It can be observed in the constructed STC that a high number of weekly COVID-19 cases recorded were mostly in the northern part of the city, particularly the barangays in Districts 2, 5, and 6. Some of these barangays were Batasan Hills, Commonwealth, Pasong Tamo, Tandang Sora, Holy Spirit, Culiat, Bahay Toro, Payatas, Fairview, and Kaligayahan. Moreover, the STC shows that the weekly cases were high on the same weeks, which were approximately from Week 17 to Week 24, and from Week 37 to Week 44. On the other hand, most barangays in the southern part which are Districts 1, 3, and 4 had weekly cases that only ranged from 0 to 132 cases.

A Local Outlier Analysis (LOA) was conducted using the STC. The results of the analysis are presented in Table 5 and Figure 12.

Table 5. Results of Local Outlier Analysis

District	Barangay
1	Santo Cristo
2	Payatas
3	Socorro
4	Bagong Lipunan ng Crame
5	Bagbag Kaligayahan Nagkaisang Nayon Novaliches Proper San Bartolome
6	Tandang Sora Pasong Tamo Culiat

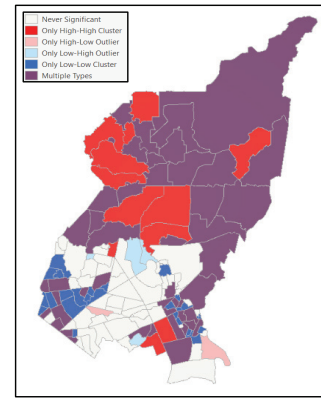

Figure 12. Local Outlier Analysis result.

As a result of the Mann-Kendall trend test, the majority of the barangays had multiple clustering. This type of pattern, which was mostly seen in Districts 2, 5, and 6, is a grouping where multiple types of statistically significant clusters and outliers had been present throughout the period. This is followed by 28 barangays which only had a low-low clustering pattern. A total of 12 barangays had only a high-high clustering pattern which is shown in Table 6. Most barangays with only high-high clustering were found in District 5, which is followed by District 6. Only four barangays had only low-high outliers throughout the study period, and these were from District 1 (Katipunan, Vasra, Project 6), and District 4 (Horseshoe). These barangays had a low value of COVID-19 cases but are surrounded primarily by barangays with high COVID-19 cases, but they should be monitored since they can be a hot spot. Lastly, Bagumabayan from District 3 and Roxas from District 4 were the only high-low outliers throughout the study period.

Table 6. Barangays with only High-high Clustering based on the results of Local Outlier Analysis

Patterns	Number of Locations	Percentage
Never Significant	50	35.21%
Only High-High Cluster	12	8.25%
Only Low-High Outlier	4	2.82%
Only Low-Low Cluster	28	19.72%
Only High-Low Outlier	2	1.41%
Multiple Types	46	32.29%
TOTAL	142	100%

The LOA indicates that hot spots consistently reside in the northern and central parts of Quezon City. Other locations had shown multiple types of clustering which can be hot spots at a certain time then the cases decreased turning to cold spots or vice versa which be seen in Figure 13. These locations still contain the possibility of developing single clustering patterns, thus, it is recommended to determine the prominent type of clustering by performing an emerging hot spot analysis.

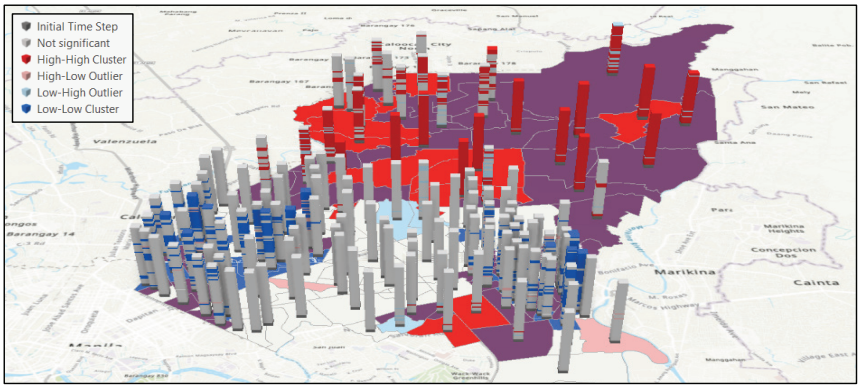

Figure 13. Local outlier output with Space-Time Cube

In determining the prominent type of clustering of a barangay, Emerging Hot Spot Analysis (EHSA) was performed and results are presented in Table 7 and Figure 14. Based on EHSA, ten intensifying hot spots, three persistent hot spots, four sporadic hot spots, and one historical hot spot were found. Table 8 shows the patterns detected and the corresponding barangays on each pattern.

Table 7. Emerging Hot Spot Output

Patterns	HOT	COLD
New	0	0
Consecutive	0	0
Intensifying	10	0
Persistent	3	0
Diminishing	0	0
Sporadic	4	0
Oscillating	0	0
Historical	1	0

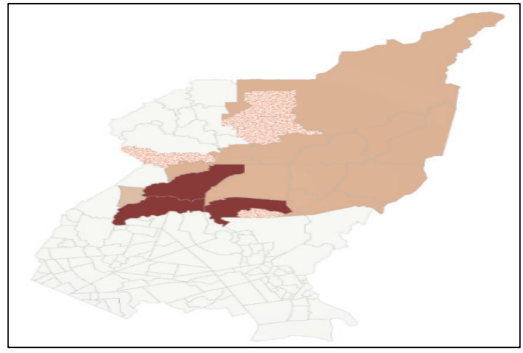

Figure 14. EHSA results,

Table 8. Barangays and Patterns detected based on EHSA

Pattern	Pattern Name	Barangays	Population
	Intensifying Hot Spot	**District 2**	
		Bagong Silangan,	106,886
		Batasan Hills,	166,572
		Commonwealth,	213,229
		Holy Spirit,	111,901
		Payatas	139740
		District 3	
		Matandang Balara	69,475
		District 5	
		Pasong Putik Proper	39,896
		Fairview	61,813
		District 6	
		Pasong Tamo	11,738
		Sauyo	76,289
	Persistent Hot Spot	**District 1**	
		Bahay Toro	59,639
		District 6	
		Culiat	67,804
		Tandang Sora	83,114
	Sporadic Hot Spot	**District 5**	
		Bagbag,	64,653
		Greater Lagro	23,569
		North Fairview	44,408
		District 6	
		New Era	14,105
	Historical Hot Spot	**District 4**	
		Roxas	10,670

Significant hot spots detected were mostly concentrated in Districts 2, 5, and 6. As explained by Tan et.al (2020), the closer a location to a hot spot, the greater the risk of infection, which can explain in part the influence of District 2 on its surrounding areas. Intensifying hot spots were mostly observed in District 2, while the only barangay in District 3 with this pattern was Matandang Balara. These barangays were found statistically significant hot spots for 90% of the time-step intervals and the intensity of clustering of high counts in each time step was increasing overall. On the other hand, persistent hot spots were identified in Districts 1 and 6. This means that Barangay Bahay Toro, Culiat, and Tandang Sora were statistically significant hot spots for 90% of the time-step intervals with no discernible trend in the intensity of clustering over time. Moreover, Sporadic hot spots were also found in Bagbag, Greater Lagro, North Fairview, and New Era. These barangays are on-again and then off-again hot spots wherein less than 90% of the time-step intervals have been statistically significant hot spots and none of the time-step intervals were statistically significant cold spots. Lastly, Historical Hot Spot was observed in Barangay Roxas wherein the most recent period in this barangay was not hot, but at least 90% of the time-step intervals had been statistically significant hot spots. These patterns can also be verified in Figure 15, which shows the hot spot and cold spot bins in different periods.

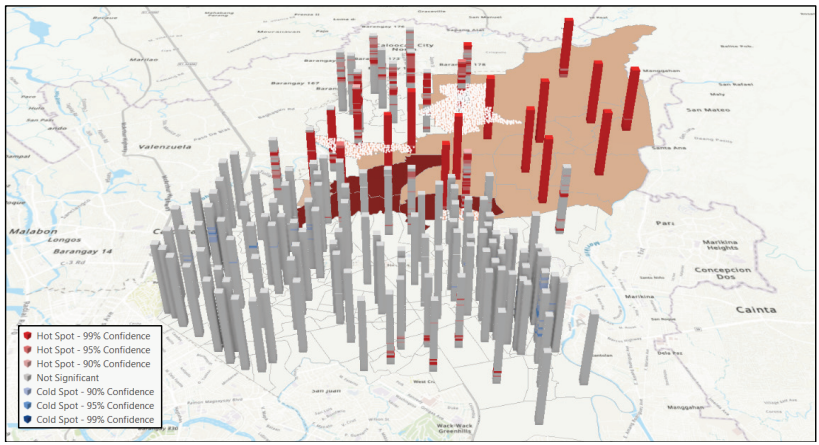

Figure 15. Result of the Emerging Hot Spot Analysis with Space-Time Cube

IV. Conclusion and Recommendation

The spatiotemporal pattern of Coronavirus Disease 19 or COVID-19 cases across barangays in Quezon City, Philippines from November 2020 to October 2021 was examined in the study. Using line graphs, heat maps, and thematic maps, the trend, and distribution of COVID-19 cases and incidences throughout the study period were analyzed briefly. On the other hand, through the construction of the Space-Time Cube, the spatial-temporal clustering pattern and change in the trend of COVID-19 were observed more intuitively.

An increasing trend in the overall weekly COVID-19 cases was discovered during the study period. Moreover, significant hot spots were mostly observed in the northern part of Quezon City, where Districts 2, 5, and 6 are located. As different patterns are observed throughout the study period, indicating that COVID-19 cases in Quezon City are yet to continue and may still intensify, it is recommended for the Quezon City Government to study the spatiotemporal pattern of Quezon city for a longer study period. To provide more efficient and effective policies, it is also recommended to conduct further research on why the barangays from Districts 2, 5, and 6, are at a greater risk for COVID-19. Specifically, conducting studies on why the barangays classified as Low-High outliers remained a low value given that it is surrounded by high values of COVID-19 cases is recommended, since determining how they handled the spread of COVID-19 in their barangays is essential. The same goes with the High-Low outliers; it is also recommended to determine why these barangays remained a high value while being surrounded by low values of COVID-19 cases.

As there is a possible resurgence in COVID-19 cases, identifying these spatiotemporal trends, and clustering is crucial for regulating and controlling the spread of COVID-19. These results can be used by decision-makers, LGUs, and the government to give information regarding the spatial and temporal spread and risk of the pandemic in Quezon City, especially for barangays in Districts 2, 5, and 6. Through rapid identification and characterization of hot spots, the timeliness and effectiveness of response efforts that can ultimately reduce the number of new COVID-19 cases can be improved.

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