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Review Article

Review of Spatial Analysis as a Geographic Information Management Tool

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Abstract: Spatial analysis is a field of study that utilizes geographic or spatial information to understand and analyze patterns, relationships, and trends in data. It is characterized by the use of geographic information, which allows for the analysis of data in the context of its location and surroundings. It is different from aspatial techniques which do not consider the geographic context and may not provide as complete of an understanding of the data. Spatial analysis is applied in a variety of fields which includes urban and regional planning, crime rate investigation, public health studies and epidemiology, environmental science, geosciences, marketing, and to gain insights and make decisions about complex spatial problems. The aim of this review paper is to explain the concept of spatial analysis as a Geographic Information System (GIS) tool, differentiate it from aspatial techniques, discuss different spatial analysis techniques including buffer, interpolation, and kernel density analysis, and highlight its importance. The paper followed a methodology that involved multiple definitions of spatial analysis from various sources. Comparative analysis of spatial and aspatial datasets and techniques was conducted, followed by application of spatial analysis in various fields including land cover classification, public health management, solid waste disposal management, and identification of the impact of urban sprawl. Applications of spatial analysis techniques were also reviewed. The importance of this paper lies in its contribution to the understanding and utilization of spatial analysis as a GIS tool. By explaining the concept, differentiating it from non-spatial techniques, and providing examples of its applications, the paper highlights the significance and potential of spatial analysis in various fields.

Keywords: Aspatial Technique, Buffer Analysis, Epidemiology, Interpolation, Kernel Density

1. Introduction

Spatial analysis is a branch of Geographic Information System (GIS) that deals with the analysis of data that possesses a spatial or a geographic component. It involves the application of techniques which are mathematical as well as statistical to analyze and have a detailed knowledge of patterns and data relationships which are linked to specific locations [1]. It also involves the use of techniques and tools such as mapping, spatial statistics, and geographic information systems (GIS) to analyze and visualize data in a way that critically considers the location and context of the data. Spatial analysis is used in a variety of fields, including urban planning, environmental science, epidemiology, and marketing, to gain insights and make decisions about complex spatial problems.

Spatial analysis entails the way we comprehend our world – delineating areas where things exist, how these things inter-relate, the meaning of it all, and the actions to be taken [1]. In this description, it can be deduced that spatial analysis focuses on location, it talks about where things are and how they relate to other things and how understanding these relationships helps in making better decisions. Whenever people look at a map, they unconsciously start transforming it into valuable information through detecting patterns, analyzing trends, and making decisions. This is the concept of spatial analysis, and it's a natural process that takes place in the minds of people when viewing a map.

This paper aims to present various definitions of spatial analysis from various published literature and highlight the distinctions between spatial analysis and traditional techniques. Additionally, it will provide examples of spatial analysis approaches and comparative assessment of spatial and non-spatial analysis.

2. Some Basic Definitions

Fotheringham, A. S. *et al.* [2] described spatial analysis as the study of the relationships, patterns, and trends of phenomena that have a geographic or spatial aspect. The authors describe spatial analysis as a study of the spatial aspect of phenomena, the patterns they make and the trends that can be observed. In other words, it is the use of GIS and related technologies to study the spatial dimensions of phenomena in the social, biological, and physical sciences [2]. The key element in this definition is that spatial analysis is more interested in the geographic aspect of the data than the other aspects such as statistical aspects.

Spatial analysis was defined by [3] as the series of steps involved in the studying by checking, assessing, evaluating and modeling the features of spatial data including location, characteristics, and their interrelationships that display geometrical features of the data. It is described as the process of utilizing various methods to analyze and evaluate geographical location data and the spatial attributes or characteristics that are exhibited and their relationships. It is different from non-spatial analysis in the sense that attributes and their relationships are analyzed with respect to their geographic locations.

Goodchild & Longley [4] described this concept as a part of analytical means whose results or outcomes are location dependent; there are changes in the outcome if the location changes or the outcome is affected if there is a positional change of an object within the location. This description indicates that location is a necessary component for conducting spatial analysis. It implies that spatial analysis relies heavily on location. They also highlight that variations in location is capable of resulting to variations in the conclusions or decisions made from the spatial analysis.

3. Comparing Spatial Data and Spatial Analysis

Spatial analysis and spatial data are two related but distinct concepts. Spatial data can be said to be data that possesses a spatial or geographic component, meaning it is associated with a specific location on the earth's surface. Examples of spatial data include addresses, latitude and longitude coordinates, and shapes of geographical features such as cities, lakes, and roads.

On the other hand, spatial analysis is the series of steps involved in the use of spatial data to answer questions, solve problems, and make informed decisions. This involves using methods such as mapping, spatial statistics, and geographic information systems (GIS) to examine the relationships, patterns, and trends in the data. The goal of spatial analysis is to turn raw spatial data into meaningful information that can be used for decision making. In summary, spatial data provides the input for spatial analysis, while spatial analysis is the process of making sense of the data to arrive at meaningful conclusions.

One example of spatial analysis is the use of a GIS to analyze crime patterns in a city. By mapping the locations of crimes and overlaying that information with other data such as population density, income levels, and police presence, researchers can identify patterns and relationships that might not be apparent from analyzing the data in a non-spatial context. This type of analysis allows researchers to understand the correlation of crime with different factors in the context of location.

A typical example is the analysis of crime in Kaduna metropolis, Nigeria using geo-spatial analysis. The aim of this research was to map and analyze crime occurrences within Kaduna metropolis, Nigeria, using Geo-Spatial method. Data from the divisional headquarters of the Nigerian police in Kaduna, and an administrative map of the study area to identify and map 11 different types of crime was used for this analysis. The study used Google Earth Pro 4.2 to obtain the coordinates of each crime incident and an overlay analysis was performed to display them on a composite map. The research found that stealing/theft and fight/hurting were the most prevalent crimes, and that incidents of crime was most in Tudun Wada, trailed by Sabon Tasha and Rigachikun. The study identified Tudunwada, Sabon Tasha, Rigachikun and Rigasa as the dominant hotspots of crime in the studied metropolis. The study recommended improved effort to fight crime, especially during December and January, and for crime incidents to be documented in detail with the exact geographical locations (coordinates) by the Nigerian police.

Figure 1 shows that locations with crime incidents higher than the mean value were adjudged hot spots. Conversely, cool spots are locations or zones with crime rates less than the mean number of disorder or crime.

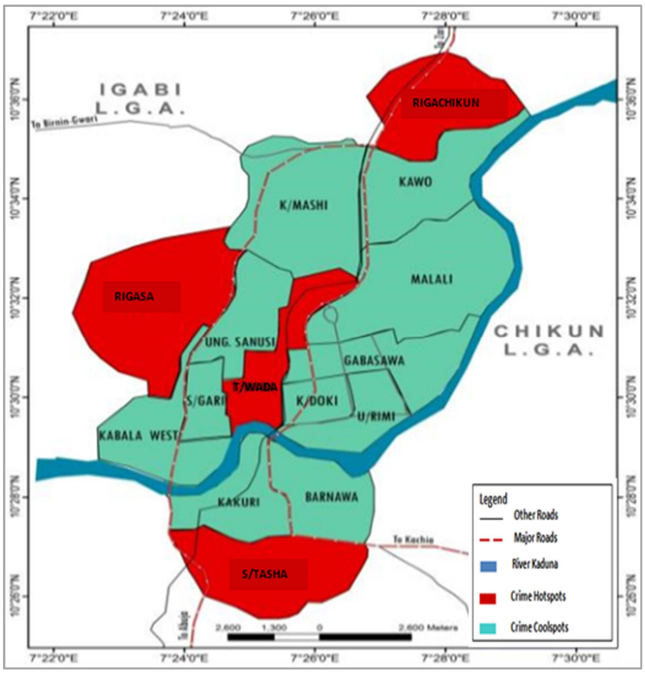
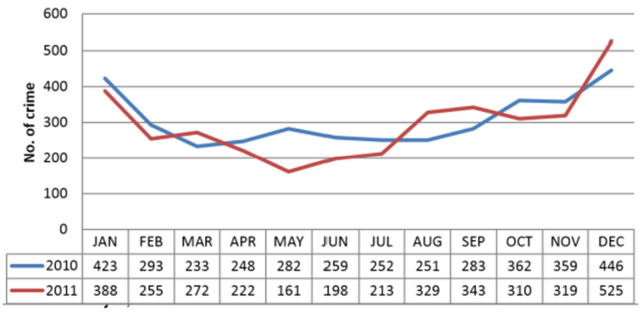


Figure 1. *Crime Hotspots in Kaduna metropolis (after [5]).*



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2010	423	293	233	248	282	259	252	251	283	362	359	446
2011	388	255	272	222	161	198	213	329	343	310	319	525

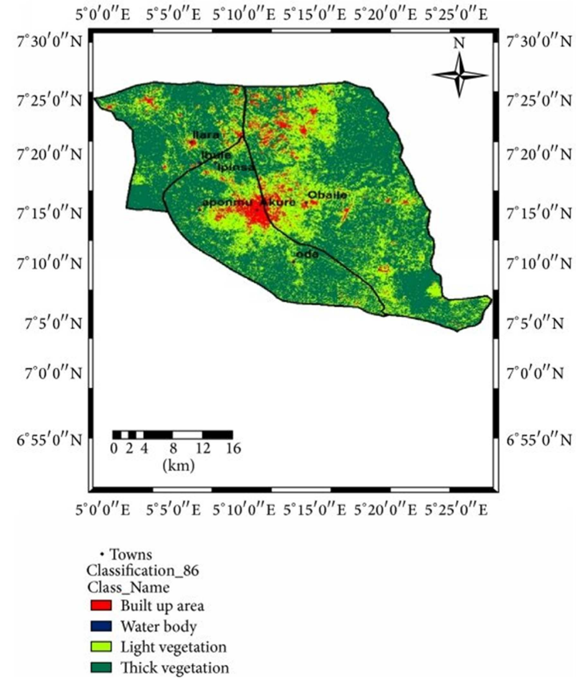
Figure 2. *Temporal distribution of crime in Kaduna metropolis (after [5]).*

A line graph which shows the distribution of crimes in Kaduna over months of the year is presented in figure 2. This graph shows that January and December are months with the most crime rates in 2010 and 2011. This analysis is non-spatial because it does not have a location component to it. It analyses the crime rates in Kaduna with respect to months of the year and can best be classified as temporal.

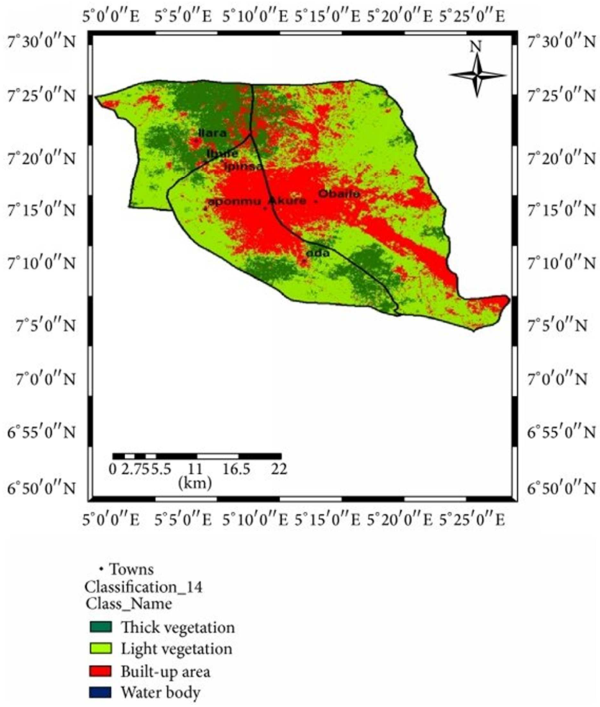
4. Comparing Spatial Analysis and Aspatial Analysis

Non-spatial techniques, such as statistical analysis, typically focus on analyzing data without considering its geographic location or spatial relationships; these techniques are often used to understand patterns, trends, and relationships within the data that are not related to location or position. In contrast, spatial analysis incorporates geographic information and considers the spatial relationships between data points. This allows for the examination of patterns and relationships that may not be apparent using non-spatial techniques alone.

Spatial and aspatial analysis share some similarities in that they use statistical and mathematical techniques to analyze data, identify patterns and trends, make predictions and support decision-making. Both types of analysis can be used in various fields and rely on the quality of the data. Several researchers employ the two methods to obtain additional detailed information and arrive at conclusions that are well-informed.



(a)



(b)

Figure 3. *Land cover classification of Akure (a) 1986, (b) 2014 (Source: Landsat 4 Thematic Mapper (TM) Imagery (1986), Landsat Operational Land Imager (OLI) Satellite Imagery (2014) after [6]).*

4.1. Spatial Analysis in Land Cover Classification

An example of spatial analysis is the analysis of land use changes over time in Akure, Nigeria. This type of analysis examines the position and changes of land use in 3-D space, and the series of steps and methods used to study this data. There is a demonstration by this example of one aspect of [4] definition of spatial analysis, which states that the outcome can change if the location or objects within the location change position.

That study examined the direction of urban expansion and changes in land cover within Akure region over a period of 28 years from 1986 to 2014, by utilizing geographic information system and remote sensing techniques. The goal of that study was to understand the direction and patterns of continuous growth of the city over time.

Comparing the figures from 1986 to 2014, it is evident that urbanization has impacted the distribution of land cover. With the Landsat imaging, we are able to analyze not just the percentage distribution of the land cover but also the geographic or spatial distribution.

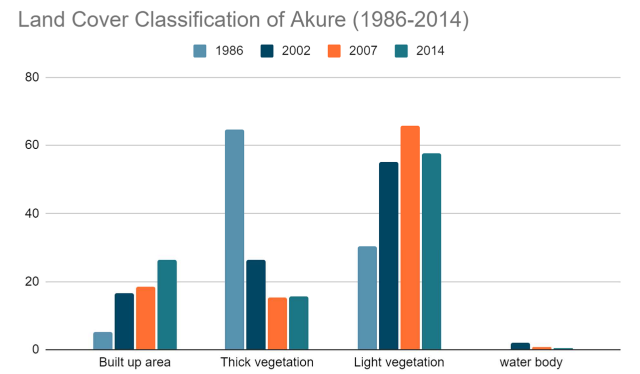


Figure 4. *Bar chart showing Land cover distribution of Akure (1986-2014) (Source: Imageries of satellite of 1986, 2002, 2007, and 2014).*

Figure 4 shows a bar chart showing the change in land cover in the area over the 28 year period. A progressive increase in built over area is observed while a decline in thick vegetation is observed over time. This is an example of the use of non-spatial analysis. This analysis measures the trend in land use cover without taking into consideration the locations which the land use changes.

There are several advantages of spatial analysis in land cover classification which makes it an invaluable tool in this discipline. In addition to offering new views on decision making, spatial analysis helps in improved accuracy in land cover classification through the application of enhanced classification methods, it offers comprehensive land coverage and in a very timely manner, it provides seamless mapping and classification of features thereby reducing complexities in interpretation and saving time. It also combines data from several sources to provide comprehensive land cover maps that offer deep insights into different phenomena. On the other hand, spatial analysis suffers from some challenges in land cover classification which includes the potential of land cover types to be diverse, from urban centers to water bodies and forests, leading to the need for special algorithms and artificial intelligence techniques. Data resolution and quality also impacts the accuracy of land cover classification; low resolution data can lead to wrong classifications. Also, keeping up with real-time changes in land cover can be challenging and requires constant updates and evaluation of the models used for classification.

4.2. Spatial Analysis in Public Health Management

Spatial analysis is also applied in public health studies, analysis, and risk assessments in a given region or locality. This is very critical in reducing the spread of communicable and several diseases that are transferable from an individual to another. This method provides important insights that can lead to public health actions including government and other agency's interventions. Results of this analysis also help in taking far-reaching decisions on the best possible ways of handling and controlling disease outbreaks in a particular region.

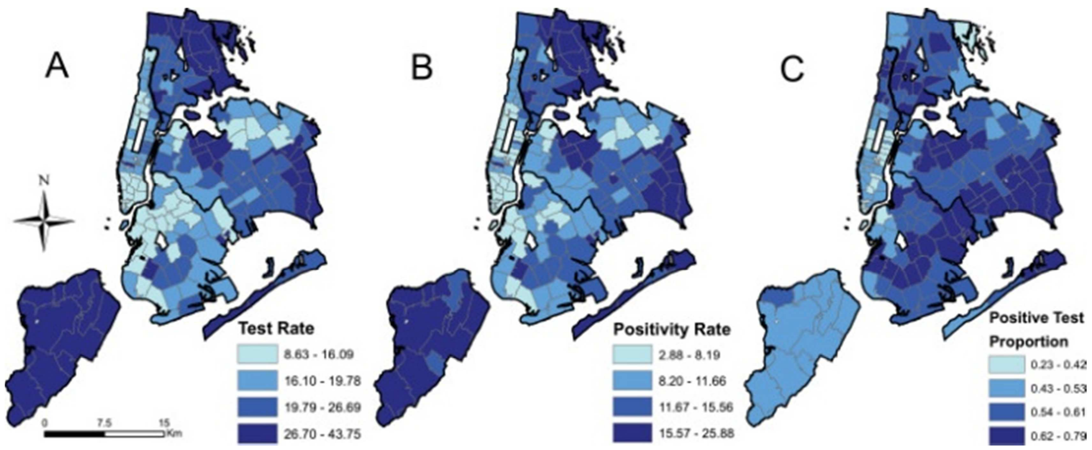


Figure 5. *Spatial distribution of (A) Test rate (B) Positivity rate and (C) Positive test proportion in the area (after [7]).*

Cordes & Castro [7] applied spatial analysis technique in the investigation of COVID-19 clusters and contextual factors in New York City. This study became necessary when in March, 2020; this densely populated city became the new epicenter of the global COVID-19 pandemic with over 104,410 cases by April 12, 2020. The study sought to identify areas with limited access to testing and high case burden as a way of understanding risk and allocating resources appropriately. The city's zip code level data was utilized in analyzing positivity and testing rates as well as proportion positive. Clusters of low and high testing rates, and high proportion positive and positivity rates were identified by spatial scan statistic as shown in figure 5(A-C).The relationship existing between contextual factors, clusters, and outcomes were determined using Pearson correlations and boxplots. It was observed that clusters made up of population of whites, high income rate and education are characterized by tests of low positive test proportion and low testing rate. On the other hand, clusters made up of population of blacks, low income earners and less education are characterized by high positive test proportion and high testing rate [7]. This analysis enabled the identification of eastern Brooklyn as a region having high positive test proportion and low testing rate hence; setting up of more testing centers with health care resources was strongly recommended for this area. Figure 6(A-D) shows spatial maps of the top ten significant clusters for high test, low test, high positivity rates, and high proportion positive tests respectively.

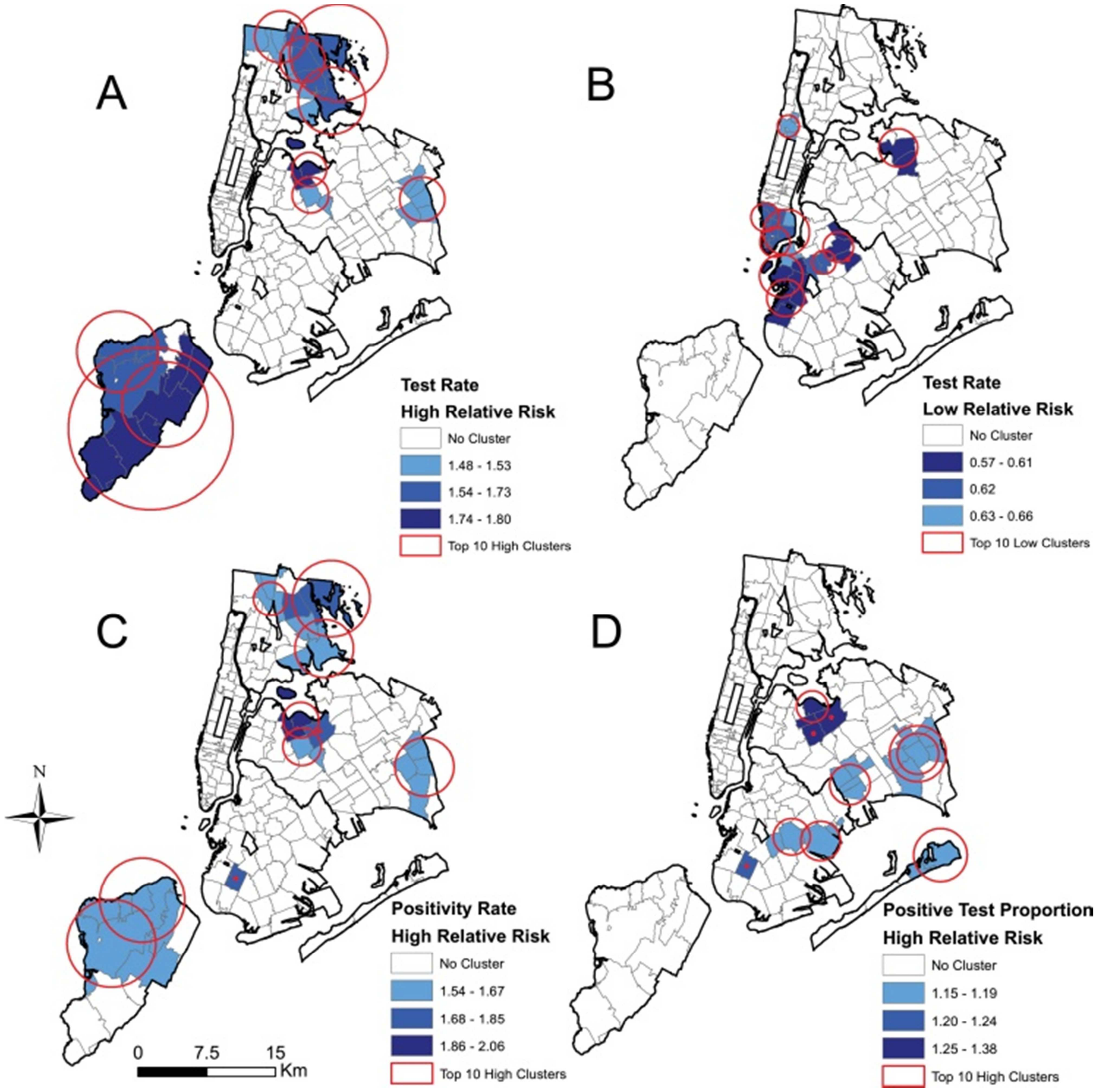


Figure 6. *Spatial maps of the top ten significant clusters for (A) high test (B) low test (C) high positivity rate and (D) high proportion positive tests (after [7]).*

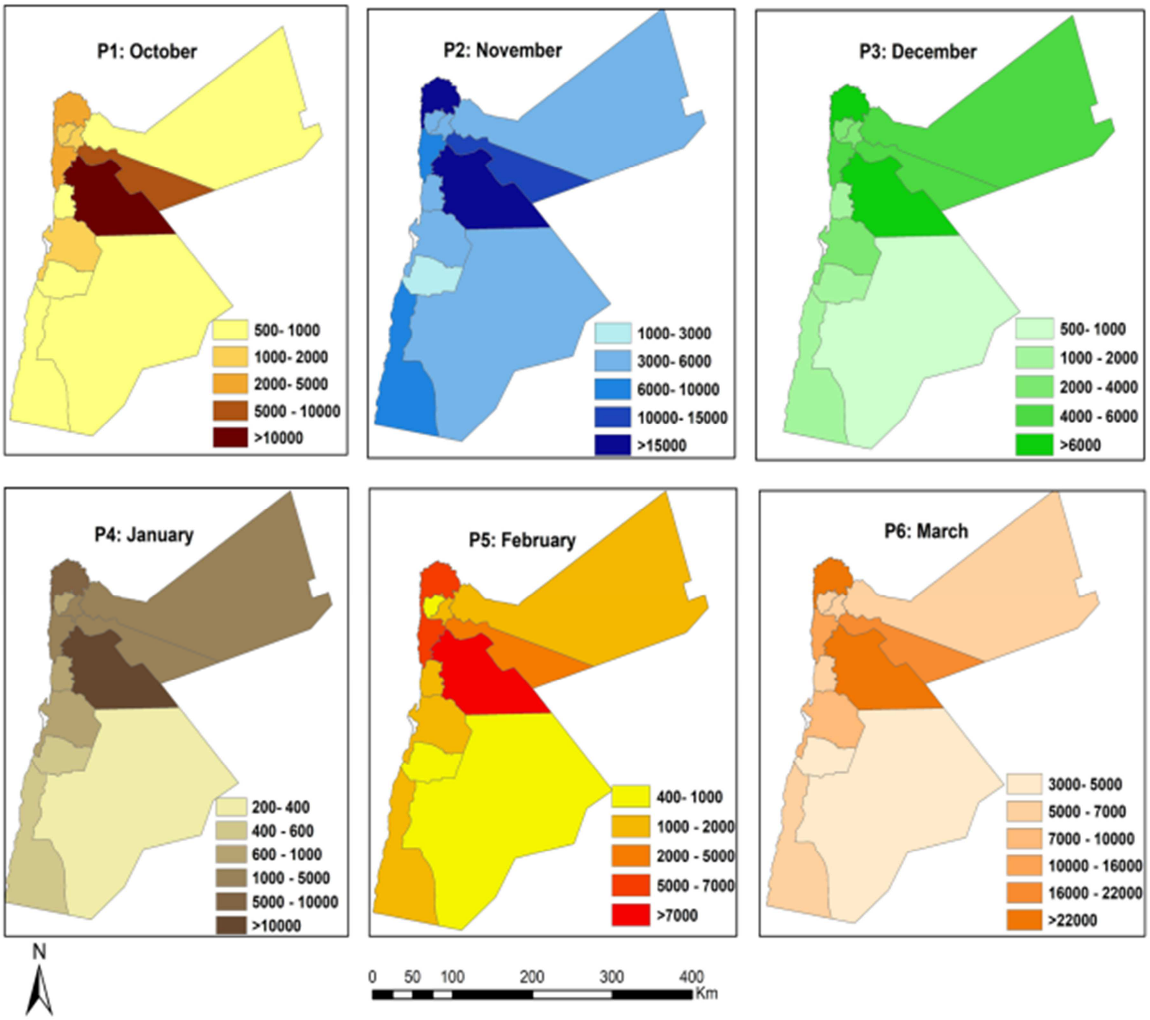


Figure 7. *Spatial distribution of cases of coronavirus infection in Jordan between October 2020 and March 2021 (after [8]).*

Similarly, spatial analysis technique was applied in the study of the spatial/geographical distribution of Corona virus cases in Jordan for a period covering between October 2020 to March 2021. This study was necessitated by the rate of increase in infection and mortality due to the virus in Jordan. In the study by [8], four hotspots in the area were identified including Balqa, Irbid, Amman, and Zarqa. The location quotient (LQ), Moran coefficient, and G* test were applied in the study leading to the identification of the outbreak and prevalence of this virus within the area as shown in figure 7. This information will help decision and policy makers predict future spatial dynamics of the virus while taking public health actions in the immediate.

In public health management, spatial analysis has the advantage of providing real-time identification of differential risk areas which enables proper action plan. It offers understanding of the spatial variations in the spread in humans of highly infectious diseases. The tool aids health care authorities to understand disease cluster locations, often referred to as hot spots, at a glance and take calculated steps to avoid spread. Spatial analysis also has the advantage of correlating disease hot spots to environment and physical features such as markets, slaughter outlets, and rivers identified on the maps. Spatial analysis also has the advantage of permitting disease prediction from available epidemiological data after evaluation. However, spatial analysis in epidemiology suffers from the problem of the possibility of huge random component predominating rates of disease over small areas [9]. Though it is possible for Bayesian statistics to solve this problem, when there are little expected amount of cases, detection of high risk areas will be limited.

4.3. Spatial Analysis in Solid Waste Disposal Management

Spatial analysis tool can also be utilized in the management of solid waste disposal particularly in urban centers. Solid wastes are materials which are no longer needed and therefore, discarded and abandoned either by being incinerated, disposed of, burned, or, in some cases, recycled. If not properly managed, solid waste can be a source of public health concern through air pollution and water pollution through groundwater contamination as a point source. Improper management of solid waste can also destroy the beauty and environmental aesthetics of an urban center. Spatial analysis in waste management provides adequate information that can guide local authorities and agencies in making policies and laws that can mitigate the negative impacts of poor solid waste management system.

Volsuuri *et al*. [10] investigated the spatial distribution of solid waste disposal sites (SWDS) in urban Ghana by applying the location theory. They observed a skewed, clustered, and random distribution of the SWDS in the area. Certain factors influenced the distribution of the SWDS and they include capability of paying for waste disposal services, and accessibility. Sequel to this, densely populated areas made use of the container collection system which is central to the area while high income residential zones used the collection system carried out door-to-door. Several residents in low-class and semi-urban centers had the challenge of accessing the regular waste collection system. Residents with challenging waste disposal method are very likely to be at risk of the potential negative effects of bad waste management. Volsuuri *et al*. [9] used spatial analysis to determine and map the spatial locations of household waste bins and communal waste containers in Tamale region of the area as shown in figure 8. These maps will no doubt serve as a guide in the proper management of waste in the region.

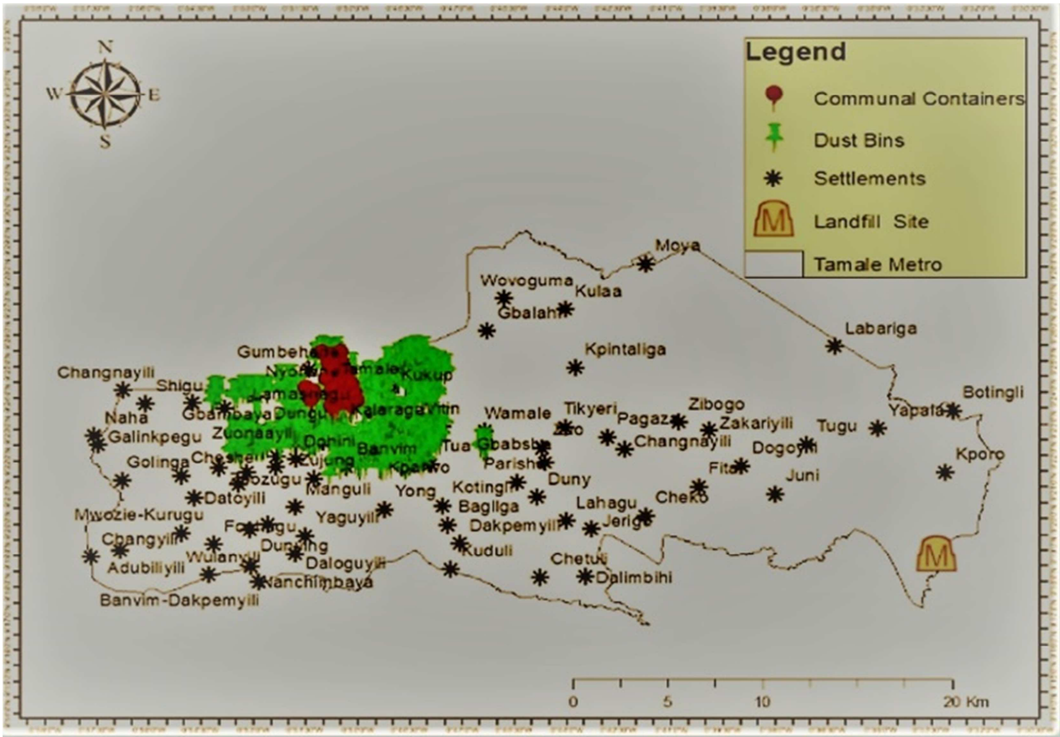


Figure 8*. Geo-spatial distribution of waste bins belonging to households in Tamale (after [10]).*

In solid waste disposal management, spatial analysis has the advantage of drastically reducing cost and time spent in the selection of disposal sites and also aids in the future monitoring of such sites. The method helps in waste collection optimization in a given area, identifies suitable sites for waste dumping and even recycling, and is also efficient in the mapping of refuse hotspots for effective allocation of resources [11]. Spatial analysis also has the advantage of assessing and monitoring activities related to the handling and management of wastes in any region or district. In general, spatial analysis increases the efficiency of waste management systems. However, low quality and inadequate data can negatively impact the application of spatial analysis in solid waste disposal management.

4.4. Spatial Analysis in Marketing

Data analysis can also be a veritable tool in marketing and data-driven business decision making. It permits businesses to represent, in a visual manner, complicated datasets on interactive and simplified maps, allowing for easy identification of correlations, trends, and patterns. It makes available a wider and clearer view of the market which can drive key business decisions with utmost confidence. This tool enables businesses to locate perfect target market environments through analysis of socio-economic, demographic, and psychographic data represented on maps. Businesses can leverage on these information to channel their marketing strategies towards meeting the definite needs of their target customers and clients. With spatial analysis, there can be a segmentation of the target market based purely on several factors including lifestyle, income, age, purchasing attitude, etc. Businesses can create individual marketing strategies that can appeal to different market segments, thereby increasing the probability of achieving success. The location, customer base and market share of business competitors can also be understood with the aid of spatial analysis. Based on such information, businesses can take critical decisions regarding market entry, and even expansion. Also, highly strategic locations that can serve as delivery outlets, retail points, and warehouse locations which are critical in the optimization of distribution networks can be identified using spatial analysis. This increases the satisfaction of customers by way of efficiency in availability of products and services on one hand, and saves cost on the other hand.

In a 2023 study on the density of community group buying points (CGBPs) in Xi'an city, China, [12] utilized point of interest (POI) data of 2,433 CGBPs to evaluate their accessibility, spatial distribution, and operation mode within the area while proposing the location optimization model. They observed that the CGBPs were distributed spatially in the form of clusters at $\alpha = 0.01$. The mode of operation of the CGBPs was separated into preparation, marketing, transportation and self-pickup. The spatial arrangement of the CGBPs was driven by such factors like population density, housing type, number of communities, and GDP. The study also reported that the distribution of the CGBPs was influenced by protection regulations for cultural relics, land use, and urban planning, and that it showed an elliptic distribution style having a little oblate nature. The density of the CGBPs revealed a low-high-low circular distribution arrangement from the Tang dynasty palace outwards as shown in the kernel density map of figure 9.

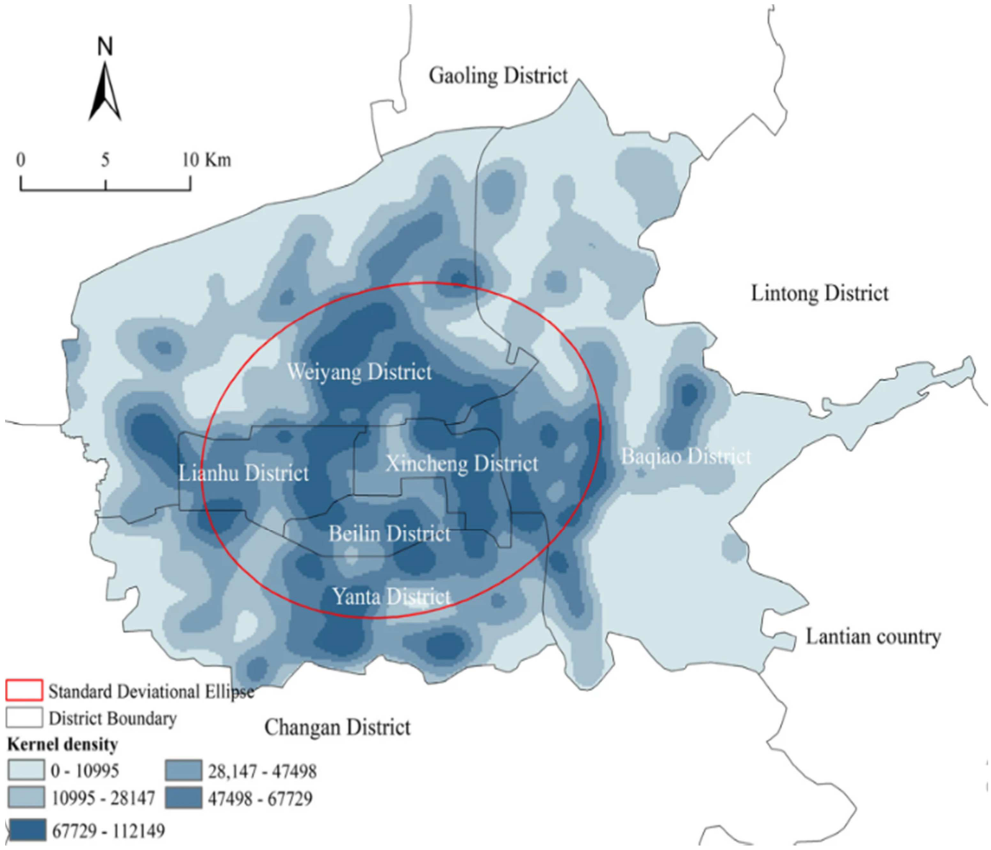


Figure 9. *Kernel density map showing the standard deviational ellipse of CGBPs in the area (after [12]).*

One of the advantages of spatial analysis in marketing is in the visualization of market trends. This helps in the identification of hotspots, patterns, and trends across various cities. It helps in segmenting target markets based on certain factors in addition to aiding in revealing market opportunities that are unexplored. Spatial analysis also has the advantage of providing vital business information that can drive the establishment of distribution outlets within a region. The method reveals potential business risks such as closeness to crime prone areas, natural disaster prone areas, and areas with environmental concerns which enables businesses to consider mitigation strategies. On the contrary, there is some level of complexity associated with the use of spatial information and data in marketing. Any problem related to low data quality and accuracy errors are enlarged due to the data size and the possible dependencies created.

5. Investigating Spatial Analysis Techniques

Three different applications of spatial analysis techniques will be discussed. They include Buffer analysis, interpolation, and Kernel density analysis also known as multi-distance spatial cluster analysis. Examples of the techniques, advantages and limitations will be highlighted thereby making it possible to discuss on how it is related to aspatial method.

5.1. Buffer Analysis Method

Buffer analysis is a spatial analysis technique used to identify features or characteristics within a certain distance of a central point or feature [13]. It is commonly used to identify patterns and relationships within spatial data and is particularly useful for identifying features that are located within a specific distance of a central point or feature of interest.

This technique is commonly used in GIS to identify potential areas of impact, such as areas that may be affected by a proposed development or areas that may be suitable for conservation efforts. Buffer analysis is widely used in many fields of study such as urban planning, environmental management, natural resources management, wildlife conservation, transportation planning, crime analysis, and emergency management.

5.1.1. Assessing the Impacts of Urban Sprawl on the Spatial Patterns of Urban Heat Islands

An Urban Heat Island (UHI) is described as a phenomenon in which urban locations experience increased temperatures than adjoining rural areas [14]. Urban heat island is a widely recognized observable fact that has a notable effect on the society and environment. The effects of UHI can be seen on various factors such as climate, vegetation, water quality, air pollution, human health and energy consumption in urban areas. The turning of natural land to urban surfaces changes the energy processes of the land and causes an increase in temperature, which leads to the formation of greater UHIs [15]. Their study aimed to widen prior studies and make available pertinent information from recent aspects through investigation of the spatio-temporal variability of Surface Urban Heat Island (SUHI) in addition to thermal comfort and estimating the connection of intensities of SUHI and concentrations of air pollutants in Tehran.

Swamy, G. *et al*. [15] used buffer analysis to identify the effect of urban sprawl on the spatial styles of urban heat islands in the metropolitan area of Tehran. They used Landsat images from four different time periods (1986, 2001, 2007, and 2016) and temperature data from meteorological stations to map the urban heat islands in Tehran. They then applied buffer analysis to identify the areas within different distances of the city center that were affected by urban heat islands.

The main purpose of buffer analysis used in this study was to identify the effect of urban sprawl on the spatial styles of urban heat islands in Tehran. The authors wanted to understand how urban development affected the urban heat islands and how they changed over time. Figure 10 shows maps of Land use/land cover (LULC), maps of surface urban heat Island (SUHI), and maps of urban thermal field variance index (UTFVI) of Tehran for the period of 1989, 1999, 2009, and 2019 respectively for top to bottom.

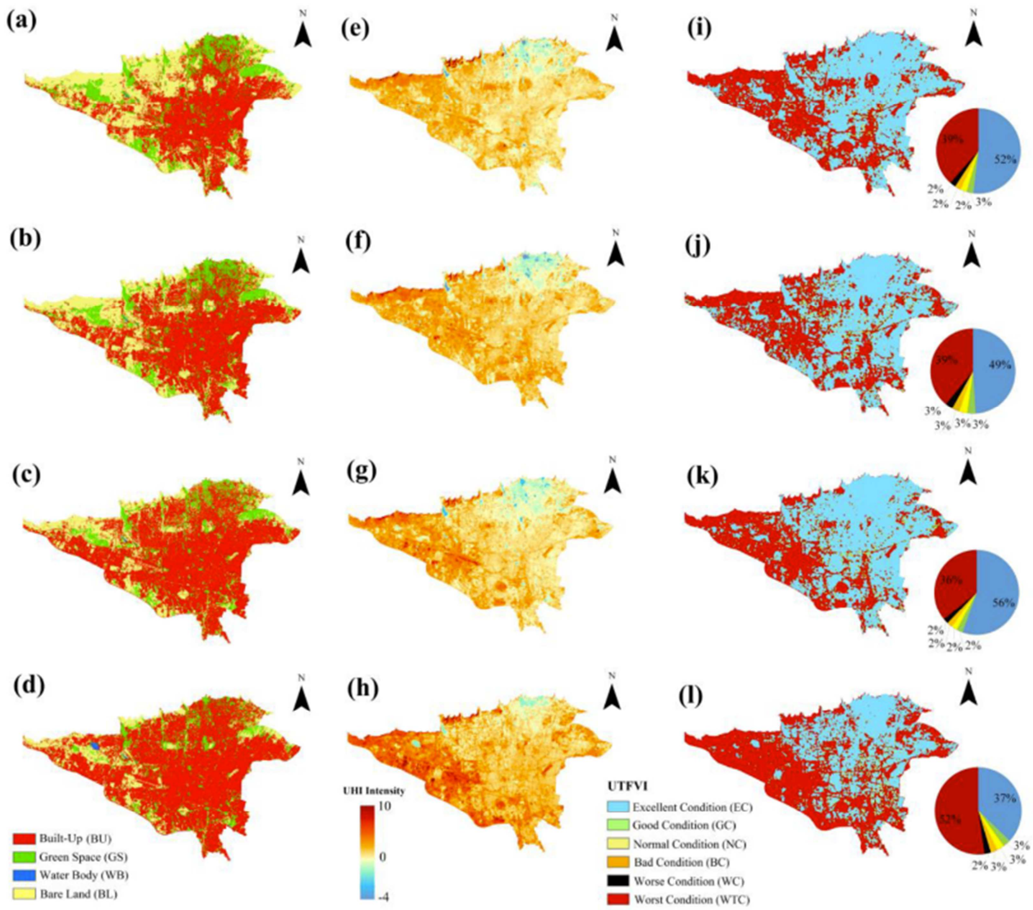


Figure 10. *(a–d) maps of Land Use/Land Cover (LULC), (e–h) maps of Surface Urban Heat Island (SUHI), and (i–l) maps of Urban Thermal Field Variance Index (UTFVI) of Tehran for 1989, 1999, 2009, and 2019 respectively for top to bottom (after [16]).*

Outputs of buffer analysis in this study were interpreted in relation to the spatial question set. The question was to identify the effect of urban sprawl on spatial styles of urban heat islands in Tehran. The output of buffer analysis was a map showing the areas within different distances of the city center that were affected by urban heat islands. The authors found that the urban heat islands had expanded over time, and that the areas most affected by the urban heat islands were located within 3-5 km of the city center.

One of the principal capabilities of buffer analysis is its ability to identify patterns and relationships within spatial data that may not be immediately apparent. This technique allowed the authors to identify the areas most affected by the urban heat islands and to track changes in the spatial patterns of the urban heat islands over time.

5.1.2. Aspatial Comparison

Aspatial statistics can be used to summarize and describe the urban heat island intensity distribution across the metropolitan area of Tehran. This can include measures like the mean, median, and standard deviation of urban heat island intensity.

Regression analysis can also be used to identify the relationships between urban heat island intensity and various factors related to urban sprawl, such as population density and land use. This can be achieved using linear or non-linear regression models.

5.2. Interpolation Technique

Interpolation is a method employed to roughly calculate the value of a parameter at areas where such variable has not directly been determined. This is done by using data from nearby locations to infer the variable's value at the unmeasured location. The interpolation process involves selecting an appropriate interpolation method, such as inverse distance weighting (IDW) or kriging, and then applying it to the data to determine the variable's value at the unmeasured locations.

The principal aim of carrying out interpolation is to determine a variable or parameter's value at locations where it has never been directly measured. This is very useful in a variety of applications, such as weather forecasting, environmental monitoring, and GIS. Interpolation can also be used to create a continuous surface from a set of scattered point data, such as elevation data from a topographical survey.

One of the strengths of interpolation is that it can be used to estimate the value of a variable at locations where it is difficult or expensive to measure directly. It can also be used to create a continuous surface from scattered point data, which can be useful for visualization and analysis.

Interpolation also has some weaknesses. One of the main weaknesses is that the accuracy of the interpolated values is dependent on the density and distribution of the measured data. If the measured data is sparse or not well-distributed, the accuracy of the interpolated values may be low. Additionally, interpolation methods are based on assumptions and simplifications, which may not always be appropriate for the data being analyzed.

Interpolation is related to traditional statistical approaches in that it uses statistical methods to estimate the value of a variable at unmeasured locations. However, interpolation is specifically designed for spatial data, whereas traditional statistical approaches are more general and can be applied to any type of data. Interpolation methods such as IDW and kriging are based on assumptions about the spatial relationships between the measured data and the unmeasured locations, whereas traditional statistical methods may not make these assumptions.

Mapping of Soil Organic Carbon using Ordinary Kriging Method

In a 2013 study titled "Mapping soil organic carbon stocks in Zambia, using ordinary kriging", [17] applied ordinary kriging method to create a surface soil organic carbon (SOC) map in Zambia. They collected soil samples from various locations across the country and measured the SOC content at each location. They then used the point data to interpolate SOC values across the entire study area using ordinary kriging.

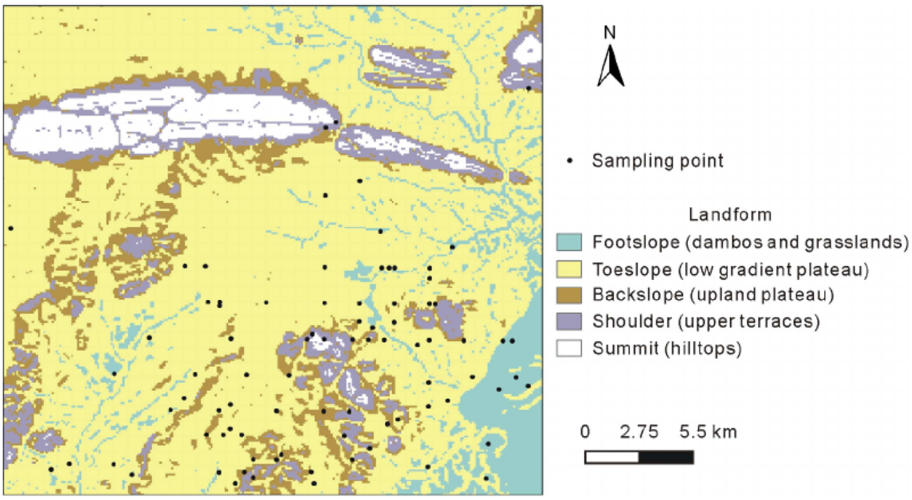


Figure 11. *Areas of soil sample collection as recorded in Zambia's landform map (after [17]).*

The spatial technique used in the study is ordinary kriging, which is a type of interpolation method that uses the values of the point data to estimate the value of the surface at any point. The purpose of this method is to produce a continuous surface map of SOC across the study area that accurately predicts the variability of SOC spatially in the area. The strengths of ordinary kriging include that it can produce accurate predictions of the surface and that it can account for spatial autocorrelation in the data. Figure 11 shows areas where soil samples were taken as recorded in Zambia's landform map.

The outputs of the study show that the interpolated SOC surface map accurately predicted the spatial variability of SOC within the area of study, with the highest SOC stocks found in the southern and western regions of Zambia. The study also identified areas with high potential for increasing SOC stocks through conservation agriculture practices. The technique relates to traditional statistical approaches in that it uses statistical methods to analyze spatial data and produce a surface map. The main difference is that traditional statistical approaches typically focus on analyzing a single variable, while this study used spatial interpolation to create a surface map of multiple variables. Figure 12 is the map of the spatial distribution of SOC produced on the basis of data measured and fitted variogram in an area of Zambia selected, and figure 13 shows map of standard error of spatial prediction of SOC within a selected area of Zambia [17].

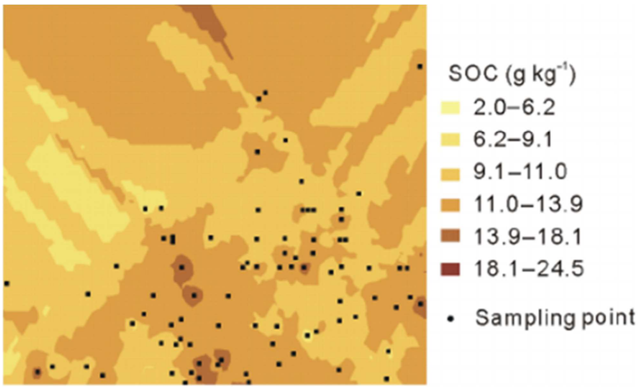


Figure 12. *Map of spatial distribution of SOC within an area of Zambia (after [17]).*

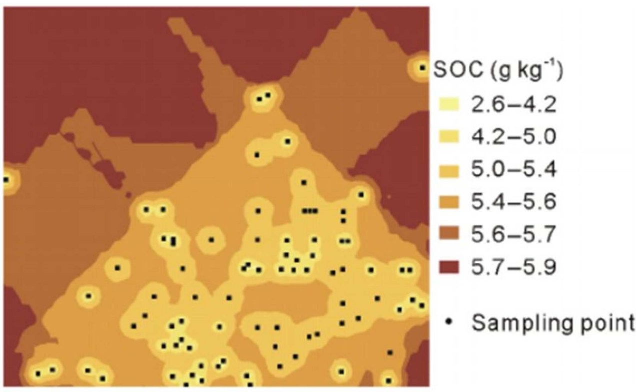


Figure 13. *Map of standard error of spatial prediction of SOC within an area of Zambia (after [17]).*

5.3. Kernel Density Method (Multi Distance Spatial Cluster Analysis)

Kernel density analysis is a spatial analysis method applied in the determination of the probability density function (PDF) of a set or group of data points. The technique uses a mathematical function, called a kernel, to estimate the PDF of the data points. The output of kernel density analysis is a surface that represents the density of data points in the space being analyzed. The Kernel density technique takes into consideration the relative position of features [18].

It is often used to analyze point data, such as crime incidents or land use changes, in a geographic context. One of the strengths of kernel density analysis is its ability to handle non-uniform data distributions, such as those that are skewed or have multiple modes.

In the interpretation of the outputs of kernel density analysis, the spatial distribution of data points is the main focus. High density areas represent areas with a high concentration of data points, while low density areas represent areas with fewer data points. The outputs can be used to identify areas with high or low data point density, as well as to compare the density of data points across different areas.

Kernel density analysis is a useful spatial analysis technique for estimating the probability density function of a group of data points. Its strengths include the ability to handle non-uniform data distributions and account for spatial autocorrelation, while its limitations include sensitivity to the choice of kernel function and bandwidth and a lack of robustness when dealing with outliers or sparse data. The outputs of kernel density analysis can be used to identify areas with high or low data point density and to compare the density of data points across different areas.

Analyzing Toronto Homicide Data Using Kernel Density

The kernel density for crime rate related to homicide in Toronto was created in ArcMap to investigate whether the homicide crime is not statistically significant, diffused, or clustered as shown in Figure 14. It is feasible to clearly observe the patterns of the data and establish whether the rates of homicide crime in this area is concentrated, random, or dispersed.

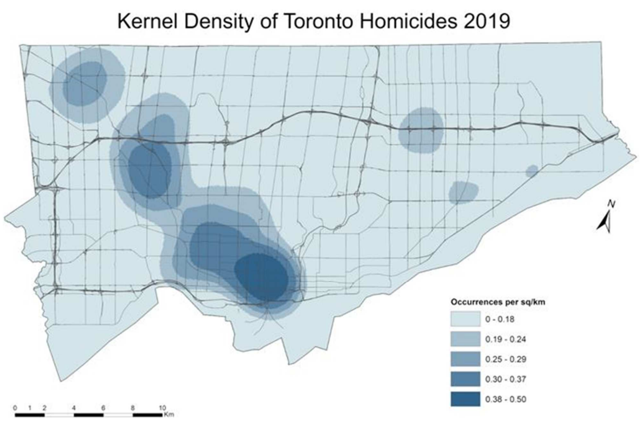


Figure 14. *Map of Kernel density of Toronto homicides of 2019 (after [19]).*

6. Conclusion

It can be clearly observed from this paper that spatial analysis is a very powerful tool in analyzing geographic datasets. It enables one to handle challenging difficulties that are based on location and acquire a robust knowledge of what and where it is taking place in the environment. The concept transcends simple mapping to permit one to inquire into the characteristic features of areas and their interactions. It lends new perspectives to one's decision making. Spatial analysis takes into account geographic information and the spatial relationships between data points making it a very efficient tool in crime monitoring, land cover classification, surface urban heat islands monitoring, urban thermal field variance index assessment, urban and regional planning, public health studies, urban solid waste management and many more. In fact, it is an invaluable tool in geographic information management.

Author Contribution

Chidiebere Agoha and Armstrong Awuzie contributed to the conceptualization and design of the study. Tochukwu Mgbeojedo, Chukwuebuka Onwubuariri and Joy Njoku reviewed existing literature and data. Francis Akiang and Emeka Epuerie developed the imageries for statistical analysis. All the authors contributed to writing the research draft, read and approved the final manuscript.

Data Availability

The datasets analyzed during the current study were obtained from the study area, and some have been made available with the article. The remaining datasets not submitted with the manuscript are available from the corresponding author on reasonable request.

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Ethics Approval

The paper reflects the authors' research and analysis completely and truthfully.

Conflicts of Interest

The authors declare no competing interests.

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