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Annals of Biological Research, 2011, 2 (5) :533-540
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0976-1233
CODEN (USA): ABRNBW

Implementation of GIS in Natural Resources

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ABSTRACT

The demands for better management of natural resources require management of spatial data and information. Geographic Information Systems (GIS) refer to the broad collection of Information Management Techniques, which store and analyze such information to contribute to the needs for planning and resource management. The use of GIS has produced remarkable changes in the way and rate at which georeferenced data are produced, updated, analyzed and disseminated, making production and analysis of geographic information very efficient. Furthermore, it is characterized by diversity of applications and can be effectively used in urban planning, natural resource management, query of species on the verge of extinction, selection of suitable species for afforestation, wood supply simulation, fire control management, monitoring fire decline, forest road designing, tourism development and other land use fields (e.g. land resource mapping and land use changes). In the past three decades, this potential has led to rapid developments in both theory and technology resulting in increasing technical capabilities and decreasing hardware and software costs. This paper focuses on implementation of GIS in forest science. In conclusion, GIS is an extremely powerful tool in proper management of both public and private sector organizations and is very profitable or timesaving in situations with high risks where the scale is suitable, where there is creativity, and where identical procedures are used repeatedly.

Keywords: GIS, Management of natural resources, Forest science, Land-use.

INTRODUCTION

Geographic Information Systems (GIS) is defined as a computer based information system that is designed to work with data referenced by spatial or geographic coordinates. The use of GIS is rapidly increasing, as city, regional and environmental planners, resource managers and the scientific communities become aware of the capabilities these systems have to offer [89]. This technology has the ability to incorporate many different forms of data, and can be used for analysis in many areas [35]. The geographical data which is stored describes objects from the real world in terms of their position on the earth with respect to a known coordinate system, their attributes which are unrelated to their position, and their spatial interrelations with objects around them [16]. There are many functions and benefits that are likely from GIS. In the early 1990's, spatial information was used by public land managers to estimate the forest types and forest distribution in the US [43] [58]. It was also used to produce thematic mapped data [30] and mapped forest density [60]. The global community has depended heavily on GIS for tropical forest assessment and its relation to the global warming [39]. The systems were used to identify and map areas of different social groups in some social studies [59]. It was also used to monitor and solve some urban problems of overpopulation [23, 7]. They were also used in medical and public health applications, for example to trace wide-spread medical problems [40, 10, 81] and to coordinate planners and public health personnel [99]. GIS also was of great use in routing traffic and traffic control in the US and around the world [84, 38, 20, 55]. GIS has proved to be a success in Environmental Impact Assessment, a procedure becoming mandatory for any large project in many places in the world [50]. It has been used in a wide variety of natural resource management practices [85]. It has been used in evaluating damage from natural disasters [3, 93], and in monitoring pollution contamination of various types [80]. GIS have been integrated with knowledge bases to produce expert systems for natural resource management [47]. It was widely used for National Parks and wild land protection, management, and planning [100, 88, 67, 69]. The GIS has been used in watershed-related studies and decision-support systems for management [73, 46, 2, 37]. It has been used widely in environmental monitoring [75] [48], e.g. monitoring land degradation and soil loss [79, 101, 97]. Additional GIS use has been as a tool for data collection about habitats and forming a habitat data bank [64, 91]. GIS were used in landscape architecture, urban and regional planning and studying regional growth [15, 94, 38, 6] [14]. GIS were used also in finding different alternatives for projects planning and in visualizing the future state of a study area [95, 9]. The military have intensively used GIS for 30 years [52, 86]. Lately the military has used GIS to find other uses for military lands [87]. GIS has been used in archeological studies around the world, revealing hidden cultural and historical sites [63, 67]. GIS has now entered many businesses, connecting information bases with branches on regional, national, and international scales [21, 62, 17, 19]. The planning of some businesses has now become dependent on GIS applications [12, 92, 91, 90]. GIS is made up of three major components which include: 1) The digital map data, 2) The hardware used to enter, store, retrieve, process and display these data and 3) All the computer software used to perform GIS operations. The unique characteristics and capabilities of GIS technology have led to its widespread adoption and implementation. But in addition to its technical and information handling capabilities, GIS is capable of numerous organizational and economic opportunities, which have emerged during the last few years. This potential of GIS has led to emergence of the multi-participant approach for GIS [35]. Historical records have also been used in GIS to identify changes in forest cover. Between 1979 and 1984, a land resource inventory project was completed in the Jhikhu Khola watershed in Nepal [83].

Query of species on the verge of extinction

The query of species on the verge of extinction is one of the most important factors in the biodiversity and sustainable structure forests [61]. Projecting, selection of suitable species for planting and considering of different multiple factors in afforestation is possible using GIS capability and information-simultaneous management [28] and also it was announced that, GIS can be a valuable tool in selection of suitable species for afforestation [27]. The study was accomplished to determine species query of planting on the verge of extinction, using Analytical Hierarchy Process (AHP) method in Guilan province located in the north part of Iran. Another study [26] showed the importance of GIS for the extension of Viper's bugloss (*Echium amoenum* Fisch. et Mey.), a medicinal plant, in the Northern part of Iran.

Land resource mapping

As part of the land resource mapping project in Nepal, fuel wood sufficiency for the 75 district in the country was evaluated and mapped using GIS. This was part of a larger resource overview for national land use planning that also included food and fodder resources [85]. The calculations for the future were not actual predictions but a test to examine the model's response to population and livestock growth. The researchers suggested that the projection maps could be used to direct attention to districts that will likely experience severe resource deficits. Also, GIS capabilities could be used to develop deficit elimination scenarios. If we assume current growth and consumption rates, the model can calculate what changes in key variables would be required to eliminate the deficits in each critical district. To eliminate such deficits, we can calculate by how much we would have to increase the tree biomass production or how much we would have to enlarge the area of tree planting [82].

Wood supply simulation

Timber management focuses on efforts to provide a continuous supply of trees for economically optimal wood production. In the recent past, foresters have relied on wood supply models to guide planning for optimal harvests that typically ignore specific geographic locations [51, 76, 78]. These simulations (WOSFOP, OWOSFOP, NORMAN, FEM, FORMAN, and FORPLAN), developed over the past 10 years, use a spatial optimizing approach. The problem was described as follows [51]: While today's models are sufficient for defining and developing a spatial management design strategies for wood supply, they lack consideration of the geographic structure of forests and are insufficient for design of wildlife sensitive and operationally, economically, acceptable management.

Fire control management

The effect of fire on forest resources is another important management concern. Management activities include fire prevention, wildlife control, prescribed burning, and post-fire recovery actions. The modeling capabilities of GIS have been quite effective in this context. Forest fire managers have used GIS for fuel mapping, weather condition mapping, and fire danger rating [45]. Several examples illustrate a range of fire applications. At Cuyamaca Rancho State Park in California, USA, GIS has been used to guide prescribed burning. After decades of wildfire suppression in the park, fuel loads had dramatically increased, chaparral had replaced other vegetation, biotic diversity had decreased and exotic grasses dominated the park's grasslands. Beginning in 1970, fire was reintroduced into the park's ecology [98].

Forest non-timber values

Most of the studies presented so far, have emphasized single management concerns. However, contemporary forest management should incorporate non-timber values and multiple resource concerns. In some situations, sites to be protected for non-timber uses are defined before a harvest supply model is implemented [24]. In other cases, issues of visual quality or habitat requirements are integrated as constraints in overall harvest plans [49]. This clearly involves a more complex analysis. Fortunately, the ability of GIS to simulate ecological, social, and economic changes lends important support to multi-resource management [60, 11]. For the Mad River Valley, a forest site index (based on the average height of trees at a site at a given age) and soil erosion estimates were combined to produce land suitability classes of resource protection, forest management, multiple-use, and trade-off [44].

Forest decline monitoring

Gradual forest decline is another type of change that can be monitored. Vegetation is sensitive to stress factors associated with changes in moisture, temperature, as well as anthropogenic factors, such as air pollution, forest pests and disease. GIS, together with remote sensing (RS), offers the means to monitor the magnitudes and rates of forest decline [78]. In Germany and Poland, forests have been dying gradually due to industrial air pollution. In Germany, a three-year project was initiated in 1986 to establish methods to detect, classify, and map forest decline using a combination of the Land-sat MSS and airborne multi-spectral imagery. The researchers found that characteristic spectral signatures could be identified for different tree species (spruce, pine and beech) depending on the degree of decline [57].

Land-use changes

The current global rate of land use change is unprecedented [36]. In the United States, urbanization is one of the most prominent land use changes occurring nationally. Interestingly, even in the presence of such intensive urbanization in many areas of the United States, afforestation also occurs throughout rural areas of Northeast and the Upper Midwest [13]. New forest growth is principally occurring on private lands although the exact nature of the rates and patterns of afforestation are poorly understood. More knowledge of how afforestation patterns occur across landscapes is needed for improved natural resource management for several reasons. First, increased forest cover on the landscape is likely to ameliorate any deleterious effects of urbanization on the hydrologic cycle [54]. Currently, the Michigan Department of Natural Resources uses the satellite derived land use/cover database for most of its natural resource management decisions but the aerial photography derived database has been assumed to contain similar information. However, if these two databases are used as inputs to land use change impact models, such as hydrologic models [54], then large discrepancies are likely to occur depending upon which database in used.

Forest road design with GIS

Forest roads are at risk of road surface erosion and are subject to cut-and-fill slope failures. Therefore, it is important to design forest roads by considering not only cost efficiency but also the appropriate management of water and soil [4]. Some researchers applied the GIS techniques to design the optimal forest road density in northern forest of Iran [74, 68, 1].

GIS in urban forestry

GIS has long been recognized as a useful tool in the management of natural resource development, land use planning, wildlife management, environmental planning, and forestry planning. The use of tree inventories is essential for the management of trees in an urban community as previously discussed. However, street tree inventories can be greatly enhanced by using a geographic information system. The ability to include various data sets in conjunction with tree inventory data allows urban foresters to make more thorough and cost effective management decisions in urban forests [41]. A GIS allows the user the ability to quickly manipulate, analyze, display geographic or spatial data and take advantage of existing spatial information [66].

Tourism development

GIS can be used to demonstrate tourism impacts on various industrial sectors in a time-series and spatial format [18]. In the context of ecotourism, however, it has limited but important applications. GIS provides a set of tools, which can be used for sustainable tourism planning and development [25]. GIS is a useful application in selection of suitable sites for tourist settlement with consideration ecotourism theory [29]. Using GIS it is possible to integrate ecotourism information, visualize complex scenarios, present powerful ideas and derive effective solutions. GIS can be an effective tool in the design and monitoring of sustainable development [56]. Applications of GIS in tourism has been limited to recreational facility inventory [102], tourism-based land management [34], visitor impact assessment, recreation-wildlife conflicts, tourism information management system [53], and decision support systems [56]. GIS also can be a valuable tool for investigating specific questions that pertain to tourism development including location, condition of the area, trends and changes, routing to and through the site, and patterns associated with resource use [22]. GIS can be considered as a toolbox that provides techniques and technologies to achieve sustainable tourism development [8].

Disadvantages for GIS use in the government

There are some disadvantages to using GIS in a government setting. Possible concerns include the idea that GIS decreases the democratic right of the people or that the technology is taking power away from the masses and into the hands of a few because only a limited number of people know how to use the technology. This is true to some extent. First, costs for GIS software and powerful computers to operate it are decreasing; however the costs of producing high-quality data are increasing [35]. Companies who produce data can charge high prices, and the cost of hiring staff to generate data on site can be expensive as well. Therefore, many cities or small local governments could afford the computers and necessary software but creating the data suitable to their individual needs may be out of reach. The costs of using GIS once the data have been collected and created are minimal; however, the initial building phase involves a significant investment from the agency [102].

CONCLUSION

A GIS is a compilation of overlays for a specific geographic region. The overlays may consist of raw data such as topographic elevation or thematic information which could consist of soils, land use or geologic data, and many others [5]. Many authors have written about the importance of learning about nature and the environment and working with it [70, 71, 72, 31, 32, 33, 65, 96]. Using alternative epistemological bases, involving GIS with site-specific knowledge, noting the limited funding, and accepting lower confidence level for conclusions and subsequent actions are some paradigms integrating science and economics in land management [42]. According to [5] an ideal GIS should be able to execute the following capabilities: 1) Accepting data inputs in several formats (e.g. analog map and overlay information, tabulations and digital - image data). 2) The ability to store and maintain information with the necessary spatial relationships. 3) Manipulating data such as search and retrieval, computations and analysis in a timely manner. 4) Analysis that would take into account the interrelationships of data as well as cause-and-effect responses of the appropriate factors and 5) produce several forms of data outputs (e.g. computer generated maps, video displays, graphics, and tabulations).The two biggest problems facing most of the application of geographical information systems are time and cost [37]. GIS proves to be much less expensive and much faster than manual work. In the extreme, GIS is much more efficient and effective. Even for smaller coverage, the costs of field work are high; potential savings from GIS use are very great. On the other hand, it would be totally cost ineffective to consider such application for a private land ownership of small size [48]. It is also unexpected that all land owners or their managers will find GIS to be applicable in their case. GIS is characterized by diversity of applications and can be effectively used in urban planning, natural resource management, query of species on the verge of extinction, selection of suitable species for afforestation, wood supply simulation, fire control management, monitoring fire decline, forest road designing, tourism development and other land use fields (e.g. land resource mapping and land use changes). As a result of this review, it has been found that GIS is a large, complex system and that it is inexpensive. It can, however be very profitable or useful in situations with high risks where the scale is suitable, where there is creativity, and where identical procedures are used repeatedly.

Acknowledgment

We would like to thank the helpful comments from anonymous reviewers, whose remarks significantly improved the original manuscript.

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