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The Application of GIS Technology in Environmental Management in Ghana

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Abstract

This article traces the evolution of Geographic Information Systems (GIS) from the early days of cartography into contemporary time, within the context of environmental decision-making. The quantitative revolution influenced the development of cartography. In the 1970s computerized mapping and GIS automated cartography. The format and management of spatial data got transformed in the 1980s with the development of geo-query in GIS. In the 21st century GIS included social perspectives in managing GIS data bases. The technology was introduced into higher educational institutions of Ghana in the 1990s. Government departments recognized it to be an important tool for resolving spatial problems. Its potential for consensus building is yet to be fully exploited because the technology was considered to be complex. This was solved by shifting from generating GIS codes, to graphical interface and spatial model applications. From its initial focus of mapping and spatial database management, GIS now concentrates on varied degrees of complexity in modeling. Uses to which the technology has been put in Ghana include mapping the spatial distribution of Buruli Ulcer; using Digital Elevation Model (DEM) in geospatial and hydrological modeling to delineate drainage and watershed to predict flood prone areas in parts of Accra; and, in groundwater projects to select well sites for drilling bore holes. It was concluded that continued application of GIS in Ghana and other parts of the world could result in rare and timeless solutions being found to spatial and environmental problems that confront humanity.

Keywords: Ghana, land use allocation, conflict, consensus building, geographic information system

1. Introduction

Managing the environment is basically a spatial enterprise. The data needed for environmental management basically requires two descriptors: namely, the exact location of spatial phenom `1ena, and a clear description of physical features of spatial phenomena. The first maps that were developed sought to address the "where is what" question. The quest to establish the accurate location of physical features encouraged early geographers, explorers, and navigators to accurately represent on paper unexplored places of the earth.

The original objective for making maps was the development of exploratory guides for explorers. But that has shifted to establishing spatial relationships between physical features/natural phenomena and man-made phenomena. This marked the turning point in the use of maps. There has been a shift in the use of maps from describing geographically designated areas to establishing relationships between geographically mapped data and geographically based decision factors. The use of modern maps to address environmental issues have developed approaches that are radically different from previous ones. Therefore, an understanding of the evolution of mapping up to present day cartographic technologies are necessary for environmental policymakers and administrators to appreciate their applicability.

2. Stages of Evolution

The onset of the quantitative revolution in geography during the late 1950s and early 1960s caused decision-making in the spatial sciences to become quantitative (Burton, 1963; Barnes, 2001). This resulted in the development of mathematical models for the spatial sciences to guide decision-making (Enemark, Williamson, & Wallace, 2005). Computerized mapping and Geographic Information Systems (GIS) technology provided an efficient means of handling large volumes of data; and are capable of doing effective analysis of spatial data. They rapidly replaced manual procedures of spatial analysis (Jones, 2014).

3. Computerized Mapping

In the early 1970s the process of drafting maps got automated by computer mapping (Newman, 1949; McHarg, 1969; & Berry and Ripple, 1994). Points, lines, and areas that determine spatial properties of geographical features on maps begun to be represented as sets of 'X' and 'Y'coordinates. Through computer technology this data rapidly connects to produce geographical features in different colours, scales, and map projections. As a result of using computer assisted technology to produce maps, cartographic representation of object on paper shifted from representing geographical features in 2 dimensions to include 3 and 4 dimensions.

This period established most of the crucial principles and procedures for modern GIS technology (Abler et al., 1971; Kimerling, Muehrcke & Muehrcke, 2016). A major benefit that was derived from computer assisted cartography is the ability to redesign parts of a map without much difficulty. With this advantage in GIS, it became possible to quickly update maps within a few hours which previously required several days. Another advantage GIS had on cartography was the radical shift from analogue inked lines on paper to digitized data sets on computer storage devices.

4. Spatial Management of Databases

The 1980s experienced a change in the format and environment of mapped data. This came in the form of the development of spatial data base management systems which merged computer mapping with data base management systems of traditional maps (Burrough, 1987; Shepherd, 1991). Identification numbers were given to every geographic feature. For example, a cocoa farm or a timber concession area. This made it possible for data base mangers retrieve information about any location on a map. Also, it has become possible to geographically search for locations that meet specific criteria and the results of the search would be displayed on a map. For example, a spatial database with data on different types of vegetation and soil types could yield a spatial search result of all places that have the same vegetation and soil combination.

In the early days of the development of GIS there existed two data structures for encoding maps. Much debate went on as to which of the two data structures is the most suitable method for managing spatial data. The data structures which caused the debate are the vector data model and the rasta data model. Vector data is similar to the manual technique of representing map features as lines. These features are stored as 'X, Y,' coordinates. Rasta data models use imaginary reference grids to represent spatial units and stores the resource information in cell grids. The GIS community tried to determine which of the data structures is universally acceptable as a data model for capturing and storing geographic information. After much deliberation it was realized that the overall strengths of both formats are useful for advancing GIS as the new approach for capturing, storing, and retrieving geographic information for purposes of resource analysis and management (Hu et al., 2018; Yao & Li, 2018).

The debate arrived at the consensus that the type of data captured and the type of output to be generated should determine the type of data structure that would be appropriate to use. This dual nature of capturing data for spatial analysis revolutionized GIS as an approach for geographic studies and spatial analysis. Maps are represented as boundary units which are delineated by lines. For instance, ownership of property, power lines, right of way, and road networks constitute data structures in which lines are required to represent data. Natural features such as soil types, river systems, geomorphic landforms and representation of weather conditions consist of abstract representations of environmental conditions. The use of lines to describe such conditions depends on the type of statistical analysis of captured data, broad classifications of spatial of spatial distributions, and the judgment of the user.

The inauguration of the GIS age in cartography quickly increased the demand for accurate, standard, and available data, as well as reliable GIS data management infrastructure. Digitizing equipment continually got improved while automated scanners replaced manual digitizing tablets in GIS laboratories. This ushered in a new era of storing geographic data and map making. The problem of user judgment prompted regional, national, and international organizations to insure universal compatibility of between independent geographic systems. With the successful introduction of GIS as an approach to geographic studies and spatial analysis of captured data, the development of the GIS database moved from individual endeavors of gathering and storing geographic information to corporate investment in data base development on resource availability and use.

5. GIS Model

Progress in the development of GIS technology has resulted in the development of prescriptive analysis of spatial data. The automation of traditional mapping techniques has eliminated tedious and repetitive operations of previous techniques of making maps. The dawn of the mid 1980s witnessed the development of geo-query operations in GIS systems. As a result of these developments a user-friendly theory of spatial analysis emerged.

Spatial data started being represented in numerical form. The maps in a GIS system are a set of floating maps which enable the geographic analysis system to look down and across a pile of digital floating maps. Also, analyzing the spatial relationship of data between maps became possible to summarize through the medium of data base geo-queries or mathematical manipulations through the medium of analytic processing. Digital representation of data afforded GIS far reaching opportunities to quantitatively and qualitatively process data. GIS can therefore be said to have accomplished two technological breakthroughs in geography; namely spatial statistics and spatial analysis. From the foregone, it was generally recognized that GIS technology would greatly revolutionize environmental management.

Spatial statistic from GIS has been used to describe geographic distributions or spatial patterns of field data (Grekousis, 2020; Kirilenko, 2022). The statistics describe spatial variations of data. Spatial statistics has move from being descriptive to become prescriptive. This has enabled models to be optimized in geographic and spatial studies. Because of this it has become possible to use GIS to determine, for example, spatial relationships between crop yield and soil nutrients (Denton et al., 2017). Global Positioning System (GPS) is used to locate geographic positions of natural and man-made features. For instance, soil samples could be used to determine nutrient levels of farm units and spatially interpolate them into maps to establish spatial patterns of variation (Xie, Yang, Du, Zhao, & Huffman, 2012). Predictive techniques of GIS, used simple regression to do knowledge-based modeling in order to relate dependent mapped variables with independent mapped variables.

Applications such as those developed for retail marketing to forest management use spatial statistics to analyze mapped variables. The environmental sciences often rely on quantitative techniques of expressing relationships between systems. Spatial statistics have been found to effectively explain variations in geographic space. Therefore, floating maps in a geographic analysis system shows spatial distributions of mapped variables. In GIS each map is a variable; each location is a case; and each map value is a measurement.

Spatial analysis has developed overtime to have several applications (Zhu, 2016; Argent, 2004; Blaschke, Lang, Strobl, & Zeil, 2000). For instance, it is possible to characterize the supply of charcoal by taking the accessibility of fuel wood harvesting lots and charcoal selling communities into consideration. Wildlife officers are able to use road proximity and housing density to map human activity. This information can then be used to outline human habitations within a specific geographic area. Also, town and country planners are able to use spatial analysis to produce panoramic views of landscapes to facilitate decision-making when it comes to the development of facilities such as recreational facilities and scenic overlooks. A case in point is the panoramic view of the Kwahu Scarp in the Eastern Region of Ghana and the scenic overhang of the Nakpanduri Scarp over the Kusasi-Mamprusi-Bimoba areas of the Upper East Region and North West Region of Ghana for paragliding activities, tourist purposes, and the development of tourist facilities for tourist. When it comes to soil science spatial analysis for environmental management is able to identify places of high sediment load based on proximity to riverine systems and intervening slope vegetal cover, and soil type. Ground water and atmospheric scientists are able to create the complex movement of ground water and atmospheric phenomena as they respond to environmental conditions affecting their flow/movement through space.

Mathematics is recognized as a powerful tool that is used to support spatial analysis (Kintigh, 1990). A form mathematics called map algebra has been developed for GIS to do sequential processing of spatial operators for map analysis (Mennis, 2010). It uses entire maps that contain innumerable numbers as variables for spatial equations.

For instance, map algebra can be used to determine changes in the lead concentrate of an aquifer by using the algebraic expression:

$$\% \text{ change} = ((\text{new value-old value})/\text{old value}) \times 100$$

The average values for two separate time periods would be substituted in the expression to determine the percentage change in lead concentrate. With map algebra, simple averages are replaced with spatially interpolated maps using data gathered from the field. Percentage changes are examined at each location of the map to generate required percentage changes on a map. To identify areas of unusual percentage, change the standard normal variable (SNV) would be evaluated with the expression:

$$\text{SNV} = (\text{new value-\% change average})/\%\text{ change standard deviation}) \times 100$$

This procedure normalizes the change in lead concentration with areas of unusual increase with SNV values that are greater than 100. The generated results can be superimposed on a demographic map to show areas of different levels of environmental risk.

Traditional mathematical applications and advanced mapping techniques have been incorporated into modern GIS software. GIS makes it possible to add, subtract, multiply, divide, exponentiate, root, log, cosine, and integrate maps. GIS maps are basically a set of organized numbers. The integration of several mathematical operations into GIS has resulted in the creation of new operations with respect to spatial coincidence and juxtaposing values within and between maps.

Distance has been defined as ‘the shortest straight line between two points’ (Goodchild, 2002). This definition is not suitable for most environmental applications. In environmental applications phenomena are not arranged in straight lines (Laniado, Volkovich, Scellato, Mascolo, & Kaltenbrunner, 2018). To overcome the anomaly in this definition in GIS the concept of distance has been replaced with the concept of absolute location and relative barriers (Berry, 2011, 1987).

Another tool for spatial analysis is landscape analysis. Quantification of landscape structure is required for the study of landscape function and change. This has resulted in the development of landscape metrics (Hay, Blaschke, Marceau, & Bouchard, 2003). Relationships are arrived at by analyzing the shape, pattern, and arrangement of landscape elements which are spiritually depicted as patches (individual polygons), groups of related patches (polygons of the same type/condition), and whole landscape mosaics (all polygons). Convexity and mean proximity indices are used to determine per unit area of irregularly shaped parcels and average distances between patches as a measure of relative dispersion respectively. Fractual dimensions of landscape assess edge and interior of patches to determine whether they are simple shapes or complex shapes. These landscape indices are used to determine landscape fragmentation caused by for example shea tree harvesting. This can then be used to examine changes in wildlife habitat.

GIS has radically transformed environmental science. The tools and modeling approach it has introduced to environmental studies has heightened the accuracy of record keeping systems, and turned decision-making models into efficient decision support tools.

6. Spatial Thought and Discourse

The 1990s built the cognitive stage and data base for the furtherance of GIS development in the 21st century. This paved the way for GIS to go beyond mapping, management, and modeling to include spatial thought and discourse. Initially, analysis models paid attention to management options which were considered to be technically optimal. The social perspectives were not incorporated in early management options of GIS. Incorporating the social perspective of management options posed a challenge to resource managers and environmental decision makers. This is because social issues such as human values, attitudes, beliefs, judgment, trust and understanding are subjective and were not amenable to computer algorithms and decision-making models which are quantitative.

The shift from technically feasible options of GIS modeling to socially acceptable options is not radically different from the way spatially constructed data communicates in a GIS environment. Communication is effective when interested parties are actively involved in the decision-making process. The incorporation of social options in the communication process results in consensus building and conflict resolution. Technical communication facilitates consensus building. This enables resource managers to put considerations identified by stakeholders into GIS inspired spatial models. At this stage the spatial models is implemented. At this point the spatial model presents different scenarios for the best alternative to be used for decision-making. When the model is combined with the active involvement of stakeholders in the decision-making process the outcome could be the achievement of group consensus.

Failure to reach consensus would necessitate the activation of conflict resolution mechanisms. This stage of communication is used during the stage of decision formulation. This is done by developing a conflict map which examines the outcomes of competing interest.

Traditional scientific approaches of conflict resolution have been found to be deterministic models, which are hardly effective in solving GIS related problems. The final result which are based on mathematical assumptions are usually biased. Arriving at mathematically determined solutions could still leave a lay person in doubt. As to its fairness. To overcome this problem GIS came up with an alternative approach which emphasized human rationalization and trade-offs this is done by persuading interested parties and discussing among groups the benefits each would have if they make sacrifices in one form or another. This is considered an effective decision-making approach GIS employs to optimize the use of GIS as a technique for spatial planning. The human rationalization process therefore uses the information system to focus attention on spatial units with unique distribution conditions and potential uses.

7. Current Frontiers of GIS Technology in Ghana

Computer mapping and spatial data base management are increasingly being made available. Concepts and procedures for GIS modeling and spatial reasoning/dialogue are constantly being perfected and made user friendly. GIS technology is increasingly being taught in higher educational institutions in Ghana. Government departments have over the years recognized GIS technology as an important tool for resolving land related issues. However, the number of users of the technology is still woefully inadequate because of the perceived complexity in receiving training to apply GIS knowledge to solve spatial problems.

8. Basic Questions in GIS Application

The questions that engage the attentions of GIS trainees and first time GIS users are mostly related to inventory (data) and analysis related issues (understanding). Figure 1 outlines these questions in relation to their functions and approaches.

The first question the GIS technology addressed when it began as an emerging technology in geographic studies was “Can this phenomenon be mapped”. Most GIS applications are concerned with updating and producing map products. Applications that answer the ability to be mapped question posed by GIS have become more and more user friendly with their output being far higher than the manual cartographic procedures for mapping objects. These applications mostly restate current inventories of mapped data.

The second question which engaged the attention of GIS was “What is where?” (location). This question establishes the linkage between digital maps and database management technology. It show cases current practices and at the same time explores possibilities of geographic searches in relation to coincidence of data. What is where questions in GIS greatly influence the design of system to capture data and display it with regard to location. Circumstances that surround these questions: “Can a phenomenon be mapped” and “What is where” actually determine the character and design of a GIS environment.

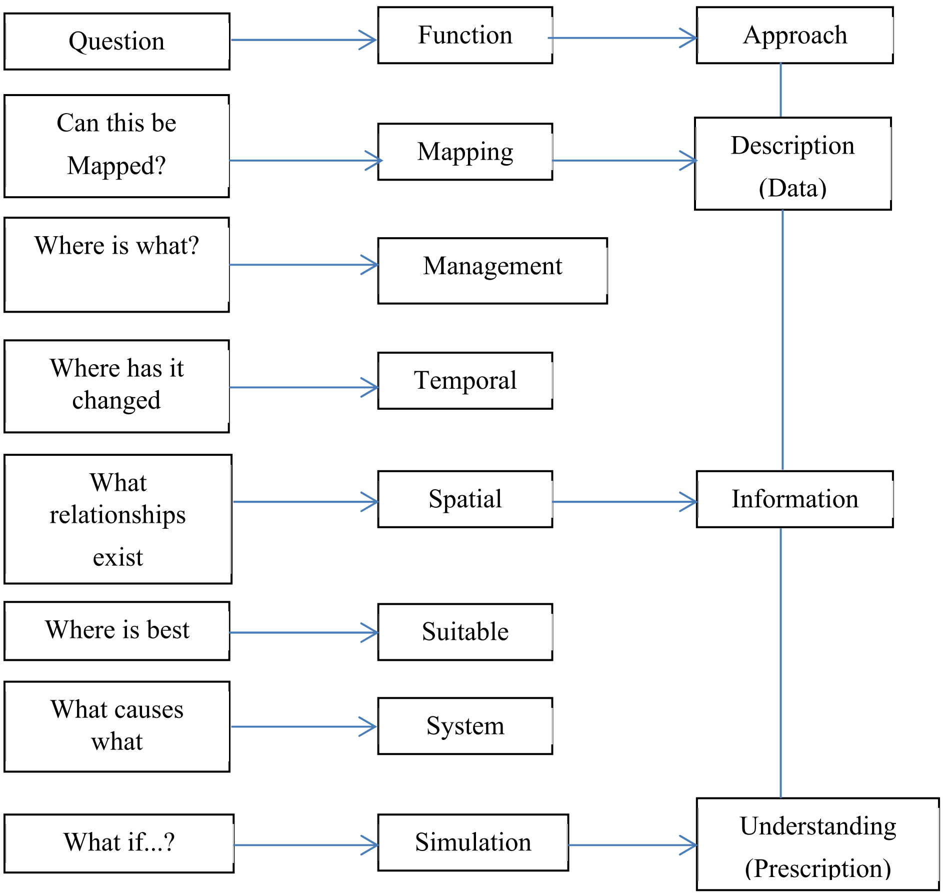

Figure 1. Questions GIS tries to solve

The question “what has changed?” deals with momentary analysis of spatial data. This question enables geographic data to be packaged for formulating plans and policies. When GIS users address questions of spatial change, it is most likely that mangers and planners want to see the reality of spatial change on the ground via a GIS medium. The display of spatial change using a GIS medium gives users of the product a clearer understanding of the nature of the change for informed decisions to be taken based on what has been seen.

The question what “what relationships exist?” feeds directly into the GIS tool box of analytic operations by addressing queries like “where are the steep places?”; “Is it possible to see proposed telephone masts at specified location?”; “What is the distance between a university campus and the nearest hospital?”; and, “In which areas is vegetal cover more diverse than others?”, etc. establishing spatial relationship questions using GIS technology depends on derived information. Therefore, users of GIS must be made to know about the varied analytic operations on spatial relationships that the technology can handle for it to be put to maximum use.

Questions of “where is it best?” constitute the end product of planning. They are meant to address the goals and objectives of a planning process. Spatial considerations were previously thought to be inputs to decision processes, and not an aspect of throughput. Potential users of GIS prefer the composition (base and derived maps) of map layers. Suitable questions must be answered in such a way as not to put decision makers in doubt with respect to the problem they would be confronted with. These questions require that interpretation of situations should be such that they would directly influence the kinds of decisions that would be taken.

Questions of “what effects what?” address issues related to system models. This question falls within the domain of scientists and engineers. Models that engage the interest of GIS technicians and users are system models and suitability models. Suitability models include expert opinion in their analysis, whereas system models use “cause and effect” to track empirically derived relationships. The main problem of addressing of addressing such questions arose from the fact that GIS provides spatial summaries for input which generates colorful output models of maps. Because GIS modeling uses spatial specificity in the analysis process and responds to spatial autocorrelation of field data, this makes the use of GIS to address this question a challenging one.

Questions of “what if …?” does iterative processing of suitability models or system models. Suitability models makes users of GIS products understand different perspective of a project. That is to say answers could be found for questions like “what if visual impact is the most important consideration? or if road access is the most important; where would it be best for development.” system models make users of GIS products to understand uncertain situations or special conditions. That is to say system models provide answers to questions like “what if there was a x-in rainstorm, or if the ground was saturated; would the surface run runoff need a larger culvert?” (Berry, 1999)

The questions “where has it changed?”; “what relationships exist?”; “where is it best?”; “what effects what?”; and, “what if …?” influence the coverage and level of sophistication of GIS applications.

To determine the future of GIS, the first thing that should be done is to make current applications and procedures user friendly. Direct translations of procedures would meet the requirements of some of the questions GIS was designed to address. GIS now does application modeling to address the more nuanced questions GIS set itself to answer when generating final map products. Maps being the basic tool of geography is very important in every GIS enterprise; however, the objective for the development of every map must be able to provide useful insights for decision-making. From this point of view, models from GIS applications have become more powerful tools for decision-making than the geographic output of GIS.

9. Approach and Structure of GIS Modeling

A simple GIS model outlines suitable areas for structural development with the objective of maintaining the integrity of the environment. This type of model would begin with a generalized statement, or abstraction of important things in the real world. This scenario represents suitability modeling in GIS. Suitability models are normally represented as a flow chart of boxes with maps and connecting lines to indicate logical processes of data processing. Flow charts of suitability models in GIS are read from left to right.

Flow charts are compartmentalized with the aid of horizontal and vertical lines. Horizontal lines perform the function of showing suitability criteria. That is to show the best locations for proposed development projects, etc,. Some suitability criteria usually highlight constructional b emphasis aesthetic aspects of the environment. Suitability criteria of flow charts are connected to a set of GIS commands (command macros) for GIS specialist to manipulate to generate GIS end products. Vertically arranged maps indicate increased levels of abstraction. Primary maps which constitute the first group of vertically arranged maps show base maps which are needed in the initial stages of a GIS modeling process. Primary maps basically show physical features which were captured during field surveys. In short primary maps are inventories of features of the bio-physical environment.

Derived maps come immediately after primary maps. The descriptors of derived maps are difficult to collect and encode. This difficulty gave rise to the need to use computers to assist in the development of derived maps. For instance, the slope of an area can be measured, however, measuring the slope of an entire area would prove impracticable to execute. Also, the distance of roads can be measured, but that would be time consuming. These forms of model abstraction are tangible descriptions of landscapes. The accuracy of these maps (primary map and derived map) are empirically verifiable through ground trothing.

After developing and merging primary maps with derived maps, the process of modeling within a GIS environment is moved from factual situations to judgment. That is a movement from factual descriptions of landscapes to prescribing proposed uses of to which land should be put. Maps are interpreted based on the assessment of landscape factors with respect to intended land use. This means giving relative goodness values to every map condition. For example, gentle slopes would be given a goodness value different from upland places, or flat plains are assigned goodness values different from mountainous places, for preferred places for specific development.

The last product which is a suitability map is an assemblage of a number of interpreted maps. This map indicates the best overall scores for determining where it would be most suitable to locate a development project. However, if the consideration for another development is considered more important than what the suitability map presented, then reference would have to be made to the particular derived map in which the development project is most important the suitable areas for that particular project to be located.

The ability to interact with the results of a prescriptive map is what makes GIS modeling to be preferred to earlier methods of computer mapping and spatial data base management. GIS introduced the following modeling modifications to revolutionize GIS modeling approach and structure: weighing; calibration; and structure. Weighting modification transform interpreted maps into overall suitability maps. Calibration modifications enhance individual goodness ratings. Weighting and calibration simulations edit model parameters to evaluate changes in the suitability map. By repeating model simulations much insight is gained into spatial sensitivity of proposed decision-making.

Structural modifications show revisions in the logic of models by introducing new criteria. These modifications are accomplished by making changes to the structure of flow charts and making additions to programming codes command macros. For instance, decision makers may decide that dry savanna flat lands are better for irrigation development than forest environments. This decision would call for the introduction of new criteria, new sequences of primary, derived, and interpreted maps. These additional flow charts would also have to be linked to the aesthetic unit of the model, to enable graphic display of the new decision which was arrived at. These changing relationships with maps coupled with the derivation of new points of view with respect to developing plans have become the current focus of spatial reasoning and dialogue.

10. GIS: A Tool for Consensus Building and Conflict Resolution

Land use plans are designed to have a map. They are used to determine "what should go where." This calls for careful deliberation before deciding on the final output of a land use map (Gimblett, 1990; Pinilla & Arteaga, 2021). This is to make geo-queries of databases of project areas simple and meaningful. The essence of a land use model and the interpretation stakeholders may give to its output is effective decision-making. This is to say that land use models give clearer understanding of the thought process during deliberative processes during decision-making.

Interactive GIS modeling has enormous potential beyond the technical implementation of spatial features, by drastically revolutionizing decision-making within a GIS environment. Cases in point in Ghana to support this claim are discussed below.

Ghana has become a rapidly growing and urbanizing nation. This has given rise to large volumes of waste generation. However, they are not properly managed. This situation has given rise to indiscriminate disposal of waste, resulting in adverse impacts on human and environmental health. This has created the need for enhanced waste management methods. Solutions which have been contemplated and implemented include: source reduction, reuse, recycling waste to energy and composting. However, residual waste needs final disposal. This gives rise to the need for enhanced waste management approaches such as engineered landfills to provide efficient and environmentally safe waste disposal sites for the disposal of waste that cannot be recycled, reused, incinerated, or processed in one form or the other. Landfills at one time was the common and accepted form of waste disposal in Ghana. However, increased awareness of the adverse effects of landfills in fringe and rural areas has made them an unacceptable method of disposing waste in most fringe and rural communities in Ghana. Therefore, the process of selecting landfill sites in Ghana has become complex in the decision-making process. To contribute towards resolving this problem some GIS applications have been used to assist in decision-making to select suitable places for landfill sites without offending the sensibilities of residents in those places.

Asori, Dogbey, Morgan, Ampofo, Mpobi and Katey (2022) applied GIS-based multi criteria decision-making analysis (GIS-MCDA) to select locations that are most suitable for siting engineered landfill sites in the Ashanti region of Ghana. After identifying the most sensitive variables that influence the siting of landfills, GIS-MCDA modeled and selected places that were suitable for sitting landfills. Sixteen (16) variables including wind speed and hydraulic conductivity were weighted and integrated using the Weighted Linear Combination (WLC) of GIS to develop sub models. Thematic areas the sub models covered were physical environment, sociocultural, economic, technical, climatic, and hydrogeological. After further weighting the sub models were further integrated to produce the final suitability model. Results from the final suitability model showed that 13% i.e. 3067 km² of parts of the region was most suitable for developing landfills. Eleven sites were identified as places most suitable for locating landfills in the region. Out of the five sub models, the hydrogeological and physical environmental sub models proved to be the significant predictors of areas and specific locations for engineered land fill sites.

In developing risk models for predicting wildfires using GIS-based multi-criteria decision-making analysis, Asori, Dogbey, and Dumedah (2020) noted that wildfires have devastating effects on plant community regeneration, earth ecosystems, and human societies. They used the Analytical Hierarchy Process (AHP) to model wildfire occurrence and risk to assist in responding to and mitigation of wildfires. To this end, spatial variables of biophysical and environmental variables and anthropogenic factors were used to assess environmental conditions that influence the spread of wildfires. These variables were integrated into a GIS-based multi-criteria decision-making analysis to predict spatial variation in hazard, vulnerability, and risks of wildfires in parts of Northern Ghana. From their models they predicted that 72% of the study area was highly exposed to the hazards of wildfires, while 13% was at greatest risk when wildfires occur.

Also, Stem and Kumi-Boateng (2019) employed multi criteria decision analysis to facilitate the process of selecting suitable waste landfill sites in western Ghana. To this end, evaluation criteria were arranged into hierarchies with respect to geo-environmental, economic and social factors. Intermediate suitability maps were generated from the evaluation criteria which were then aggregated to come up with a composite landfill suitability map of the study area. Finally, optimality criteria was employed on the composite suitability map to identify optimal areas and highly suitable places for consideration and deliberation in decision-making on the location of waste landfill sites.

Through the analytical models that were used, decision makers saw their concerns translated into cognitive maps. The sensitivity of each model to change was easy to understand. Decision makers were therefore engaged in the analysis process and understood the map analysis that was done. These approaches of GIS analysis transformed decision makers into informed choice makers. It was therefore observed that involving decision makers in the analysis process facilitated the process of building consensus.

The analysis discussed above determined areas that were suitable for waste management and other environmental uses. In analyzing maps areas that are common to two or more of the maps were identified as zone of potential conflict. The areas of potential conflict afford decision makers the opportunity to resolve issues that may give rise to conflict. Conflicts are resolved in a GIS based environment using hierarchical dominance approach, compatible use approach, and trade-off approach. When the hierarchical dominance approach is resorted to, the assumption is that 'certain land uses are more important and, … supersede all other … uses'(Berry, 1999, P.66). The compatibility use approach for resolving conflict 'identifies harmonious uses and can assign more than one to a single location' (Berry, 1999, P.66). For trade-offs 'mutually exclusive uses [are recognized] and attempts [are made] to identify the most appropriate land use for each location' (Berry, 1999, P.66). For land use conflicts to be effectively resolved elements from all three approaches to conflict resolution should be taken into consideration.

From the point of view of map processing the hierarchical approach is better expressed quantitatively which gives rise to a deterministic solution. This is because when governing bodies identify a location for superseding use the are marked out and assigned the use/uses to which they would be put. Compatible use is easy from the point of view of map analysis, but relatively difficult from a policy and consensus building perspective.

Most causes of conflict in land use allocation arise from the fact that potential uses to which areas could be put could coincide. Quantitative solutions to such conflicting situations have been found to be unsuitable. The solution to such situations is dialogue between stakeholders. GIS technology contributes to resolving such conflicts by creating maps that outline areas which are suitable for several uses, and which could give rise to conflict situations.

By examining data in GIS graphic form, decision makers are able to apprehend conflicting uses which would inform dialogue between stakeholders to determine which land use allocation should an area with several uses be put. GIS also aids the deliberative process between making comparisons in making comparisons between different allocation scenarios to identify areas that are most suitable for particular land use allocations. Such comparisons it must be noted are included in the deliberative process between decision makers and stakeholders, and not making land used allocations based only on most suitable land use determinations using GIS technology.

In using the hierarchical dominance approach to determine which areas are suitable for land use allocation it was realized that stakeholders found it uncomfortable to identify some land uses or some place as being better suited for a particular use than others. However, compatible use and trade-offs are preferred to the hierarchical dominance approach because these approaches describe some land uses or places as being more important than other uses or places. The methods of determining suitable land use allocation areas could generate comprehensive land use maps that show areas of competing land use and areas of potential and actual conflict. Usually, land use allocations that result in actual or real conflict have to be solved 'the hard way' (Berry, 1999, P.68); which is engaging stakeholders in dialogue and taking into consideration group dynamics and making firm decisions which may not be palatable to all interest groups. When an observed situation is one of potential conflict individual personalities, force of persuasion, rational arguments and force should be deployed to influence collective opinion to arrive at a final and acceptable decision. When diverse opinions achieve consensus, the result would be a rational land use map. Such interactive processes afford stakeholders the opportunity to better understand the spatial complexities of land use allocation areas in conjunction with the varied opinions of others.

11. A User-Friendly Technology

The shift from descriptive mapping to prescriptive mapping has revolutionized concepts in map structure, content, and use. The potential of GIS in decision-making in Ghanaian institutions is yet to be fully exploited. This is because the use of the technology was considered to be inherently complex, users found it difficult to familiarize themselves with its products, and the cost of setting up GIS laboratories and training personnel to make full use of the technology was considered to be capital intensive.

Spatially modeled maps derived from GIS are very different from traditional analogue maps. This is because whereas analogue maps are made up of inked lines, shading, and graphic symbols to indicate the location of phenomena, GIS modeled maps reflect the logical reasoning of the GIS specialist. That is to say the modeled map comes forth as a 'spatial expression … than a … geo-query of … coincidence of base maps …' (Berry, 1999, P. 71). Initially, GIS operability was hidden in the technical language of the command macro. This made it necessary for GIS users to rely on GIS specialist as translators of the technology. Now, dynamic maps use graphical user interfaces to convey massages on spatial models. GIS technology has gotten to the point where end users can directly engage in, map analysis an interpretation and, spatial modeling (Alemy, Hudzik & Matthews, 2017). This indicates the progress GIS has made in bringing the technology to the door step of Ghanaian institution where the need for GIS technology is imperative.

12. A Tedious Free GIS

Application models focus their attention on analysis and the graphical image of the final map. The thought process that goes into the development of maps is supposed to give real insight for the development of programmes, plans and policy. Dynamic map pedigrees have been improved to use flow charts in the logical reasoning process and GIS commands (macro) to communicate spatial relationships (Berry, 1999; Yao, Jiang, & Yang, 2021). To make full use of GIS, users of the technology are encouraged to learn to use it within the context of spatial models at the following levels: casual level, interactive level, and developer level (Fischer & Nijkamp, 1993). At the casual level users are trained to interrogate the logic of models by using mouse clicks on maps or line (process) for the specifications of the model to pop up. The casual level makes users to have the opportunity to examine the spatial reasoning supporting the application to give a good understanding of the model.

The interactive level gives users the opportunity to change specifications for a particular model for it to be rerun. Updated macros are automatically integrated in to the legend of the new map. This level provides a quick insight for investigating "what if …" scenarios. Such capability makes it possible to compare different suitability situations to determine which scenario is most suitable for consideration. Suitability maps that are generated after changing specifications for a particular model can be compared with other model runs to identify changes in spatial arrangements of relative suitability. The highest level of use of GIS technology is the developer level. At this stage users are trained to be able to modify the logical framework of models, because flow charts can be edited and accompanying GIS codes can be rewritten and updated. For more on these levels of spatial modelling in GIS see

Fotheringham & Wegener's (1999) *Spatial models and GIS: New and potential models* and Stillwell & Clarke's (2004) *Applied GIS and spatial analysis.*

Some major improvements that dynamic map pedigree has achieved include: the shift to 'graphical interface [and] spatial models [has relieved] users of the burden of [having to] directly [generate] GIS code …'; it has given rise to an interactive stamp of model logic and specifications with every generated map; and it has also established broad guidelines for spatial modeling which is not directly linked to independent GIS setups (Ruvane & Dobbs, 2016).

13. Trends And Challenges

As general users of GIS technology increases, the greater the need to make the technology more and more user friendly. GIS' initial focus was mapping and spatial database management. It has moved on and currently lays emphasis on modeling interrelationships between map variables. These applications mostly rely on cartographic modeling and uses GIS operations to mimic traditional map processing. Form its earliest beginnings GIS has made phenomenal progress from mapping and spatial data base management and now concentrates on varied degrees of complexity in GIS modeling, using spatial statistics and advanced statistical procedures. New application that keeps emerging within the field of GIS are broadly grouped into the following categories: data running; predictive modeling; and dynamic simulation.

The application of GIS technology in Ghanaian institutions covers a broad range of activities. It mostly involves determining the location of natural resources, natural and cultural features, as well as determining areas that would be suitable for specific development projects and places that may be at risk of being exposed to natural disasters. Some activities in which GIS was successfully applied are mapping the spatial distribution of Buruli Ulcer for intervention (Kenu, Ganu, Calys-Tagoe, Yiran, Lartey, & Adanu, 2014); mapping population environment interaction with respect to agriculture and changing socio-economic conditions (Codjoe, 2007); mapping high yield ground water sites for drilling boreholes in the Voltain Sedimentary Basin in central and northern Ghana (Sander, Chesley, & Minor, 1996; Forkuor, Pavelic, Asare & Obuobie, 2013); and determining and mapping areas that are at risk of flooding in Accra and its environs and Tarkwa in the Greater Accra and Western regions of Ghana respectively (Nyarko, 2014; Osei, Ahenkorah, Ewusi, & Fiadonu, 2021). Also, the technology was employed to map changes in land cover and identify systematic land cover transitions in southwestern Ghana (Alo &Pontius, 2008). In addition, geospatial and hydrological modeling of the technology made it possible for watershed and flood impact analysis to be conducted for parts of Accra (Konadu & Fosu, 2009) and to map areas of conflict between planning and cadastral maps on one hand and encroachment on public land on the other (Karikari, Stillwell, & Carver, 2005). Lastly, GIS has been introduced into Ghana's institutions of higher education in order to improve on the spatial reasoning skills of students (Acquah, Asamoah, & Konadu, 2017).

In this a few applications would be discussed to illustrate the Ghanaian situation with respect to the application of the technology. In a study to predict floods in Accra, Ghana, Konadu and Fosu (2009) used Digital Elevation Model (DEM) in a GIS environment to perform geospatial and hydrological modeling to delineate drainage and watershed to be able to predict flood prone areas in parts of Accra. In this regard contour data and planimetric features were used to derive bare earth DEM and built environment DEM. These models were combined and used to perform spatial analysis to delineate drainage patterns and watershed areas. The analysis paved the way for flood impact analysis to be done. The vector approach indicated possible areas of inundation at different levels of flooding. By means of DEM, GIS was able determine properties that could be inundated during a flood. Also, in another study in the Tarkwa mining area of Ghana, Osei, Ahenkora, Ewusi, and Fiadonu (2021) used DEM to delineate areas that are susceptible to flooding. From the map and results which were generated it was found out that 42.59% of the mining area is highly prone to flooding.

In a rural ground water project in the Voltain Sedimentary Basin in Ghana, Sander, Chesley, and Minor (1996) combined remote sensing data with GIS analysis to develop better well siting strategies for drilling bore holes. Remotely sensed data was used to effectively map features that are conducive to ground water development, while GIS analysis played the role of identifying phenomena that influence successful well development. The integration of these technologies, created the opportunity for GIS to determine the position of bore holes before ascertaining the suitability of their locations on the ground. As a result, GIS exposed the possibility of the technology accounting for spatial reference while at the same time determining the accuracy of data from different sources.

At the outset there was the problem of the technology having to be accepted by previous technician of cartography who were used to the traditional and labourious technique of manually developing maps. Some who received training in GIS application found it complex and difficult to learn. Technical issues like overlaying maps and querying the system for particular outcomes proved burdensome to some and so lost interest in acquiring knowledge on how to use the technology. Those who acquired knowledge in the technology were few. And as a result, the use of GIS was found only in higher institutions of learning like the University of Ghana Department of Geography and Resource Development and the University of Cape Coast Department of Geography and Tourism. Government departments, like Survey Department, department of Town and Country Planning, Lands Commission, Minerals Commission and the Geological Survey Department, that should have adapted the technology in the early days of the introduction of GIS in Ghana were slow to pick it up. When benefits to be gained from the technology were realized, institutions started investing in it. The technology is now recognized to be relevant for decision-making in most Government institutions and agencies and are taking steps to digitize their spatial data for quick geo-referencing and analysis while away from the field. The other challenge that confronts the development of GIS in Ghana is the amount of time required for one to acquire sufficient expertise in the technology to make its application useful and meaningful –

Entering data, manipulating data – and can be relied on for decision-making. It is therefore important to note that there is a huge man power deficit of GIS specialist in Ghana; and steps should be taken to slowly but progressively shore up the numbers of GIS specialist in the country to make the use of the technology pervasive and accessible in all sectors of spatial studies and decision-making.

14. Technological Advances

In GIS, data mining is employed to discover relationships between mapped variables. For instance, a map of withered or withering cocoa farms in the cocoa producing areas of Ghana or a map of thriving cotton fields in the cotton producing area of Ghana, could be statistically compared with ‘driving variables like elevation, slope, aspect, soil type, and depth of bedrock’ (Berry, 1999, p. 73). When a strong spatial correlation (coincidence) is detected for some combination of driving variables, this could inform the allocation of resources to places where plants are in danger of yielding unsatisfactory results. Derivation of empirical models is another type of data mining. For instance, the geographical distribution of e-waste at waste disposal sites can be interpolated from waste samples gathered from waste disposal or landfill sites. When sites of unusually high concentration are detected, those sites could be isolated. Running a time series of samples would show sites with high concentration of e-waste among landfill sites – thus giving rise to an empirical waste disposal site model.

GIS has both spatial and non-spatial predictive models. Large areas are sampled to gather data on the environment. The data gathered is used to solve mathematically related models, like regression, to establish links between variables. GIS models collect data based on driving variables for other places or of an area over a period of time, to determine a prediction equation.

Models in GIS spatially interpolate data into maps for each variable to solve an equation for phenomena scattered across an area of investigation. When spatial patterns coincide, variables are preserved so as to relax ‘unrealistic assumptions of random/uniform geographic distribution and spatial independence’ (Berry, 1999, p. 74). By directly considering spatial patterns and coincidence, mapped data will improve the accuracy of environmental predictions and management actions which would result in them becoming more responsive to unique conditions that may exist in a project area.

Dynamic simulation makes users to interact with GIS models. One benefit of dynamic simulation in GIS modeling is the ability to investigate the behaviour of models when parameters within the model get modified. This is because it affords users the opportunity to track changes in the final map. Dynamic simulation is able to identify the relative importance of every mapped variable. It also creates room for GIS to be used as a spatial spread sheet for resolving ‘what if …’ questions. This function satisfies natural curiosity of users and at the same time provides insights into system sensitivity.

Predictive modeling and dynamic simulation assist decision makers to understand linkages between variables and identify critical ranges. Decision makers are expected to increasingly use resources embedded in dynamic simulation to analyze issues involving environmental policy and governance/planning.

15. Convergence of Technology and Science

GIS has become a storehouse for tremendous volumes of descriptive data and has become a versatile tool for overlaying myriads of maps to detect coincidences. It possesses great versatility in expressing spatial relationships between mapped variables. However, there exist a wide gap between GIS technology and applied science. Most of the applied sciences do not express results from their variables in terms of spatial relationships. The role of GIS in this regard is to bridge that gap between GIS and applied science by making GIS relevant in applied science.

GIS can organize changes in landscapes by means of fractal dimension maps. This permits analysis of landscape structure. The technology in terms of environmental decision-making can among other thing characterize environmental phenomena like sediment loading distance from streams by taking into consideration slope, vegetative cover and soil type.

GIS is known to be capable of integrating multiple phenomena. It has the advantage of relating spatial phenomena between map variables. What is needed in Ghana to make full use of these capabilities is in-depth technical knowledge to use the technology. Until recently, GIS in the country has been erroneously thought of as a tool for taking inventory and keeping records. What the country needs from GIS is an era of GIS application where spatial analysis would be spatially interwoven into the results of GIS models. The scientific and managerial community needs to collaborate in the use of the technology to make it one of the basic tools for decision-making at the technical and institutional level. Such collaboration would shift managers and decision makers away from using the analytical capabilities of the technology from constructing common sense and uncommon sense models.

It is expected that once general users of GIS get directly involved in using the technology traditional concept which govern the development and use of maps would be called into question. To solve this problem, GIS should go beyond its classical objective of developing maps. It is a known fact that traditional concepts for developing maps does not adequately portray features in their three-dimensional form; they are known to selectively show few elements of interest while being unable to show the actual complexity of spatial reality (Berry, 1999, p. 75); and, puts forth environmental gradients as distinctive spatial phenomena. GIS is therefore expected to radically replace historical concepts of constructing maps with increasingly sophisticated digital mapping technology.

Concepts such as synergism, cumulative effects, and ecosystems management in environmental and natural resource managers have evinced the need for GIS to come up with a unified landscape for preserving and presenting digital GIS data. A unified landscape has been proven by its nature to be able to holistically handle spatial data in digital form. That is to say an atomistic approach when applied could with time become monotonous. However, applying a holistic modeling approach entails the assimilation of the whole system at the beginning of the analysis. Using this approach from the onset makes it possible to analyze data using artificial intelligence, chaos theory, and fuzzy logic. The holistic modeling approach has the advantage of making meaningful inferences, accounting for abrupt change and uncertainty. This is because they establish appropriate sidebars for system response. This is beneficial for GIS because these techniques of presenting spatial data in digital form provide very realistic descriptions of a system “who’s whole is greater than the sum of its individual parts”.

Perception is an important element for appreciating landscape. People have their own appreciation of landscape based on their spiritual, cultural, social, and interpersonal experiences. One’s ability to fairly map landscape within the context of GIS requires a deep understanding of the relationship between GIS and the social sciences. GIS has come to be accepted as an active process that captures inherent spatial variability taking into consideration perceptive experience of users over time and spatial descriptors.

16. Conclusion

The cornerstone of environmental policy, governance and planning is information. At the beginning of gathering spatially related data information was preserve by physical storage and manual processing of data. The computer automated the process and procedures for storing and retrieving data. This made the processing of environmental information more and more quantitative. As a result, techniques for systems analysis developed links between descriptive data for space related phenomena and management actions. This approach to environmental management of data was caused by the development of modern information systems of technology. Digitally mapped data thus created a wealth of new analytical operations which was accompanied by an unprecedented ability to perform model spatially complex scenarios of environmental issues. However, the full effect of GIS technology in Ghana with respect to environmental policy and decision-making is yet to be fully realized. GIS is effectively used when users thoroughly understand the technology, are imbued with creativity, and sufficient perspective. The real impact of GIS in environmental management and decision-making is for users of the technology in the country to demonstrate within the decision-making process that the technology is increasingly being used to answer ‘so what’ questions instead of simply asking ‘where is what’ questions and stopping there. The development of GIS as discussed above were made possible through the conversion of physical data into digital data, and transforming digital data into information. Information obtained from possibly more than one combination of digital analysis are studied to gain heightened knowledge within a context. The acquisition of such knowledge could result in wisdom being gained and applied to find rare and timeless solutions to spatial and environmental problems within Ghana and other parts of the world.

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