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Assessing the Impact of Spatial Planning on the Spread of COVID-19 within Kampala City

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Abstract

Spatial planning has previously had an impact on the dynamics of pandemics. However, its influence on the spread of COVID-19 has not been explored. This research therefore focused on assessing the impact of spatial planning on the spread of COVID-19 in Kampala City. The research was based on the confirmed COVID-19 cases registered between 21 March 2020 and 27 March 2021 and was conducted in conjunction with the spatial analytical methods of the Global Moran's Index, Anselin's Local Indicator of Spatial Association (LISA) and the Geographically Weighted Regression model (GWR). Global Moran's I and Anselin's LISA were used to determine the spatial distribution of COVID-19 cases. The GWR was used to model the relationship between conformance to spatial planning and the spatial distribution of COVID-19 cases. Results attained through these methods showed a random distribution of cases, with LISA results indicating parishes located in the Central Division as major disease risk sites of COVID-19. Furthermore, results from the GWR revealed a negative relationship, with an R^2 value of 0.51, between spatial planning and the spatial distribution of Covid-19. This means that variations in spatial planning initiatives could explain 51 per cent of the variations in COVID-19 cases in Kampala City. Therefore, to change Kampala into a pandemic-resilient city, there is a need to develop appropriate compact spatial planning designs, especially in the parishes of Nakasero 1, Nakasero 11, Nakasero III, and Kagugube.

Keywords: *Covid-19; Spatial Planning; Spatial Distribution*

1. Introduction

Spatial planning is a key issue in urban development because it plays a significant role in influencing what types of development will occur, where, when and how they will occur (Omolo-Okalebo *et al.*, 2010). Initiatives in spatial planning originate from attempts to address cities as unhealthy environments plagued by deadly and infectious diseases. Spatial planning initiatives originate from attempts to deal with cities as unhealthy sites ravaged by contagious and fatal diseases (Martínez and Short, 2021). According to Scott (2020), the origins of the early planning movement in the late 19th Century were rooted in concerns for public health and slum conditions in Europe's rapidly industrializing cities. A famous example is John Snow's 1854 mapping of cholera cases in the streets of London where major spatial planning issues of poor sanitation and inadequate sewerage management systems were identified as the causal factors (Tulchinsky, 2018). Thus, cities were engineered to provide clean water, manage solid waste, and treat sewage to provide safer urban spaces (Begum, 2016). In essence, spatial planning originated as a public health intervention and evolved into a unique approach for targeted place-based interventions (Gouveia and Kanai, 2020). Nevertheless, spatial planning has since moved away from its public health origins in the mid to late 20th Century, and it is only due to the outbreak of the COVID-19 pandemic that there has been renewed interest in the relationship between place, health and well-being (Scott, 2020).

COVID-19, first identified in Wuhan, the capital city of Hubei China, was declared a pandemic on 11 March 2020 by the World Health Organization (WHO). To curb the spread of the COVID-19 virus, the WHO in 2020 issued recommendations that were based on its transmission characteristics (Douglas *et al.*, 2020). These recommendations included frequent hand washing, maintaining an adequate physical distance between people, the quarantining of infected patients and the use of face masks (Chiu *et al.*, 2020). However, even though countries all over the world adopted these recommendations, the spread of the virus continued to rise. As of 25 January 2021, almost 100 million coronavirus cases were registered in different parts of the world (Elflein, 2021), thus making Covid-19 an inherently spatial phenomenon. Consequently, a search for the factors contributing to the origins and spread of the virus became a matter of urgency. Abebe, Mekuria and Balchut (2020) recommend that an understanding of the factors contributing to the emergence or re-emergence of COVID-19 in different local contexts is a step at the forefront to mitigate the problem. In this regard, urban environments were hypothesized to be extremely affected by the spread of the virus (Menculini *et al.*, 2021).

Different attempts have been undertaken to understand the dynamics of COVID-19 within the urban environment. Studies undertaken in European, American and Asian cities highlighted population density, humidity and temperature as major variables contributing to the spread of COVID-19 (Mecenas *et al.*, 2020; Zangrillo *et al.*, 2020; Menculini *et al.*, 2021). African cities, including Kampala, have also served as epidemiological foci for COVID-19, with high population densities coupled with overcrowded public transport facilities and marketplaces considered to be major factors contributing to the spread of the disease (UN-Habitat, 2020). A few of the investigations conducted during the COVID-19 pandemic focused on social aspects; however, spatial planning was not considered among the most critical of factors (Sharifi and Khavarian-Garmsir, 2020). There are many ways in which spatial planning and urban design can alleviate or, conversely, aggravate the spread of public health risks (AbouKorin, Han and Mahran, 2021). Long before data statistics were accessible, health officials suspected that city amenities, their layout and design, the type of land use and sanitation measures were in some way related to the way in which the disease spread. These factors led turn to harsh consequences that emerged from such pandemics/epidemics which in turn augmented the severity of infection and reinfection (Wintle, 2020). It is, therefore, important that cognizance be taken of the healthcare impacts emanating from healthcare planning and that its applications are carefully considered in the context of COVID-19 (Sharpe *et al.*, 2021).

This study therefore focused on the impact of spatial planning, particularly in respect of its conformance to spatial development plans and how it has contributed to the spread of COVID-19 in Kampala City. The relevant steps taken include highlighting the major disease risk sites, determining the level of conformance to spatial planning in the different parishes and modelling the spatial co-variation between conformance to spatial planning and the spatial distribution of COVID-19 cases. This information can be used to develop pandemic-resilient designs for urban places, to identify the main focus and to improve control over these places, thus transforming them into resilient and attractive places (Dastjerdi and Nasrabadi, 2021).

2. Methods

2.1. Study area

The study, focused on Kampala City, covers its five divisions, namely, Kawempe, Makindye, Rubaga, Central and Nakawa. As depicted in Figure 1, Kampala is the capital city of Uganda, in the Eastern region of Africa, and lies along latitude 0°18′ 49″ N and longitude 32° 34′ 52″ E. Based on the study by Bamweyana *et al.* (2020), the Ugandan population most vulnerable to the COVID-19 virus was concentrated mainly in the Greater Kampala Metropolitan Area (GKMA), with Kampala City presenting with the greatest vulnerability. Furthermore, Kampala City accounted for over 50 per cent of the COVID-19 cases registered in Uganda. As a result, it was identified as the epicentre of the disease (Ario *et al.*, 2021). According to the Ministry of Health (MOH), Uganda (2020), a total of 18879 cases were confirmed in Kampala City between 21 March 2020 and 27 March 2021.

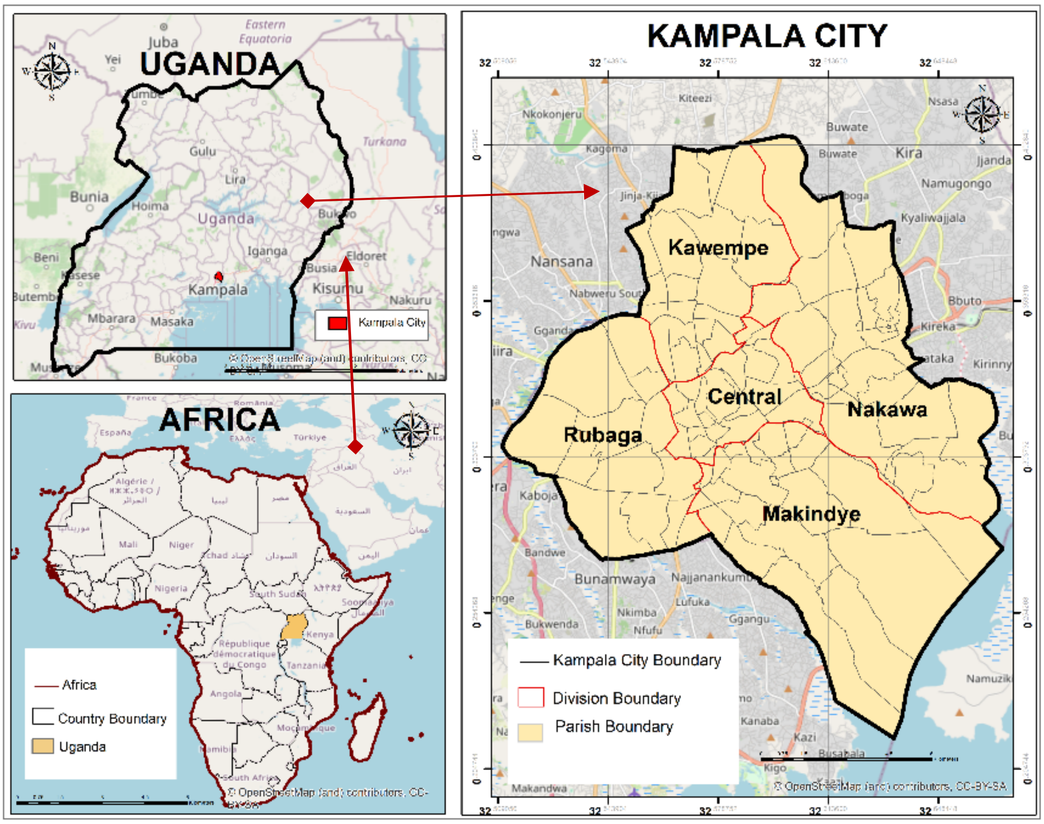

Figure 1: Study Area

2.2. Methodology Workflow

The study adopted a quantitative approach to determine the spatial distribution of COVID-19 cases to evaluate conformance to spatial planning initiatives between the existing land use types and the Kampala Physical Development Plan (KPDP) 2012 and to model the relationship between the level of conformance to the relevant spatial planning initiatives and the spatial distribution of COVID-19 cases. Figure 2 details the processes that were undertaken, including data collection, data preparation and the spatial analytical methods of spatial autocorrelation, namely, Global Moran's Index, Anselin's Local Indicator of Spatial Association (LISA) and the Geographically Weighted Regression model.

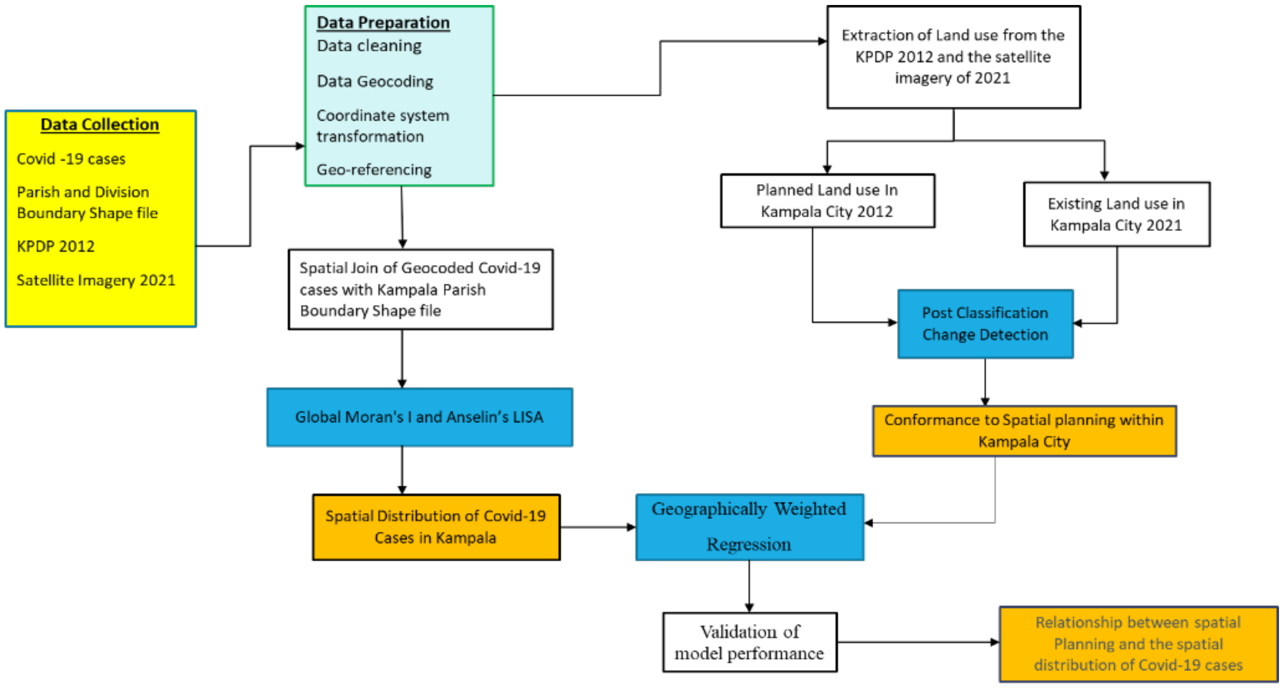

Figure 2: Flow Chart

2.3. Data Collection

This study applied data collected mainly from secondary sources, including raster and vector datasets. Confirmed COVID-19 cases registered within the period, 21 March 2020 to 27 March 2021, were obtained from the Ministry of Health (MOH), Uganda. The division, sub-county and parish boundary shapefile, was obtained from the Uganda Bureau of Statistics (UBOS). The KPDP 2012 was retrieved from the Kampala Capital City Authority (KCCA), while a high-resolution Worldview 4 satellite image, dated January 2021, with a resolution of 0.29 m and a spatial reference WGS84, was obtained from the GIS department of the Buganda Land Board.

2.4. Data preparation

A data preparation process was undertaken through data cleaning, geocoding, geo-referencing and spatial reference transformation. This was mainly to eliminate errors, to duplicate data and to ensure data usability. By using a G-Map extractor tool in conjunction with Google Maps, a geocoding process, with sample collection points attached to the locations of an x, y coordinate pair, was undertaken. All the retrieved raster datasets were geo-referenced and aligned to the respective spatial extents defined by the Kampala parish boundary shapefile. All datasets were transformed to comply with the requirements of the spatial reference system of WGS84.

2.5. Global Moran's I

The global Moran's I statistic was used to measure the respective correlations between the location of neighbouring COVID-19 observations, to find the patterns and levels of spatial clustering among neighbouring parishes. Moran's I measure, ranging between -1 and +1, was used. In this case, a positive value indicates a positive correlation; a negative value indicates a negative correlation; and a value that approximates 0 indicates a random spatial distribution (Anselin, 1995). Modelling was performed using the spatial autocorrelation tool in Arcgis10.7, where the conceptualization of the respective spatial relationships was based on the continuity, edges and edges of the parish boundary. The global Moran's I was used in conjunction with results from the P-test value and z-statistical score to determine whether the distribution was random, clustered or normally distributed. Once again, a positive value indicates a positive correlation; a negative value indicates a negative correlation; and a value that approximates 0 indicates a random spatial distribution.

2.6. Anselin's Local Indicator of Spatial Association (LISA)

This method allowed for the decomposition of the study area into small locations, thus enabling the researchers to assess significant levels of local spatial clustering around individual locations (Livings and Wu, 2020). In addition to the level of spatial clustering, the detailed variations of clustering in the locally defined geo-space, as well as the locations of the spatial clusters, were identified. By using the cluster and outlier tool, these statistics: were modelled in Arcgis10.7. A result displaying a measure of concentration of the numeric values based on the definitions of High-High (HH), Low-Low (LL), High-Low (HL), and Low-High (LH) was used to show spatial clustering and outliers. The HH corresponded with the case where the high value for COVID-19 in a particular parish was surrounded by observations also presenting high values in respect of the neighbours; hence, a hot spot. The LL corresponded with the inverse of the case where the low values for COVID-19 cases in a particular parish were associated with low values for the neighbouring observations (Cold spot). The HL corresponded with cases where high values for the variable were associated with low value for the neighbouring variables, while the LH corresponded with the inverse situation where low values for COVID-19 cases were associated with high values for the neighbouring values.

2.7. Post-classification Change Detection

By using Post-classification Change (PCC) detection, the planned land use and the existing land use maps generated from the KPDP 2012 and the satellite imagery of 2021, respectively, were compared for changes. The planned 2012 land use map was reclassified by multiplying the raw pixel values by a factor of 10 to simplify subsequent comparisons. By using the raster calculator in Arcgis10.7, the reclassified planned land use map was added to the resultant raster of the existing land use value for 2021. All pixels with values such as 99, 88, 77, 66, 55, 33, 22 and 11 were reclassified as unchanged, thereby conforming to the relevant spatial planning initiatives. Shifts from one classification theme to another were also detected from pixels that did not retain the same value; these were classified as changed areas (areas that do not conform to the relevant spatial planning initiatives). The change detection outcome was then transformed to vector data since the latter provide for improved mapping in a GIS. The conformance value in respect of the relevant spatial planning initiative in each parish was quantified using a four-point Likert scale, classified as conforming significantly, moderately conforming, conforming, and not conforming

2.8. Geographically Weighted Regression

GWR has a high utility value in epidemiology, mainly because it is a technique that considers non-stationary variables and models the local relationships between predictors and an outcome of interest (Taghipour Javi, Malekmohammadi and Mokhtari, 2014). The GWR equation is expressed as

$$yi = \beta 0i\ (ui,\ vi) + \sum \beta n\ (ui,\ vi)\ k\ n{=}1 + \varepsilon i$$

Where yi is the dependent variable at a certain location, (ui, vi) represents the coordinates of the location, i, of the variable under study. βoi, βni, respectively, represent the locally computed intercept (βoi) and effect (βni) of variable n for the explanatory (independent) variables affecting the dependent variables (Fotheringham and Martin, 2014). This method was adopted and used to establish the strength and direction of the relationship that exists between spatial planning initiatives and the spread of COVID-19 across different parishes. It was modelled using ArcGIS 10.7, with a kernel function set to an adjusted Gaussian. The model outputs, namely, the local R^2 and the model coefficients, were used to determine the impact of spatial planning on the spread of COVID-19. R-squared, which is a measure of goodness of fit, was used to quantify the relationship between spatial planning and the spatial distribution of COVID-19. Its value varies from 0.0 to 1.0 which were interpreted in this study as the proportion of COVID-19 case variance accounted for by the regression model. The model coefficients for the different parishes were used to determine the direction and strength of the relationship that exists between conformance to spatial planning initiatives and the spatial distribution of COVID-19 cases.

3. Results and Discussion

3.1. Spatial Distribution of COVID-19 Cases

Figure 3 presents a visualization of the distribution of COVID-19 cases across different parishes in Kampala. Results reveal that parishes located in the Central Division, within the Central Business District, such as Nakasero II, Kololo II, Nakasero III and Kagugube, stand out as areas that registered the highest number of COVID-19 cases. There are also instances of a large number of cases registered in parishes located outside the CBD, in parishes such as Nakulabye, Mulago, Naguru Butabika, Bukoto, Ntinda and Kisugu. This spatial gradient pattern results from the fact that although Kampala City has assumed a concentric type of development, with the Central Business District at the core, it presents with instances of multi-nucleic development, with different nodes as business centres. These business centres attract intense commercial activity that requires face-to-face interactions and hence increases the spread of the disease, thus leading to a large number of cases being registered. In addition, student-based parishes, such as Makerere I, Banda II, Nabisunsa, Kyambogo and Makerere University, also registered only a few cases. This was due to the Presidential Directive on 18 March 2021 that required schools to close, thus causing most of the areas to be left vacant.

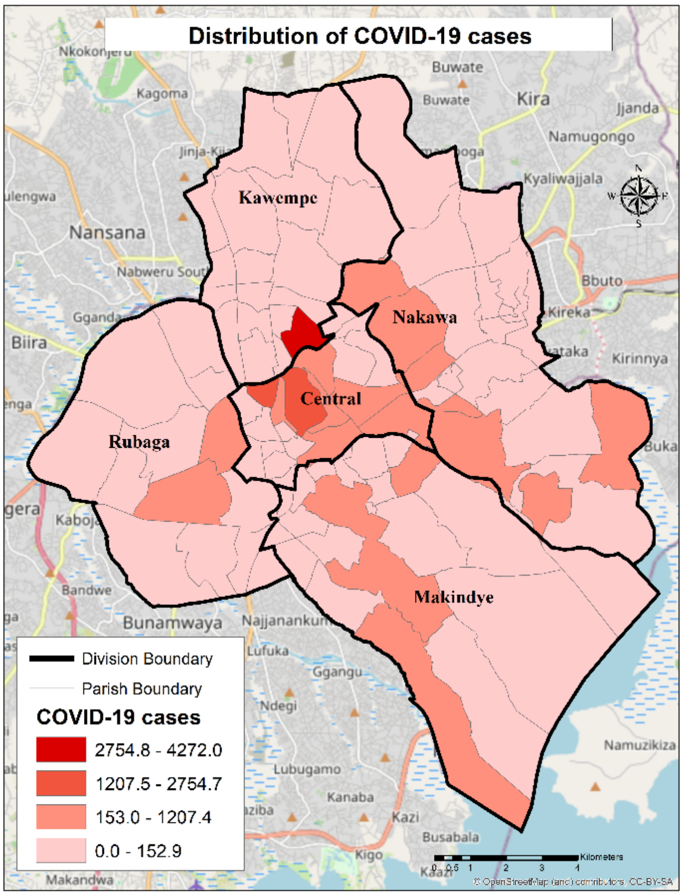

Figure 3: Distribution of COVID-19 Cases

Figure 4 displays a global Moran's Index of 0.01, a p-score of 0.69 and a z-score of 0.38. Testing for spatial autocorrelation through Moran's I statistic provided evidence that there is a random distribution pattern for COVID-19 cases. This means that there is a significant correlation between the incidence of COVID-19 in the parishes in Kampala City and the demographics in these parishes. This is because of the different dynamics prevailing in the respective parishes and leading to the random occurrence of low and high values. Different areas have different demographics related to population, land use, the intensity of activity and adherence to spatial planning regulations. An exploration of the LISA results revealed clusters and outliers, as displayed in Figure 5. Parishes categorized as High-High proved to be the major disease risk sites in Kampala City and include Nakasero II, Nakasero I, Nakasero III and Kagugube. They are characterized by highly intensive activities, with a dense concentration of offices and commercial activities. Moreover, they present as major transportation nodes, with bus parks and taxi parks. These host a variety of activities that attract an influx of commuters, bringing the urban population up to a count of around 4.5 million during the day (KCCA, 2014). This influx of commuters has increased the likelihood of physical interaction between infected and uninfected people, thus leading to the spread of the virus. On the other hand, areas with low concentrations of activity were interpreted as the cold spots of COVID-19. These include Makindye II, Najanankumbi, Katwe, Lubya, Bwaise II, Makerere III, Nabisunsa, ITEK, Upper Estate and Komamboga. This is because these areas are predominantly residential areas with a low level of commercial activity that requires face-to-face interactions.

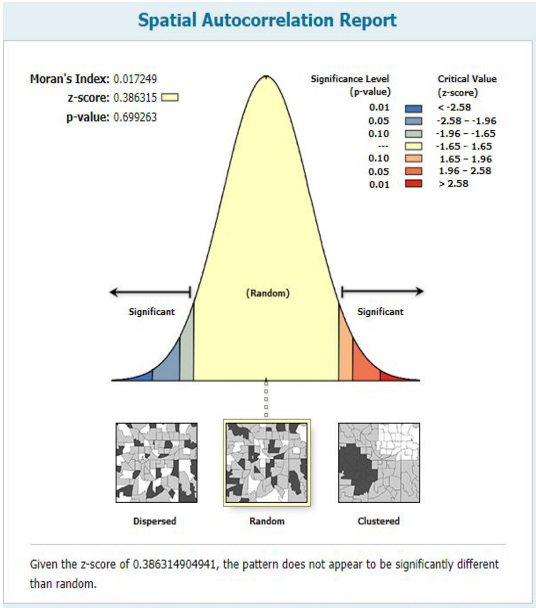

Figure 4: Spatial Autocorrelation Report

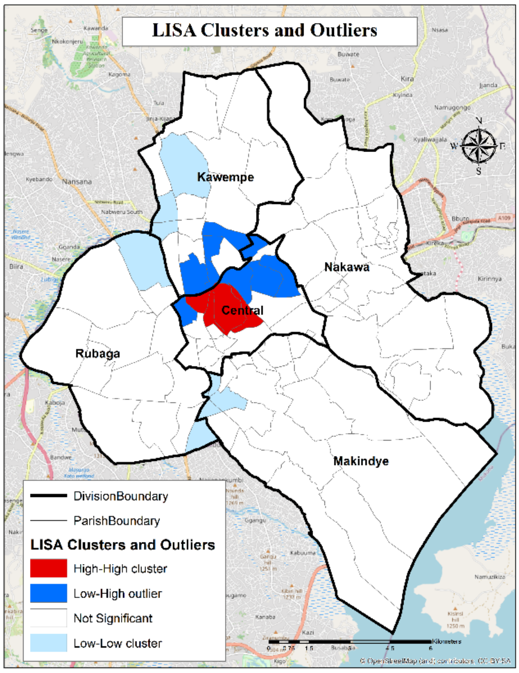

Figure 5: LISA Clusters and Outliers

3.2. Conformance in respect of Spatial Planning in Kampala City

Conformance to spatial planning initiatives in Kampala was evaluated through an assessment of what was planned through the KPDP 2012 and what actually existed on the ground in 2021. The results, displayed in Figure 6, reveal that parishes located in the Central Division, such as Kamwokya, Kagugube, Nakasero II and Nakasero III, registered the lowest levels of conformance in respect of spatial planning initiatives as opposed to parishes in other divisions of Kawempe, Nakawa, Makindye and Rubaga. This is because the land in the Central Division that was initially demarcated as an inner-city residential area has been taken over by commercial and mixed-use development, thereby not conforming to spatial planning initiatives. This trend can be attributed to land rent and the location theory, where areas located in close proximity to and within the Central Business District command higher land rents and hence require uses that ensure profit maximization. In that aspect, rent-seeking owners transform the land use from residential to profit-yielding commercial, industrial and mixed use.

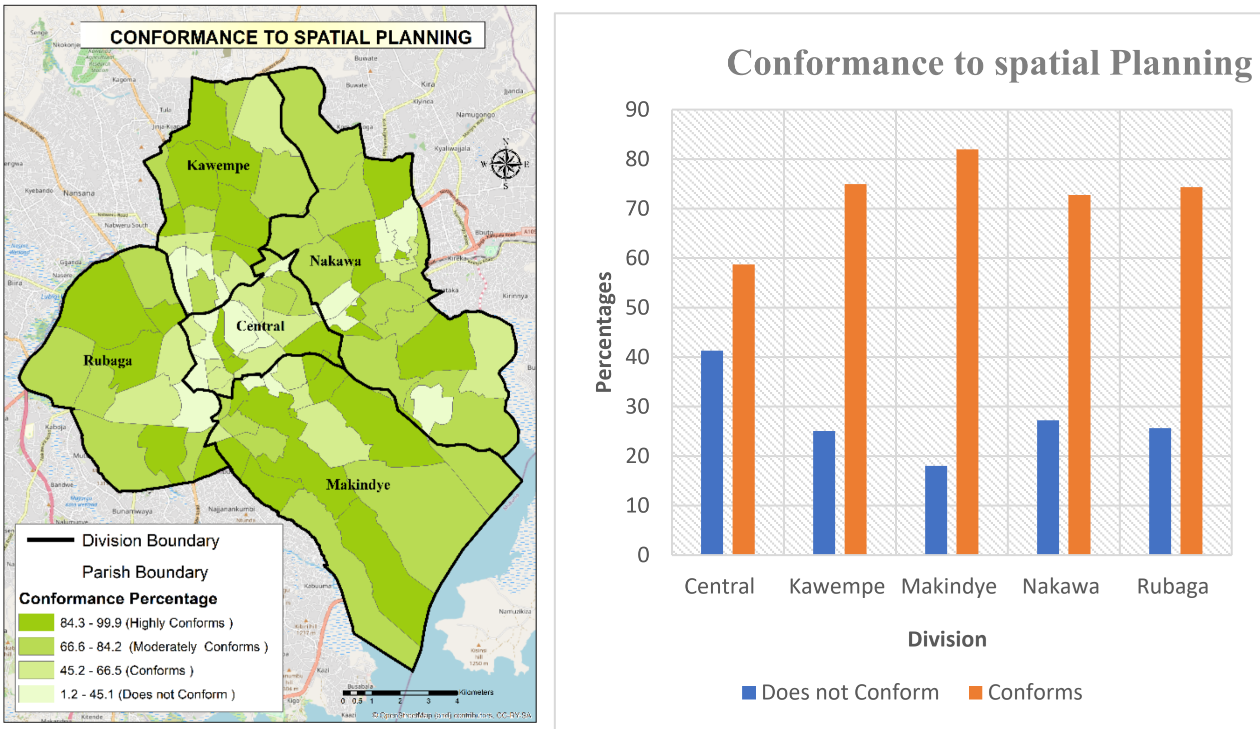

Figure 6: Conformance to spatial planning in Kampala

3.3. The relationship between conformance to spatial planning initiatives and the spatial distribution of COVID-19

Modelling the relationship between conformance to spatial planning initiatives and the spatial distribution of COVID-19 through the GWR provided results indicating a global R^2 of 0.51 and a negative correlation between the two variables. To better understand the spatial co-variation of these two variables across the respective parishes, an examination of the local R^2 and the GWR coefficient was conducted. The local R^2 values reveal parish-level variability in GWR model performance. Figure 7 shows that the GWR model yields high local R^2 values for the parishes in the Central Division that registered a large number of COVID-19 cases, the parishes being Nakasero I, Nakasero II, Nakasero III and Kagugube. This means that conformance to spatial planning initiatives significantly impacted the occurrence of COVID-19 cases in those parishes with a percentage of up to 70%. Figure 8 indicates a strong negative correlation between conformance to spatial planning initiatives and the spatial distribution of Covid-19 cases in the Central Division parishes of Nakasero I, Nakasero II, Nakasero III and Kagugube. This means that a low level of conformance to spatial planning initiatives leads to a significant spread in COVID-19 infections. However, results also reveal a strong positive correlation in areas such as Salaama and Kisumu, where significant levels of conformance to planning and high COVID-19 infection levels prevail. This indicates that even though these areas conform to spatial planning initiatives, they are still highly vulnerable to the large-scale occurrence of COVID-19 infections.

Initiatives pertaining to spatial planning in the study region are concentrated on maintaining the separation of the various land uses, which has the consequence of preventing communities in the area from experiencing a diversity of production activities. This has necessitated long-distance travel; hence, interaction between community members, thereby leading to the spread of COVID-19 across Kampala City. Likewise, one of the recommendations for the prevention of COVID-19 is to constantly offer physical activity sessions for patients. Thus, communities need to use open spaces, including football fields, cricket pitches, and urban and leisure parks. The trend in spatial planning in Kampala City points to a loss of land in the vicinity of the areas designated as open spaces, with a decline of 23.77% in these areas. The model results also showed weak positive and negative relationships between Covid-19 infections and spatial planning activities, particularly in the parishes in the Nakawa Division. This suggests that variables other than those related to spatial planning initiatives might contribute to the emergence of COVID-19 in those regions.

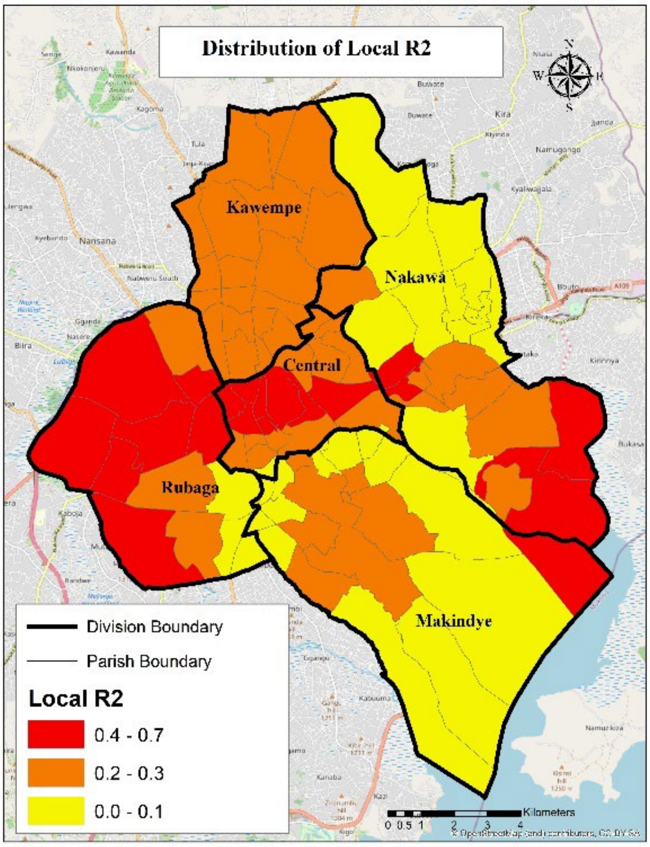

Figure 7: Distribution of the Local R^2

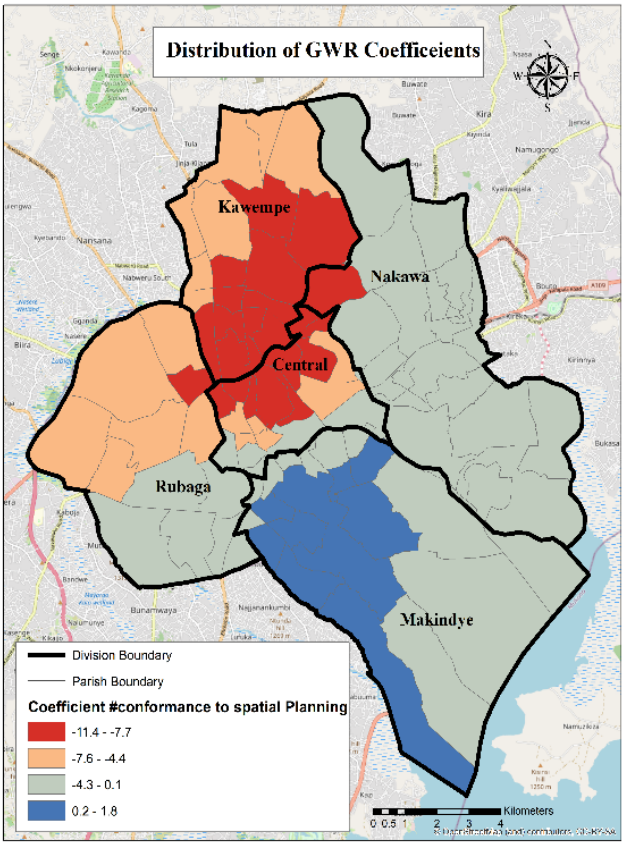

Figure 8: Distribution of the GWR coefficient

4. Conclusion

The COVID-19 pandemic outbreak has presented a chance to research and learn more about the hotspots, patterns, and contributing elements of infectious disease distribution, as well as strategies for resilient metropolitan regions to withstand and recover from pandemics. The study concentrated on assessing the impact of spatial planning initiatives as a factor in the spread of COVID-19 within Kampala City. According to the findings, the COVID-19 virus originated in Kampala City's Central Division and tended to follow an outward spatial pattern as it migrated from the city center and thinned out toward the suburbs. Hot Spot analysis also revealed that the parishes of Nakasero I, Nakasero II, Nakasero II and Kagugube were the major disease risk sites in Kampala City. The findings from the modelled correlations between Covid-19 infections and spatial planning initiatives showed a negative correlation, meaning that there was a lower chance of COVID-19 infection and transmission with more adherence to the city's spatial planning principles. Additionally, an R^2 of 0.51 indicates that 51% of the changes in COVID-19 within Kampala City could be explained by spatial planning. There is a need to develop pandemic-resilient compact spatial planning designs for the parishes of Nakasero 1, Nakasero 11, Nakasero III and Kagugube. This could be accomplished by developing self-sufficient neighborhoods that support the densification of specific land use patterns, like vertically developed slum residential areas, ease access to a variety of local amenities, and lower population densities. Last but not least, the results of this research indicate that spatial planning initiatives' conformance should be utilized to evaluate the relationships between spatial planning designs, adherence to spatial planning laws, and the transmission of infectious diseases. A closer examination of the relationship between spatial planning initiatives and COVID-19 cases is necessary to comprehend the ways in which building layouts and designs, as well as settlement patterns, affect the virus's ability to spread.

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