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Correlation of Geographic Information System with the Evolutionary Theory of Spatial Analysis

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***Abstract*—** Geographic Information system (GIS) is a powerful computer-based tool used in building spatially explicit models for comprehending real-world processes. Consequently, it has attracted extensive research efforts over the past half-century across the globe. Also, spatial analysis is a significant area of application within geographic information science or a computer-enhanced geographic data environment. The reason is that virtually all the occurrences we encounter daily assume a spatial context. GIS is suitable and effective for providing the requisite solutions to various problems related to these manifestations including representing, analyzing, and knowing their spatial dimensions. Thus, this review focuses on the relationship between GIS and the evolution of spatial analysis. It offers an in-depth discussion of the evolutionary theory of spatial analysis with a specific emphasis on quantitative geography, regional science, spatial statistics, and computational geometry. Summarily, GIS is highly effective in handling spatial analysis because of its ability to manage both planar and attribute data in an integrated manner.

***Keywords*—** Geometry; GIS; Modeling; Spatial Pattern; Statistics

I. INTRODUCTION

Spatial patterns and processes have peculiar characteristics, which present the basis for spatial analysis. For instance, spatial dependence suggests that spatially located semantic information provides clues about the existing fact of near positions. This is based on Tobler's hypothesis that one thing is connected to the other, but nearby things are more linked than things that are far apart, or nearby units are in some way associated. The spatial analysis emphasizes the explicit measurement of properties and relationships, with due consideration to the spatial location of the phenomenon under study [1]. The spatial analysis uses the data on spatial features to comprehend various simulations of reality. It may be developed and made interactive through alteration, manipulation of maps, and mathematical facts. Also, Cocula [2] suggested the methods of statistics, which could be ascribed to a particular geographic database.

The beginning of spatial analysis is spatial thinking. Thinking spatially includes spatial sensing with reasoning processes to support spatial understanding. It equally comprises visualization and interpretation of location, distance, direction, patterns, networks, movement, spatiotemporal modification, etc. [3, 4]. Spatial thinking depends on a useful combination of three components, that is, principles of space, tools of representation, and processes of reasoning. By comprehending what the space means, its characteristics (e.g., dimensionality, continuity, proximity, and separation) can be used as a means for structuring problems, finding answers, and expressing solutions. By expressing associations in spatial structures (e.g., maps, and multidimensional scaling models), it is possible to recognize, remember, and analyze the static and, through alterations, the dynamic features of objects and the interactions between objects. All of these make spatial thinking an important concept in science, technology, engineering, arts, and mathematics. Furthermore, quantitative geography deals with the practical approaches to the assessment of spatial phenomena, issues and problems regularly over time. Analyzing spatially–linked features is done by describing location attributes in different areas and then studying their interrelations in space. Thus, spatial analysis is connected to other areas of studies such as geography, position analysis, and GIS, etc.

GIS has greatly impacted mainstream geographic research and applications through constant evolution in the past decades, and it has demonstrated its prospective benefits to several related disciplines [5]. GIS is an assemblage of a computer-based system for collection, storage, manipulation, analysis, visualization, and displaying geospatially reference information. It is a broad technology [6], which mainly encompasses mapping science or surveying, geography, information technology, etc. Also, the contemporary innovations in computer science have driven GIS into a new era– big data GIS [7]. Nearly every historical literature on GIS consistently acknowledges the

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knowledge and scholarship of those who sought to organize, visualize, and interpret spatial data. GIS affords us the capacity required for handling spatially referenced data through manipulation, analysis, statistical application, and modelling of spatial data. The GIS allows for the assessment of spatial patterns and the determination of the correlation between human activity and the physical environment [8]. It has delivered a more effective and quick capacity to investigate spatial forms and processes. Therefore, this paper is aimed at reviewing the correlation of GIS with the evolution of spatial analysis. Specifically, detailed discussion is presented on the quantitative geography, regional science, spatial statistics, and computational geometry with emphasis on input using the GIS.

This paper is organized into four sections. Section I contains the introduction of the study, Section II contains the literature review, Section III explain the methodology, Section IV describes results and discussion, and Section V concludes the research work with future directions

II. RELATED WORK

GIS is a modern tool, which start with computerized modelling of landscape [9] and it has been of great influence in the development of the major areas of geographical thought. For instance, Aida, Amina, and Amra [10] used GIS in the quantitative geomorphological investigation of the Una River Basin, Bosnia and Herzegovina. The authors evaluated the shapes and topography of the study area. One of the major significance of the study is that the data obtained have a numerical value, are verifiable and have multiple applications in practice, etc.

Ndiaye, Ngom, and Oumar [11] conducted a study on computational geometry and GIS for digital terrain modelling. They addressed the need to get a mesh representation which can enhance the computation of surface flows in hydrologic and digital terrain models. It was found that Delaunay triangulation is an efficient tool because of its useful properties. This corroborates a result by Qiu et al. [12] that it is faster and more accurate for a true three-dimensional terrain modelling.

Nyadanu, Osei, Nawumbeni, Adampah, andPolishuk [13] carried out a spatial analysis of public health in Ghana. Diarrhoea was used as a case due to the paucity of such studies in Ghana, and the non-existence of such studies nationwide. They assessed the spatial epidemiological spread of diarrhoea and identified the hotspots using exploratory spatial analysis of GIS. The methodology used was validated by Robin et al. [14] in their exploration of map and spatial data utilization. Of course, the study indicates the significance of spatial analysis with GIS in the health sector as supported by similar studies (e.g., [15, 16]).

Hasan et al. [17] adopted spatial analysis based on statistical data to produce an innovative generation of spatial information. This corroborates an earlier study by Chabuk, Al-Ansari, Hussain, Knutsson, and Pusch [18], which indicated that new information, can be produced using existing data.

III. METHODOLOGY

This review began with a literature search through electronic databases. The emphasis is on the connection between GIS and the evolution of spatial analysis. Specific terms used to identify the relevant literature include ‘GIS’ AND ‘Spatial analysis’.

The literature search resulted in the collection of several articles, which the researcher further subjected to exclusion and inclusion criteria. Consequently, the articles that meet the criteria were retained, reviewed in full detail, and analyzed.

IV. RESULTS AND DISCUSSION

GIS affords the spatial analysis tools for better discovery, quantification, and understanding of geographic phenomena and also determining what actions to take. The development of spatial analysis may be traced through four distinctive areas of geography as presented in the following subsections.

4.1 Regional Science

The geographic disparity in resources allocation and the irregularity of administrative rules usually leads to inequality [19] or imbalances across certain area [20]. This has led to the occurrence of regional science as a concept. Regional science deals with the cautious and persistent investigation of societal issues with spatial extents, using diverse analytical research [21]. Of course, many reviews on the origin of regional science are in the literature (e.g., [22, 23]).

Regional science has advanced into an extensive multidisciplinary area regarding regional and urban issues. It has shown its nexus with several applied disciplines to explore diverse problems affecting metropolises and regions. Its growth has led to the growth of numerous groundbreaking quantification techniques including the following:

i. interregional input-output model
ii. prediction of population drift
iii. evaluation of commercial flow
iv. industrial location analysis
v. game theory
vi. transport planning
vii. shortest path analysis
viii. trend assessment
ix. urban changes
x. spatial interaction models
xi. the interregional linear programming model

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Although regional science is a multidisciplinary field; the more evident contribution comes from Economics and Geography. Economics afford us with models (micro and macro scale), which are more or less spatial, and geography provides spatial science recognition and several tools for territorial understanding.

Assessment of spatial information is a major property of GIS [24]. Both GIS and spatial analysis may be traced to the emergence of regional science. On the other way round, progresses in GIS and spatial analysis have endowed researchers in evaluation of regional growth by showing multifarious socioeconomic configurations and by classifying diverse development paths [20]. Also, regional science makes a hypothetical analysis of socioeconomic events and tries to create spatial representation in a normative and deductive way.

Current and consistent land information is essential for managing resources, and for dealing with regional growth. This information has been traditionally stored in manual records and displayed on paper maps, which are difficult to store, maintain, update, and analyze. This traditional approach involving paper maps is also expensive to prepare. Nevertheless, the advent of GIS has given rise to an effective and accurate method of mapping procedure (see [25-28]. Thus, GIS application enables the creation of information products that are more functional. Also, GIS enhances the planners' capacity to evaluate spatially referenced phenomena.

4.2 Quantitative Geography

Quantitative geography originated in the USA as a change from individual descriptive views to pragmatic law-making. It entails the study of statistical data, spatial data, and concept, and spatial processes simulations, etc. The quantitative revolution mean a time when economic ideologies and physical concepts such as the law of gravity were employed in modeling and defining social progresses and the systems of, for instance, migration, and trade, etc. [29].

Quantitative skills and processes depends on the knowledge on computerized and data management skills and also the skill of critical thinking about quantitative methods to make knowledgeable and expert decisions regarding statistical analysis [30]. GIS which is a computerized tool that usually represents spatial data either in vector or raster models [31] is the most essential technique in quantitative geography. GIS has been in use for many years to integrate social and territorial information in quantitative research. Quantitative geography also contributes significantly to GIS in various ways. For example, it played a significant role in the rudimentary ideas of GIS architecture, the concept of attribute table based on geographic matrix, the abstraction of geographic space based on geometric principles or the idea of vector GIS.

4.3 Spatial Statistics

The spatial analysis deals with the application of statistical techniques to evaluate spatial data using location-specific information, height, distance, and topology, etc. [32]. Therefore, the growth of spatial statistics is linked to analysts seeking better ways to depict data on maps and test hypotheses based on some standard pattern or structure. Spatial statistics is the statistical technique in which spatial locations are significant in data analysis. Contemporary spatial statistics are used in the process of defining areal distributions, the nature of spatial connections, the complexities of spatial associations Hypotheses about settlement patterns etc. It involves any of the recognized procedures which study entities depending on their topology, geometry, or geographic characteristics. With spatial statistics, it is feasible to define the spatiotemporal distribution of natural variables quantitatively.

The traditional method in the spatial data analysis is to standardize a global model. This global statistic assumes homogeneity (stationarity) of links between dependent variables and predictors. However, the hypothesis is characterized by severe limitations for work in spatial data analysis. Hence, local spatial statistics called Geographically Weighted Regression (GWR) have been presented. GWR is a statistical method for exploring spatial heterogeneity between predictors and outcome variables [see 33, 34]. Studies have proven that incorporating GWR into ArcGIS package produces better-quality quality of possible results. For instance, Nkeki, and Osirike [35] shows that the GIS-based GWR can be used for spatial presentation of the parameter estimates and coefficient of determination as regard all variables in a raster surface as well as vector map.

4.4 Computational Geometry

The spatial features in the vector format are indicated by points, lines, and polygons [36, 37]. These geometric or planar structures are explicitly represented using computational geometry. Thus, computational geometry is an area of computer science used in finding the most efficient algorithms to solve geometric problems. It resulted from a generalization of the study of procedures for sorting and examining 1–dimensional space to problems relating to multidimensional inputs.

Geometric data about features on earth usually stored as coordinates and topology [38] are the basis of spatial information. Computations based on these geometric data are often performed in a GIS environment. GIS or a geometric algorithm helps in data correction, data retrieval, data analysis, and data visualization. Recent researches demonstrates the effectiveness of GIS-based computations using geometric data including location (see [39-43]), shape (see [44]), proximity (see [45, 46]), spatial distribution (see [47-50]), network (see [51]), and others.

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V. CONCLUSION AND FUTURE SCOPE

The geographic Information system is a computerized tool, which offers a means for the systematic and meaningful use of geospatially referenced data or information. It is used to find the solution to locational or geographic problems. Knowing the geographical location of things or events and their relationships to one another (locational referencing) using geographic identifiers enhances the understanding of the phenomenon and it thereby forms the core for intelligent decision making.

The primary pluses of GIS application in comparison to other information systems lie in two important factors. First, GIS can integrate and handle an enormous bulk of data from diverse sources. Second, it can perform spatial analysis using spatial and non-spatial or attribute data to solve real world problems. Therefore, it is very significant in the evolution of spatial analysis.

Of course, spatial analysis is very important in geographic information science because nearly all the phenomena we encounter daily assume a spatial context. The GIS has demonstrated to be a suitable tool for effectively providing the required solutions to various problems related to these daily occurrences. Finally, big data emergence and its versatility suggests that future GIS have to be constructed by applying cloud computing and Internet of Things. The GIS philosophy and spatial thinking concept must however be adhered to.

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