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Role of GIS as a Tool for Environmental Planning and Management

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Abstract: *A Geographic Information System is a computer based system for handling spatially referenced data and information. Its versatility has made it to find applications in a number of disciplines. This paper examines its role as a tool for Environmental Planning and Management. The capabilities of GIS in handling environmental information is looked at from four perspectives: (i) environmental information data collection and management (input, update and retrieval); (ii) display and visualization of digital environmental information; (iii) spatial analysis of environmental information; and (iv) modeling scenarios. It is considered that environmental information systems that incorporate GIS provide a platform for generating information that enables insights into environmental scenarios hence allowing for proper decision making. As environmental planning and management strives to solve the needs of human beings sustainably with minimum interruption of the environment, it is concluded that GIS will continue to provide the tools for effectively carrying out these activities.*

Keywords: *Environmental Planning and Management, GIS, Environmental Information Systems*

1. Introduction

Environmental Planning and Management (EPM) is defined as the initiation and operation of activities to direct and control the acquisition, transformation, distribution, and disposal of resources in a manner capable of sustaining human activities with a minimum disruption of physical, ecological, and social processes (Baldwin, 1985). Lein (2003), in his book Integrated Environmental Planning stipulates that a development proposal should be appropriate in terms of compatibility with the ecological system; suitability in relation to physical and environmental qualities of the site; susceptibility with regard to potential environmental impacts; and sustainability relative to long term functioning of environmental processes and maintenance of environmental integrity.

A Geographic Information System (GIS) is a computer-based information system for input, management, analysis, and output of geographic data and information. It deals with collection, storage, retrieval, manipulation, updating, analysis, display and dissemination of spatially referenced data and information (Ondiek C.M. & Murimi S.K., n.d.). GIS systems are important tools for managing natural and other resources at all scales ranging from local to global.

The activities of EPM in most cases deal with management of natural and environmental resources which naturally exist and are part of complex ecosystems. These ecosystems should not be interfered with even as human beings exploit the resources for development and betterment of their life on earth. In striking a balance between sustainable utilization of these resources and maintenance of ecosystems, information is key to decision making. GIS provides a tool for gathering relevant information, integrating the information in a database and manipulating these data to come up with scenarios and possible impacts of development programs on the environment and ecosystems.

There is a thin line between GIS and Environmental Information Systems (EIS). Hakley, (1999) divides EIS into two groups - those that are information systems in the strictest sense (they are used to store and retrieve information) and those that are geared toward analysis and simulation of environmental information. Among the latter, the predominance of GIS is striking.

2. GIS ON ENVIRONMENTAL PLANNING AND MANAGEMENT

In examining the role of GIS as a tool for EPM, it is important to look at the capabilities/possibilities and benefits of employing GIS in handling environmental information (EI). This presents a scenario of limitless application of GIS from basic inventory of data and information to complex analysis and modeling of scenarios. The type of analysis to be carried out will also be project specific, requiring specific information to answer certain spatial queries or address a specific environmental issue. As such, this paper will be addressing the role of GIS in EPM from a view of the possible applications of GIS and their relationship with environmental information. In this context, the following application areas will be discussed:

i] EI data collection and management (input, update and retrieval);

ii] Display and visualization of digital EI;

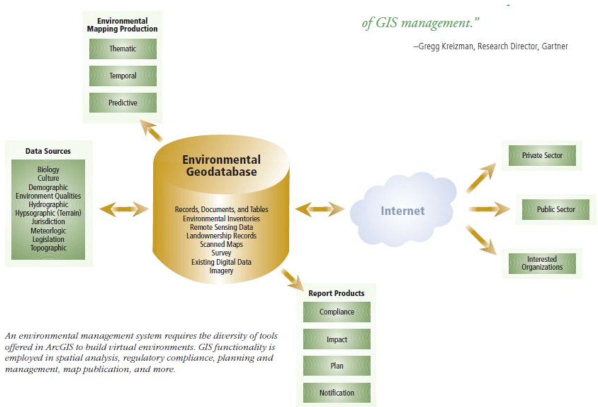
iii] Spatial analysis of EI; and

iv] Modeling scenarios.

2.1. Data Collection and Management

Information is key to decision making. This information is processed from data collected in the field and as such the data collected should be accurate, complete and relevant to a particular environmental issue being addressed. Why is there strong coupling between EIS and GIS? The customary claim is that most environmental problems are spatial and therefore GIS is the most appropriate technology for dealing with these problems (Hakley, 1999).

The establishment of an EI database is therefore the first step and requires a lot of attention as this will form the basis for subsequent analysis. In a GIS environment, this is called a geodatabase and contains both spatial and aspatial information about features on the surface of the earth. In the establishment of GIS within an organization, it has been shown that data or the establishment of the geodatabase will cost over 70% of the total cost. It is the raw material from which information will be generated. As seen in the figure below, the environmental geodatabase will contain all the data relevant to a particular project, both spatial and aspatial. The GIS allows for the integration of these two sets of datasets.



Source: *ESRI, 2005*

There are many sources of data that goes into building the environmental geodatabase. Satellite imagery, aerial photographs, field/ground surveys, topographic maps, statistical data from government agencies, research organizations, and cadastral maps are just a few of the data sources. It is important to note that the type of data to be collected is determined from a user needs assessment. The data should be able to provide the information needed to solve the problems of the users of the system.

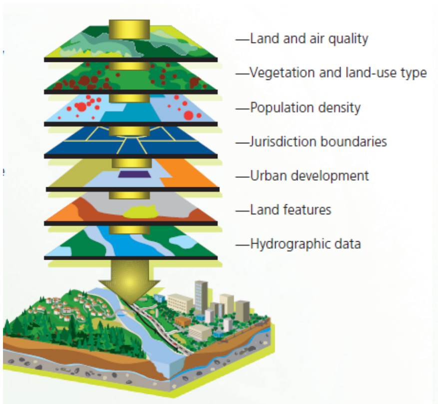
Data management i.e. input, retrieval and update must be enabled by the EIS. GIS plays a key role in the update of both spatial and non-spatial data. Most of the GIS software packages have mapping component that enable update of spatial data which is usually linked to the aspatial data.

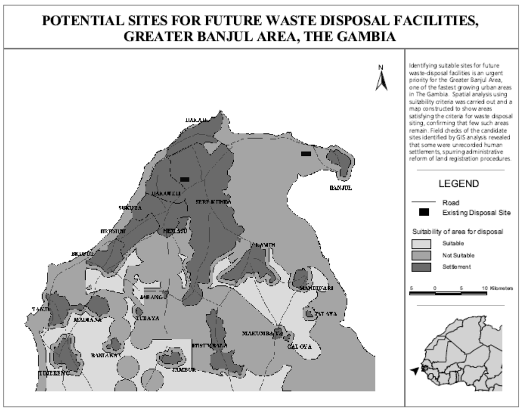
2.2. Environmental Information Display and Visualization

GIS technology is an effective tool for studying the environment, reporting on environmental phenomena, and modeling how the environment is responding to natural and man-made factors.

Environmental managers, scientists, regulators, planners, and many others use GIS to visualize data about natural resources, hazard control, pollution emissions, ecosystem health, climate change (ESRI, 2010).

GIS stores data in what is referred to as layers, each layer containing a particular theme. These layers can be displayed and visualized in a digital environment usually the computer screen and preliminary analysis of information can be assessed. An environmental example would be the relationship between population density and forest cover depletion. A dataset of population distribution overlaid over land cover data set will be able to reveal the relationship between population growth and forest cover depletion. Furthermore, the results of in-depth analysis and plans are usually displayed and visualized in map formats-products of GIS analysis.





Layers in a GIS (ESRI, 2005) *Display of results (WRI, 2001)*

2.3. Spatial Analysis of Environmental Information

Majority of GIS software offer tools for in-depth analysis of environmental information hence providing insights that are useful to environmentalists and managers for decision making. This is made possible by the capability of GIS systems to integrate different layers of information within a given reference system.

The analysis systems focus on sophisticated query, advanced analysis and visualization tools. The analysis system is based on the primary database; it is an active information production process. While in the query systems the information is depending on the human interpretation, here the GIS produce directly ‘’machine readable” information.

Using the analysis software you can understand the geographic context of your data, allowing you to see relationships and identify patterns in new ways. The software helps organizations make better decisions and solve problems faster.

With the analysis software you can build new geographic data sets quickly and easily; create publication-quality maps; manage your file, database, and Internet data resources; customize the user interface around the tasks that you need to accomplish.

With spatial analysis systems, you can find suitable locations, perform land-use analysis, predict fire risk, analyze transportation corridors, determine pollution levels, determine erosion potential, perform demographic analysis, etc (Markus, 2011).

The following are some of the analysis enabled by most GIS application software:

2.3.1. Query Functions

Once a functioning GIS containing spatial information has been established, one can begin to ask questions such as where are all the sites suitable for building new houses? what is the dominant soil type for oak forest? if I build a new highway here how will traffic be affected? Etc. Both simple and sophisticated queries utilizing more than one data layer can provide timely information to decision makers (Markus, 2011). With GIS software there are two basic forms of querying-spatial and attribute (Sahoo, nd). Spatial querying asks the question ‘what is at this location’? This is usually done by simply clicking on a feature and listing its attributes. More complex spatial queries could select all the features within a box or a polygon, or ask ‘what is near to this feature’? Queries of this type often require the use of buffering or overlay techniques. Attribute querying asks the question ‘where does this occur'? If a user has a layer consisting of the locations of churches with some information about each church, an attribute query could select all the churches whose denomination is Catholic and then draw them with a certain symbol. The user could then query the database to select all Protestant churches and draw these with a different symbol to compare the patterns.

2.3.2. Temporal Analysis

This are time series analysis that are meant to monitor the variation of an environmental phenomena over a period of time. An example is monitoring the rate of desertification. These analysis give trends that are used to predict the situation in the future.

2.3.3. Surface Interpolation Analysis

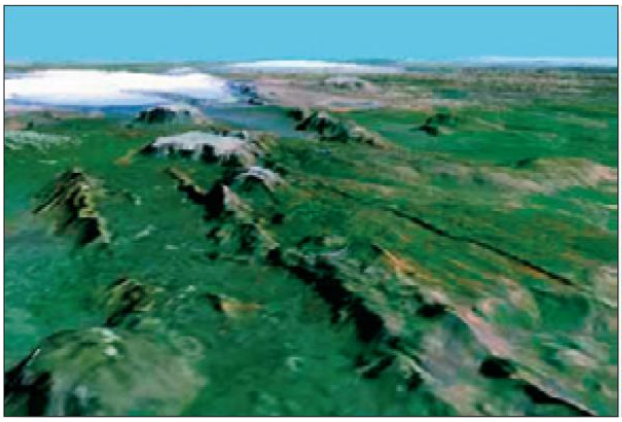
When representing data over a given area e.g. temperature variation, it is not possible to measure the temperature for each and every point. In practice, data is collected at sample points that are representative of the whole area. A temperature variation surface is then generated from the sample points. GIS software have tools for surface generation and analysis and these tools are very useful when analyzing environmental information that requires representation as surfaces.

2.3.4. 3D Analysis

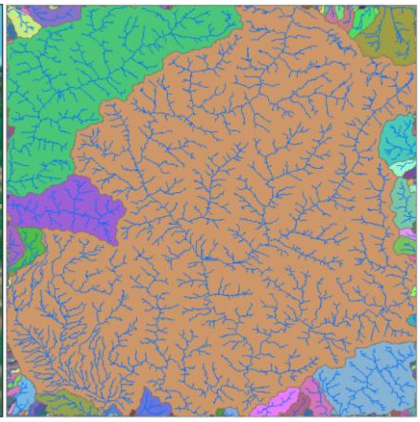
When analyzing terrain information, most often digital terrain models (DTM) are necessary. These DTM can be generated and visualized in a GIS environment and provide insights into environmental phenomena. Furthermore, the models are used in modeling other environmental issues such as watersheds. Data on elevation is usually necessary for the generation of these DTMs. It is derived from field surveys, aerial photographs, satellite imagery etc.

2.3.5. Connectivity analysis

These type of analysis takes care of connectivity between points, lines and areal features in terms of distance, travel time, area, optimum path etc. Sahoo (n.d.) identifies three types of connectivity analysis-proximity, neighborhood and network. Proximity analysis measures distances form points, lines and boundaries of polygons. An example is buffering, by which a buffer can be generated around a point, line or polygon. Neighborhood analysis evaluates the characteristic of an area surrounding a given point. Network analysis on the other hand determines the optimum paths using specified decision rules.



3D data visualization (ESRI, 2005)



Stream network in basin (Siddiqui et al, n.d.)

2.4. Modeling Scenarios

Goodchild (n.d.) defines modeling in the context of GIS as occurring whenever operations of the GIS attempt to emulate processes in the real world, at one point in time or over an extended period. Models are useful in a vast array of GIS applications, from simple evaluation to the prediction of future landscapes.

Models can be static, if the input and the output both correspond to the same point in time, or dynamic, if the output represents a later point in time than the input. The common element in all of these models is the operation of the GIS in multiple stages, whether they be used to create complex indicators from input layers or to represent time steps in the operation of a dynamic process.

Wischmeier & Smith (as cited in Goodchild, n.d.) stipulates that static models often take the form of indicators, combining various inputs to create a useful output. For example, the Universal Soil Loss Equation (USLE) combines layers of mapped information about slope, soil quality, agricultural practices, and other properties to estimate the amount of soil that will be lost to erosion from a unit area in a unit time. The DRASTIC model estimates geographic variation in the vulnerability of groundwater to pollution, again based on a number of mapped properties (Aller et al. in Goodchild, n.d.). Dynamic models, on the other hand, represent a process that modifies or transforms some aspect of the Earth's surface through time. Contemporary weather forecasts are based on dynamic models of the atmosphere; dynamic models of stream flow are used to predict flooding from storms; and dynamic models of human behavior are used to predict traffic congestion.

3. Conclusion

GIS tools play a big role in EPM and have limitless application. It is a powerful tool in the management of environmental information and is an important component of environmental information systems. GIS provides a platform for effective data input, retrieval, update, visualization, analysis, modeling among other functions. As EPM strives to solve the needs of human beings sustainably with minimum interruption of the environment, GIS will continue to provide the tools to effectively carry out these activities.

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