Journal of
Geography & Natural Disasters

Sonti, J Geogr Nat Disast 2015, 5:3
DOI: 10.4172/2167-0587.1000145

Review Article Open Access

Application of Geographic Information System (GIS) in Forest Management

Sonti SH*

Department of Environmental and Occupational Studies, Symphony Way, Bellville South Industrial, Cape Town-7535, South Africa

Abstract

The overall aim of this paper is to explore the potential application of Geographic Information System (GIS) technology in forest management in general and in 3 African countries. The use of GIS has flooded almost every field in the engineering, natural and social sciences, offering accurate, efficient, reproducible methods for collecting, viewing and analyzing spatial data.

According to Upadhyay forests are a dynamic resource, affected by many coexisting ecological processes and direct management interventions. To make better decision, to improve productivity, to save time, money and man power in forest management activities, required are dynamic both locational and descriptive inventory data, rather geographic information. The evolution of GIS, the Global Positioning System (GPS), and Remote Sensing (RS) technologies has enabled the collection and analysis of field data in ways that were not possible before the arrival of computers.

GIS has proven to play a vital role in the following

- Resource Management
- Harvest planning
- Fire Management
- Map production
- GIS for strategic planning and modeling

The range of applications reviewed in this essay is clear evidence to the significant value of forests and the potential of GIS to aid in their management. Despite the diversity of applications, however, a number of broad conclusions can be reached about the role of GIS in forestry.

Keywords: Global positioning system; Fire management; GIS; Remote sensing

Introduction

The use of Geographical Information Systems (GIS) has flooded almost every field in the engineering, natural and social sciences, offering accurate, efficient, reproducible methods for collecting, viewing and analysing spatial data. Forests are important renewable natural resources and have a significant role in preserving an environment suitable for human life. In addition to timber, forests provide such resources as grazing land for animals, wildlife habitat, water resources and recreation areas. Forestry involves the management of a broad range of natural resources within a forested area. Forest resource management in today's ever changing world is becoming more complex and demanding to forest managers.

GIS is suggested in this essay as a potential means of dealing with this complexity. Upadhyay [1] stated that "Geographical Information Systems is an information technology that has been used in public policy making for environmental and forest planning and decision making over the past two decades". GIS and related technologies provide foresters with powerful tools for record keeping, analysis and decision making. GIS can be established to provide crucial information about resources and can make planning and management of resources easier, for example, recording and updating resource inventories, harvest estimation and planning, ecosystem management, and landscape and habitat planning [1]. The evolution of GIS, the Global Positioning System (GPS), and Remote Sensing (RS) technologies has enabled the collection and analysis of field data in ways that were not possible before the arrival of computers. Nowadays, with improved access to computers and modern technologies, GIS is becoming increasingly popular for resource management.

The primary aim of this essay is to explore the potential application of Geographic Information System (GIS) technology in forest management in general and in 3 African countries. Spatial technologies and their applications will be covered. GIS application in forest management will also be looked at and thus GIS application in forest management in 3 African countries will also be looked. Lastly a conclusion will be made.

Spatial technologies and their applications

The Global positioning system (GPS): Global Positioning System (GPS) technology has provided an essential tool for management of agricultural and natural resources. GPS is a satellite and ground based radio navigation and locational system that enables the user to determine very accurate locations on the surface of the Earth [2]. Although GPS is a complex and sophisticated technology, user

***Corresponding author:** Sonti SH, Department of Environmental and Occupational Studies, Symphony Way, Bellville South Industrial, Cape Town, 7535, South Africa, Tel: 0739132588; E-mail: sh.sonti@gmail.com

Received August 26, 2015; **Accepted** September 29, 2015; **Published** October 01, 2015

Citation: Sonti SH (2015) Application of Geographic Information System (GIS) in Forest Management. J Geogr Nat Disast 5: 145. doi:10.4172/2167-0587.1000145

interfaces have evolved to become very accessible to the non-technical user. Simple and inexpensive GPS units are available with accuracies of 10 to 20 meters, and more sophisticated precision agriculture systems can obtain centimeter level accuracies. Reflected radiation in the infrared part of the electromagnetic spectrum, which is invisible to the human eye, is of particular importance for vegetation studies [2].

Remote sensing: Remote sensing technologies are used to gather information about the surface of the earth from a distant platform, usually a satellite or airborne sensor. Most remotely sensed data used for mapping and spatial analysis is collected as reflected electromagnetic radiation, which is processed into a digital image that can be overlaid with other spatial data Chuvieco and Congalton [3].

Geographic information systems: Geographic Information Systems applications enable the storage, management, and analysis of large quantities of spatially distributed data. These data are associated with their particular geographic features. For example, water quality data would be linked with a sampling site, represented by a point. Data on crop yields might be associated with fields or experimental plots, represented on a map by polygons. A GIS can manage different data types occupying the same geographic space. For example, a biological control agent and its prey may be distributed in different abundances across a variety of plant types in an experimental plot. The power of a GIS lies in its ability to analyze relationships between features and their associated data.

This analytical ability results in the generation of new information, as patterns and spatial relationships are revealed.

GIS applications in general

Anon [4] explained that the uses of GIS, GPS, and RS technologies, either individually or in combination, span a broad range of applications and degrees of complexity. Simple applications might involve determining the location of sampling sites, plotting maps for use in the field, or examining the distribution of soil types in relation to yields and productivity. More complex applications take advantage of the analytical capabilities of GIS and RS software. These might include vegetation classification for predicting crop yield or environmental impacts, modelling of surface water drainage patterns, or tracking animal migration patterns [4].

GIS applications can be grouped into various categories depending on the level of integration with other forest management and financial systems. These categories include

- Data collection and maintenance.
- Map production.
- Data viewing and query.
- Decision support systems.

GIS application in forest management

GIS for strategic planning and modeling: Forest management planning involves making predictions about what the future forest will look like relative to alternative management activities. This ability is crucial to nearly all aspects of management forecasting, particularly long term wood and wildlife supply. According to Kane [5] GIS stores both the geographic and numerical structure of the forest stands and links that spatial database to the planning models. It allows the manager to effectively add both the important temporal and spatial dimensions to the management planning process. Within the limits of the inventory and model, the manager can then map what the forest will look like in 5,10, 25, or 100 years in the future.

Map production: Forest managers require a wide variety of maps to assist with their daily activities. Plantation maps are most commonly used for location purposes and may contain additional useful information such as roads, rivers, compartment boundaries, planted species, and compartment size. Other features such as topographic features (contours), infrastructure, water points, fire breaks, neighbours and conservation areas may be also included in the map [5].

Fire 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 modelling 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. Forest fires have an important influence on the vegetation cover, animals, plants, soil, stream flow, air quality, microclimate, and even general climate [3]. The loss of timber is obvious and so is the damage to life and property. The loss of recreation value of the forest and the destruction of wildlife habitat are also consequences of forest fires.

The key to managing approved burning activities was the ability to anticipate fire behaviour after ignition. Chuvieco et al. [3] explained that fire behaviour models have been developed from fuel models to predict the fire intensity based on factors such as slope, elevation, site exposure, wind speed, relative humidity, cloud cover, temperature, and live and dead fuel moisture. These models are not spatial, however, and are typically used to predict fire behaviour for a fairly large area. To increase the sensitivity of the fire behaviour models to spatial variability within the park, fire behaviour models were fun with a raster based GIS. With input layers stored in the GIS, its mathematical modelling capabilities, along with selected lookup tables, were then used to implement several fuel and fire intensity models. By comparing the predicted fire behaviour with actual burn conditions, Wells and McKinsey concluded that the GIS implementation of fire behaviour models was useful in locating potential control areas, planning ignition patterns, and accommodating sensitive areas that would be adversely affected by high fire intensities [3].

Harvest planning: Good forest management practice requires detailed planning of harvesting activities. Harvest planning activities include the identification of felling directions, extraction routes, depots and sensitive zones such as wetlands. Maps constitute a basic planning tool for these activities [5]. Other tactical harvest planning functions utilize maps to identify planned felling over a number of years, and to consolidate felling areas and extraction routes thereby permitting the efficient use of harvesting equipment and other resources.

Resource management: Wulder and Franklin [6] mentioned that collecting forest inventory data and monitoring changes are critical to forest management activities. Yet, a GIS can build on these activities by incorporating models to guide, for example, timber harvesting, silviculture and fire management activities, or predict fuel wood and other resource supplies. Other priorities, such as providing for wildlife habitat, ensuring recreation opportunities and minimizing visual impacts of harvesting, are also growing in importance. Some applications deal with single management issues, such as timber production, while others illustrate how a mix of management concerns can be integrated through the use of GIS, such as timber production combined with habitat protection.

Uses of GIS in forest management

Upadhyay [1] pointed out that GIS is a good tool for forest management because it answers the following question that helps in forest management activities.

- Location: What is at?

Location of forest resources in the earth in many ways such as a place name, post or zip code, or geographic references such as latitude and longitude.

- Condition: Where is it?

Non forested land of certain size distance from road or river.

- Trends: What has changed since?

It helps to find out what has changed within study forest or land use an area over time

- Patterns: What spatial patterns exist?

Determine whether landslide in forest area

- Modeling: What if?

Determine what happens, if a road network is added in a forest.

GIS application in forest management in Africa

In Kenya: Kenya has a wide range of forests, from coastal forest, through central high mountain forests to the thick wet rainforests of the West. Forests are an important source of livelihood, environmental services, and economic growth in Kenya. Wachiye et al. [7] pointed out that Kenyan forest are biologically rich and harbor high concentrations of endemic species. They are a vital resource that serves the inhabitants of coastal areas. Mangroves provide wood products for house construction, firewood and other non-wood forest products such as tannins and medicine.

Arabuko Sokoke Forest, covering 41,600 ha, is the largest single block of coastal forest remaining in East Africa. It is the only forest reserve where the Forest Department has invited three partners to jointly manage the forest. The three partners are the Kenya Wildlife Service, Kenya Forestry Research Institute and National Museums of Kenya. This is in recognition of the importance of the forest as a biodiversity hotspot and its link with neighboring communities. Arabuko Sokoke Forest needs to be protected and conserved for present and future generations. Strategies for conservation must address short- and long-term goals of forest management.

Remote sensing and GIS in forest management in Kenya: Wulder [8] explained that following the advances in high resolution Remote Sensing Digital Data and Aerial Photography, mapping of the trends of cover changes have become relevant source of information for understanding land cover pattern changes. Various studies clearly demonstrated the potential of integrating remote sensing, GIS and field information for landscape assessment [9].

In Cameroon: The forests of Cameroon are a resource of local, regional, and global significance. Their productive ecosystems provide services and sustenance either directly or indirectly to millions of people. Interactions between these forests and the atmosphere help stabilize climate patterns both within the Congo Basin and worldwide.

Forest atlas software: The Interactive Forest Atlas of Cameroon provides users with up to date information on the forest sector, allowing them to access land use allocation information in their efforts to improve monitoring and management of forest resources. In addition to current information, the Atlas also contains historical records that allow the user to track and analyse land use allocation over time. Since the publication of the first version of the Cameroon Forest Atlas using data from 2004, the Atlas has continuously served as a tool to manage and track land use allocation both within and outside of the National Forest Estate.

Participatory mapping and PGIS in community forestry in Cameroon: a case study: The Cameroon Government's forestry management reforms resulted in a 1994 environmental law that introduced inter alia the concept of community forest. Community forest is defined therein as 'that part of non-permanent forest estate not more than 5000 ha that is the object of an agreement between government and a community in which communities undertake sustainable forest management for a period of 25 years, renewable [10]. McCall and Minang [10] stated that the aims of the introduction of community forests were to enhance local governance through community participation, to integrate indigenous forest management practices, to provide direct economic benefits to communities, and to improve forest biodiversity conservation.

The procedures of the Cameroon Ministry of Environment and Forestry (MINEF) prescribe the following geo information needed for granting a community forest.

- A map showing the boundaries of the intended community forest (community forest boundary map);
- A clear description of activities previously carried out in the proposed community forest area;
- An inventory report of community forest resources;
- A final management plan, zoning the forest into compartments.

The Tinto community: Tinto, in the South West Province of Cameroon, is well drained, between 160 and 280 m in altitude, with a rainfall of about 2000 mm/year and is located within the ever green forest areas of Cameroon known for endemism. The community of 1700-2000 consists of three neighbouring villages of the same clan. Most farmers grow cocoa or coffee as cash crops, along with cassava, maize and other subsistence crops. Forest activities include hunting, collecting non timber forest products and timber [10]. The Clan Council oversees local resource management policy, especially farming rights given to clear forest, and the administration of sacred groves. Some local controls are enforced, such as to reduce poisons in fishing. Part of the forest within the clan boundaries lies in the Banyang Mbo Sanctuary, wherein the Council works with Ministry of Environment and Forests projects to regulate forest activities.

The PGIS process in Tinto: The PGIS process in Tinto can be divided into four main phases, the preparatory stage; land use mapping and planning; community forest boundary mapping; and the community forest management plan mapping phase. McCall and Minang [10] pointed out that the preparatory phase was aimed mainly at the Ministry's Forest Plan at national, regional and local levels to see if forests in the area were eligible for community forestry, based on the provisions of the 1994 forestry law.

In order to designate part of the local forest area as a potential community forest, the community must proceed through a sort of land use mapping and planning process as in phase two [10]. The designated area was then demarcated and the boundaries mapped in the third phase. The process can be characterized as 'learning by doing' over a four year period.

In Congo: Mukeba [11] mentioned that the Congo Basin is the second largest tropical rainforest in the world, with almost 2 million square kilometers of humid forest an area about the size of Mexico. The Congo Basin is home to mountain gorillas, lowland gorillas, chimpanzees, and forest elephants, as well as approximately 1,000 species of birds. The basin is also home to 75 million people and 150 distinct ethnic groups, many of whom still practice a traditional hunter-gatherer lifestyle. Overall, the Congo Basin contains relatively intact forest, although mining, commercial logging, charcoal fuel wood harvesting, and bush meat hunting are significant threats [12].

The forest atlas software: Monitoring the vast rainforest that covers about one third of the Congo Basin is however, an immense challenge, particularly due to the almost complete lack of roads.

Zhang et al. [13] explained that over the past decade, new technologies, including remote sensing and Geographic Information Systems (GIS), have emerged as powerful tools in forest monitoring that can provide critical information to decision makers on how to protect this valued natural resource.

The Forest Atlas is a dynamic tool that helps decision makers in the region to achieve sustainable management of forest resources through strengthened land use planning and monitoring. Through a combination of interactive mapping applications, posters, analytical reports, trainings, and outreach, the Atlases provide users with timely, accurate, and synchronized information about land use allocation within national forest estates. The goal of this work is to improve the quality and availability of information in the forest sector to support transparent and participatory decision making across the Congo Basin. The figures below represent some of the uses of GIS in forest management (Figures 1-4) [13].

A satellite observatory is on its way to becoming a forest monitoring centre of excellence in the Congo Basin region. Zhang et al. [13] explained that over the past decade, new technologies, including remote sensing and (GIS) have emerged as powerful tools in forest monitoring that can provide critical information about how to protect this valued natural resource. Remote sensing consists of taking images

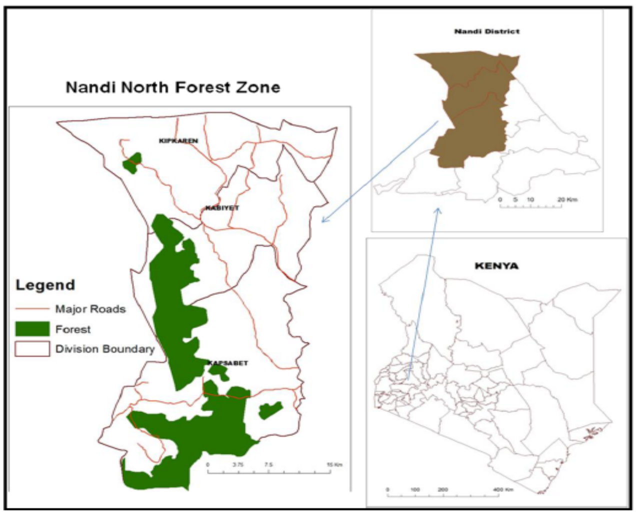

Figure 1: Map showing the Nandi North forest zone [7].

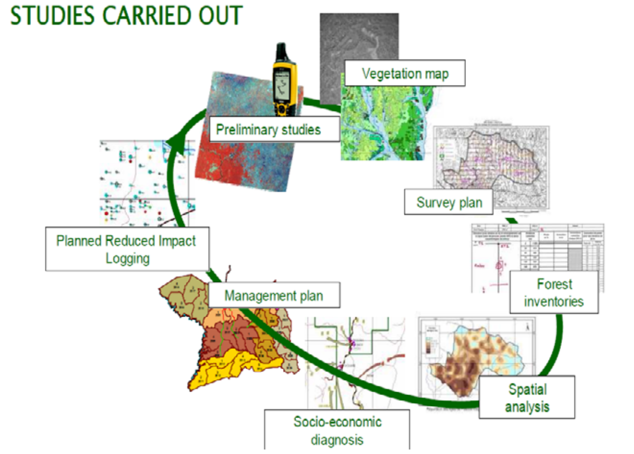

Figure 2: Studies carried out by Wachiye [7].

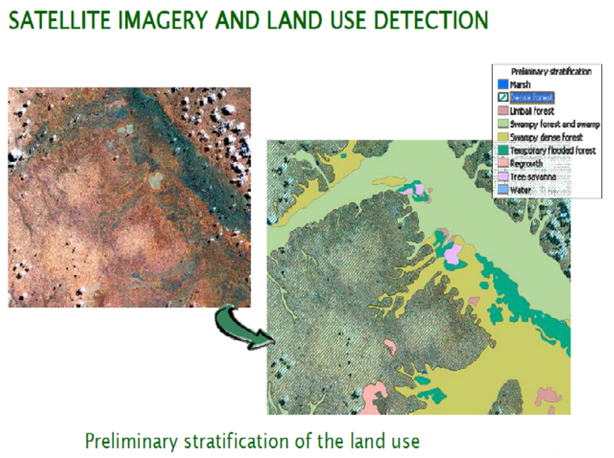

Figure 3: Satellite imagery and land detection [7].

from satellites over an area ranging from a few square kilometres to the entire globe. GIS integrates hardware, software and data for capturing, managing, analysing and displaying various forms of geographically referenced information [13].

The observatory aims to support improved management of natural resources and sustainable development by producing reliable forest-cover change information and building the capacity of public and private conservation partners to use the latest satellite-based tools. For many years, the Congo Basin was behind in using scientific data from satellites to monitor the environment, especially the forest cover change [13-15].

Conclusion

With forest management becoming increasingly complex, due to greater environmental and social involvement and pressures, GIS is likely to play an increasingly central role. Developments in greater band width, web based technology and wireless communication will provide much greater opportunities for information access even in more remote areas. This will allow real time online data capture and query in the field.

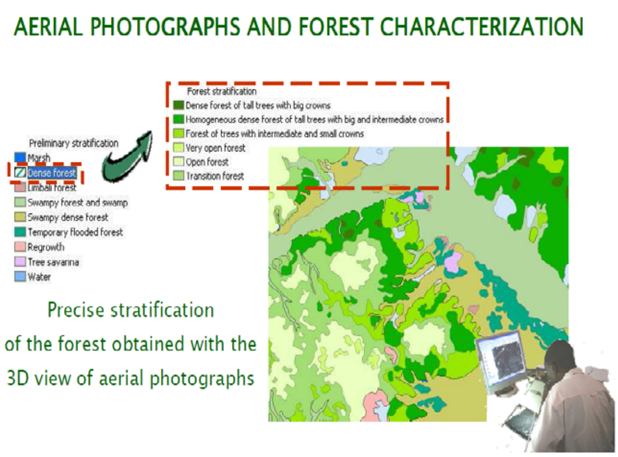

Figure 4: Aerial photographs and forest characterization [7].

The range of applications reviewed in this essay is clear evidence to the significant value of forests and the potential of GIS to aid in their management. Despite the diversity of applications, however, a number of broad conclusions can be reached about the role of GIS in forestry. GIS applications can strongly benefit from remote sensing and image processing technologies. Forests are complex assembly of species that lend themselves well to broad level inventory through remote sensing. However, the need for strong ground truth remains vital and it is likely that satellite positioning systems such as GPS will play an important role in augmenting traditional forest survey activities.

Forests are a dynamic resource, affected by many coexisting ecological processes and direct management interventions. Simulation modelling has been applied in forestry to a degree that is substantially higher than in many other disciplines. Simulation or process modelling is one of the more challenging areas of GIS applications and it is likely that this activity will increase as the research and tools to support this kind of application become more prevalent. It is clear that throughout the world, forests are subject to many demands. As a result, many forest management problems have the nature of multi-objective planning procedures. Stronger tools are necessary for the analytical resolution of conflicting suitability's and choices in resource allocation. In a sense, forestry applications embody the full scope of GIS technology. Thus its study provides an excellent overview of the state of the technology and its potential as a management tool for natural resource concerns.

References

1. Upadhyay M (2009) Making GIS work in forest management. Institute of Forestry, Pokhara, Nepal.
2. Ayhan AA, Ametin TM, Bgurcan BG (2004) Spatial and Temporal Analysis of Forest Covers Change: Human Impacts and Natural Disturbances in Bartin Forests, NW of Turkey. Landscape Ecol 19: 631-646.
3. Chuvieco E, Congalton RG (1989) Application of Remote Sensing and Geographic Information Systems to Forest Fire Hazard Mapping. Remote Sens Environ 29: 147-159.
4. Anon (2015) Applications of GIS. Administration and finance. Mass GIS.
5. Kane K (1997) GIS and Forestry.
6. Wulder MA, Franklin SE (2007) Understanding forest disturbance and spatial pattern: Remote sensing and GIS approaches. CRC press, Boca Raton 1-246.
7. Wachiye SA, Ndegwa DK, Musiega D (2013) GIS based forest cover change and vulnerability analysis: A case study of the Nandi North forest zone. Journal of Geography and Regional Planning 6: 159-171.
8. Wulder MA (1998) Optical remote-sensing techniques for the assessment of forest inventory and biophysical parameters. Progress in Physical Geography 22: 449-476.
9. Thompson MW, Whitehead K (1992) An overview of remote sensing in forestry and related activities its potential applications in South Africa. Southern African Forestry Journal 161: 59-68.
10. McCall KM, Minang AP (2005) Assessing participatory GIS for community-based natural resource management: claiming community forests in Cameroon. The Geographical Journal 171: 340-356.
11. Mukeba A (2013) Eyes in the Sky Monitor Congo Basin Forests. USAID.
12. World Resource Institute (2015) Congo Basin Forest Atlases.
13. Zhang Q, Justice CO, Jiang M, Brunner J, Wilkie DS (2006) A GIS-based Assessment on the Vulnerability and Future Extent of the Tropical Forests of the Congo basin. Springer 114: 107-121.
14. Anon (2007) Remote Sensing and GIS for Moist Tropical Forests' Sustainable Management FRM's expertise in the Congo basin.
15. Esri (2015) Manage the forest better. Forestry.