GEOGRAPHIC INFORMATION SYSTEM AS A TOOL OF ENVIRONMENTAL MANAGEMENT SOLUTION IN RWANDA

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Abstract

The Geographic Information System is a tool for better solution of environmental management in Rwanda. Rwanda's environmental resources can be categorized into land, wetlands, forests, and water resources. This paper aimed to conceptualize the integration and application of GIS and Remotes sensing in environmental context through a review of the existing literature. This paper will help to identify the areas in which their integration and application has proved the most valuable in Rwanda environment, and reveal the extent to which their potential has been realized. It will also help to identify the Rwanda environmental aspects, including the challenges to be overcome to find solutions.

According to EDPRS 2, the major problem in the field of environmental protection in Rwanda is the imbalance between the population and the natural resources (land, water, flora and fauna and nonrenewable resources, which have been degrading for decades). This degradation is observed through massive deforestation, the depletion of bio-diversity, erosion and landslides, pollution of waterways and the degradation of fragile ecosystems, such as swamps and wetlands. Geographical information system is important tool to achieve goals of sustainability science which include understanding, integrating, and modeling nature and society for well being of each nation citizens.

Key words: Environment, Geographic Information System, Remote Sensing, Global Positioning System

1. Introduction

Environmental impact assessment and strategic environmental assessment play a central role in identifying, predicting and managing the impacts of human activities on environmental sustainability. Recent studies of biodiversity planning processes (Angelstam et al. 2010a, 2011, Blicharska et al. 2011, Eriksson and Hammer 2006) show that landscape and regional planning do not satisfy contemporary policies about biodiversity conservation. Current practice suggests that the complexity of the task is underestimated and that new methodological approaches encompassing entire landscapes and even regions are needed (Gontier 2008).

Rwanda is a small, mountainous, landlocked country covering 26,328 km2; it is characterized by

vast hills and mountains interspersed with valleys. Rwanda has been described as country of a thousand hills because of the numerous highly dissected hills, separated by deep valleys.

Rwanda has a population of 10,515,973 with density of 415 sq. km (2012)

Hydrology is characterized by a dense network of lakes, rivers and wetlands occupies about 10% of the country the network of lakes, rivers and wetlands contain a wide variety of plant, animal, and aquatic species; All are threatened by coastal habitat destruction; water extraction; exotic species; fishing in breeding grounds; household and industrial pollution; and sedimentation (Chemonics International Inc.2003).

Agriculture is the mainstay of Rwanda's economy. 73 percent of the population depends on the agriculture sector (NISR, 2012).

The main environmental threat to Rwanda's farming systems is erosion, because most agriculture is done on steep slopes.

Rwanda's environmental resources are categorized into land, wetlands, forests, and water resources. In most cases, environmental degradation in Rwanda has occurred not by massive exploitation of resources, but by the cumulative effects of subsistence exploitation by an increasing population, coupled with limited alternative options for sustainable livelihoods, the demand to convert more land to agriculture has led to destruction of Rwanda's wetlands, which has resulted in flooding, loss of wildlife habitats and sedimentation, the natural forests had a high degree of biodiversity and rare animal species which was threatened by the encroachment of refugees fleeing Genocide and war.

The use of remote sensing and Geographic Information Systems (GIS) in environment management has received considerable attention in the literature. Ehlers et al. (1989) first reviewed the necessity of integrating remote sensing with GIS, and discussed the potential of integration in resource management and environmental monitoring. Two years later Ehlers et al. (1991) further elaborated on how to make remote sensing data available and useful to GIs users. Lunetta et al. (1991) addressed the issue of errors stemming from data processing, analysis, conversion, and presentation in integration. They also identified research issues arising from integration. Recently, Hinto (1996) reviewed the historical evolution toward a closer integration of GIS with remote sensing for environmental applications, and software requirements in combining raster remote sensing and vector GIS data. Wilkinson (1996) comprehensively reviewed current issues in the integration of remote sensing and GIS with an emphasis on how GIS technology should cope with increased capability in remote sensing data acquisition.

2. Environment components

Our environment is our surrounding; this includes living and non-living things around us. for better environment, all its components should be protected from pollution and the surroundings should be clean. It is also necessary to ensure a balance between these resources and living creatures, to meet our needs (http://www.doc88.com/p-369144990930.html).

Since September 2013, the Government of Rwanda has launched the preparation of the second phase of Poverty Reduction Strategy named « Economic Development and Poverty Reduction Strategy – EDPRS » that will cover 5 years, and it is an operational tool reinforced by realistic and feasible sectoral plans based on priorities, an adapted implementation framework and tangible results with significant impact on the improvement of living conditions of the population, especially the poorest ones.

Rwanda's environmental resources can be categorized into *physical environment* composed by (Relief and climate, Arable land, Soil degradation, Water resources, Wetlands); *biodiversity and forests* composed by (Protected areas, Relict and gallery forests, Biodiversity of wetlands, Biodiversity in agricultural systems, Pastoral land, Wooded areas); *socio economic environment* composed by (Population and economy, Human settlements, Energy and transport, Agriculture and animal husbandry, Pollution); *natural disasters and hazards* composed by (Natural disasters and Man induced disasters).

The major problem in the field of environmental protection in Rwanda is the imbalance between the population and the natural resources (land, water, flora and fauna and nonrenewable resources, which have been degrading for decades). This degradation is observed through massive deforestation, the depletion of bio-diversity, erosion and landslides, pollution of waterways and the degra-

dation of fragile ecosystems, such as swamps and wetlands.
(Interim PRSP, 2000)

Our relation to nature has become integral to how we are addressing the future of humanity and the management of environment. The ecosystem services approach can be a part of a larger solution (Norgaard 2010). Rockström et al. (2009) identified nine Earth-system processes and associated thresholds which, if crossed, could generate unacceptable environmental change. The processes they mention are: climate change; rate of biodiversity loss (terrestrial and marine); interference with the nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification; global freshwater use, change in land use; chemical pollution, and atmospheric aerosol loading. Rockström et al. (2009) suggested that three of the Earth-system processes; climate change, rate of biodiversity loss and interference with the nitrogen and phosphorus cycle, have already transgressed their thresholds.

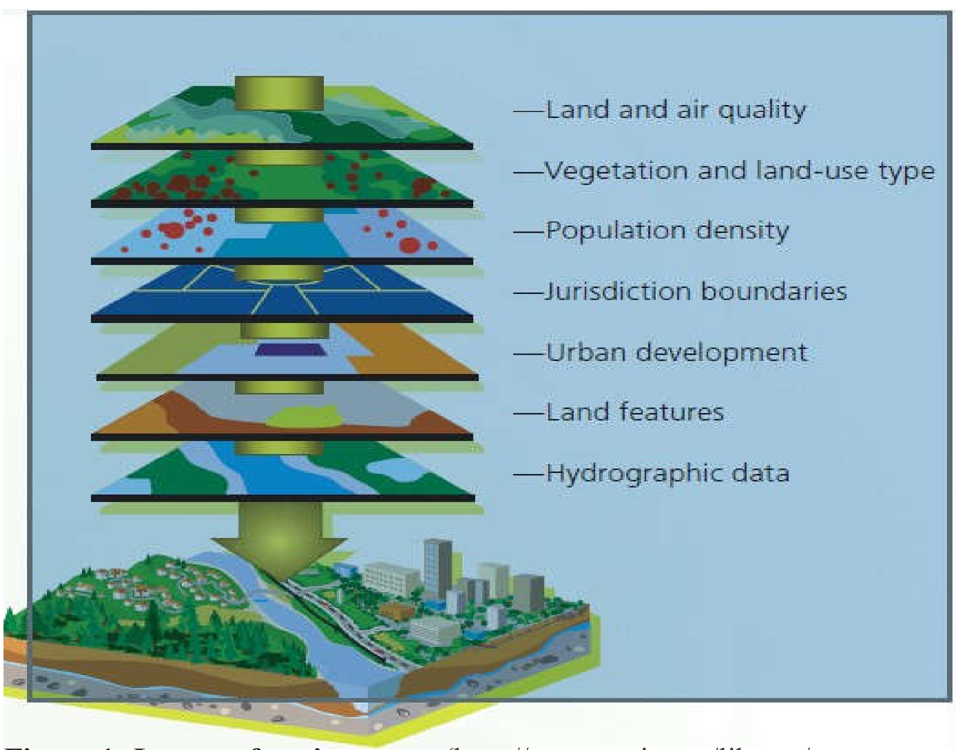

Figure 1: Layers of environment (http://www.esri.com/library/brochures/pdfs/gis-sols-for-env-mgmt.pdf)

3. Geographic Information System

Introduction

According to Rhind, Geographical Information Systems is a system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning & management problems" (Rhind, 1989).

GIS is a powerful software technology that allows a virtually unlimited amount of information to be linked to a geographic location. Coupled with a digital map, GIS allows a user to see locations, events, features, and environmental changes with unprecedented clarity, showing layer upon layer of information such as environmental trends, soil stability, pesticide use, migration corridors, hazardous waste generators, dust source points, lake remediation efforts, and at-risk water wells. GIS offers a wide variety of analytical tools to meet the needs of many people, helping them make better decisions about the environment.

GIS divides the world into objects and attribute tables, both of which can be represented spatially by raster or vector datasets which are shown on the map overlay:

Raster dataset that comes from grids, e.g. images, aerial photos and Vector dataset that comes from mathematical calculations and functions, e.g. points, lines, polygons.

Both types of dataset will be used to produce complete and extensive data in the Area of Study. GIS also has programming capabilities, however, in this thesis the programming is limited to simple queries in SQL and VB languages, for example Arc Objects. As a result, simple map algebra and calculation functions can be achieved.

A GIS is a computerized information system that supports the collection, storage, processing, analysis and visualisation of geographic information (Harrie 2008). A GIS provides a multitude of tools for spatial analysis and modelling, and visualisations that can be used for communication and stakeholder involvement in planning processes (Rambaldi et al. 2006, Zetterberg 2009). Multiple criteria analysis has been used as a decision support tool for a wide number of applications

(Curtis 2004, Hajkowicz et al. 2007, Marinoni et al. 2009). It has the potential to be used as a tool for sustainability assessment, because it can bring together the sustainability criteria from all dimensions, ecological, economic, and socio-cultural, to give an integrated assessment of sustainability (Graymore et al. 2009). Lately, there has been a rapid increase in the use of GIS based methods and models to understand, predict, and visualize the spatial distribution of organisms in a landscape. GIS has sparked interest for three main reasons (Sieber 2006). First, most information used in policy-making contains a spatial component (e.g., address or coordinate). Second, extending the use of spatial information to all relevant actors and stakeholders may lead to better policy implementation through better communication and collaboration. Third, policy-related information can often be analysed and visualised spatially, and the resulting output (mainly maps) can persuasively communicate ideas and convince people of the importance of those ideas. Involving actors and stakeholders of different backgrounds in planning processes, the GIS tool has proved to be flexible and effective in the communication and negotiation of indicators, targets, and impacts (Zetterberg 2009).

Basing to the definition of GIS as given by (Lo & Yeung, 2002), is a set of computer-based systems for managing geographic data and using those data to solve spatial problems. Therefore, Standard interfaces for data and information access facilitate data management and usability by minimizing the effort required to acquire, catalog and integrate data from a variety of sources.

Identifying data types focuses on the maps, drawings, photographs, facility observations, field measurements, inspection checklists, environmental media, analysts, sampling locations, sampling dates, number of samples, remote sensors and data quality necessary to support the intended data uses.

Global Positioning System (GPS)

GPS is a satellite and ground-based radio navigation and location system that enables the user to determine very accurate locations on the surface of the Earth. Although GPS is a complex and sophisticated technology, user interfaces have evolved to become very accessible to the non-technical user. (*http://www.joe.org/joe/2005june/a6p.shtml)*

A GPS receiver calculates its position by precisely timing the signals sent by GPS satellites high above the Earth. Each satellite continually transmits messages that include the time the message was transmitted and satellite position at time of message transmission.

The receiver uses the messages it receives to determine the transit time of each message and computes the distance to each satellite using the speed of light. Each of these distances and satellites' locations defines a sphere. The receiver is on the surface of each of these spheres when the distances and the satellites' locations are correct.

In the late 1980s a new technology, the Global Positioning System (GPS), became a valuable tool in spatial data acquisition. This emergence has not only confounded the approaches by which it is integrated with remote sensing and GIS but also the rapid development of spatial technologies in recent years has made available new tools and capabilities to Extension services and clientele for management of spatial data. In particular, the evolution of geographic information systems (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 advent of the computer.

Remote sensing

Remote sensing is the science of obtaining information about objects or areas from a distance, typically from aircraft or satellites. Remote Sensing provide large amounts of data needed, Reduces manual field work dramatically, allows retrieval of data for regions difficult or impossible to reach like Open ocean, Hazardous terrain (high mountains, extreme weather areas), Ocean depths, Atmosphere...), allows the collection of much more data in a short amount of time which is reading to increase land coverage and ground resolution of a geographical information system, digital image greatly enhance a GIS directly (Imagery can serve as a visual aid) and indirectly can serves as a source to derive information such as land use/cove, atmospheric emissions, vegetation, water bodies, cloud cover, change detection which is including sea ice, coastlines, sea levels).

Remote sensing methods are **Passive Sensors:** which use satellites namely Landsat TM, AVHRR, Spot, MODIS, IKONOS, Quickbird; **Passive Systems method** uses Air Photography and **Active Sensors** uses Radar.

Remote sensing systems which measure energy that is naturally available are called **passive sensors**. Passive sensors can only be used to detect energy when the naturally occurring energy is available. For all reflected energy, this can only take place during the time when the sun is illuminating the Earth.

Active sensors, on the other hand, provide their own energy source for illumination. The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor. Advantages for active sensors include the ability to obtain measurements anytime, regardless of the time of day or season. Active sensors can be used for examining wavelengths that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated. However, active systems require the generation of a fairly large amount of energy to adequately illuminate targets. Some examples of active sensors are a laser fluorosensor and asynthetic aperture radar (SAR). (*http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/sat-*

ellite-imagery-products/educational-resources/14639)

Spatial data infrastructures

Spatial Data Infrastructures (SDI) is an enabler for understanding space. SDI does not simply deliver maps. It disseminates spatial data with associated quality control, metadata information, and semantic descriptions. In this view SDI can play an important role in the management of the environment.

The expression "spatial data infrastructure" was initially used to describe a standardized way to access to geographic information (Maguire and Longley 2005). A SDI implies the existence of some sort of coordination for policy formulation and implementation, along with more complete and standardized metadata, possibly including means to provide online access to data sources.

Natural resource is not uniformly distributed but varies spatially and, in consequence, the social and economic development challenges also vary spatially.

In management context the spatiality of natural resources describe the development landscape as it currently exists as well as the potential pathways of change.

Spatial based Information is the base for natural resource management

Integration of GPS with Remote Sensing and GIS

Geographic Information Systems (GIS) are a new and growing concept, and continue to grow in complexity and utility in large part to the continual development of Remote Sensing. Remote Sensing plays a large role in the enhancement of any GIS, and in most cases, allows data to become much more relatable and useful for anyone.

A GIS receives much of the data for its built-in layers from Remote Sensing platforms such as satellites, radars and airplanes. Passive sensors contribute to imagery and data for land cover mapping, change detection, snow monitoring, thermal changes and terrain modeling. Active sensors contribute heavily to data for extremely accurate terrain models known as Digital Elevation Models (DEMs). These large quantities of data can be geo-referenced and integrated into one large GIS, allowing a user to access a powerful amount of information at one time with relative ease.

And as remote sensing technology continues to increase in resolution and power, the data base will enlarge and increase the potential power of users of a Geographic Information System.

Aerial photography has long been used to generate analogue geospatial products that, now, in a digital form, often constitute important components of GIS databases.

Levels of Remote sensing GIS integration (Modified from James W. 2009

Level of integration	*Principal characteristics*	*Examples of analyses supported*
First-level integration	Achieved via data exchange between separate GIS and image analysis systems	(a) Simultaneous display of GIS (usually vector) data and remotely-sensed (raster) images; (b) Ability to move the results of low-level image processing to the GIS and the results of GIS-based analyses to image-analysis software.
Second-level integration	Permits 'seamless' tandem or combined raster–vector processing facilitated by a common user interface	(a) Capability to incorporate GIS data directly into image processing; (b) Ability to accommodate heterogeneous data input in a coherent manner; (c) Ability to generate simulations combining a GIS and image data with temporal evolution.
Third-level integration	Remote sensing and GIS operate as a single, integrated system – 'telegeoprocessing'	(a) Accommodate raster and vector data in a unified data structure; (b) Facilitate real time analysis using sensor networks and linkages to other technologies.

Figure 1 .Figure of levels of Remote Sensing integration

.Source: James W. Merchant and Sunil Narumalani, Integrating Remote Sensing and Geographic Information Systems, University of Nebraska - Lincoln, 2009

Thus, the use of GIS is needed to collect data, store, manage, analyze and produce useful information. In other words, the process of GIS is to input sets of raw data to produce useful output information. A function of GIS is the ability to query databases using a selection of attributes or selection of locations for special criteria to find the relationships between different results.

The ability to interface GIS with relational databases enables integration of large data sets and many variables to support management decisions.

GIS could assist to environment for Provisioning, Regulating, Enriching, Ability to access to information of environment and to take measures to Vulnerability to natural disasters and climate change (hurricanes, earthquakes, floods, longer-term impacts of climate change).

Rwanda Poverty is intimately related to a series of interlocking issues, in particular land, demography, environmental degradation, as well as low and limited sources of growth, GIS can play an important role in poverty reduction by providing accurate and reliable environmental related data for better decision making (**Interim PRSP, 2000).**

4. Conclusion

A modern nation, as a modern business, must have adequate information on many complex interrelated aspects of its activities in order to make decisions.

GIS could be use also in Rwanda for current land use and land cover, water-resource inventory, flood control, water-supply planning, and waste-water treatment, comprehensive inventories of existing activities on public lands combined with the existing and changing uses of adjacent private lands to improve the management of public lands, to assess the environmental impact resulting from the development of energy resources, to manage wildlife resources and minimize man-wildlife ecosystem conflicts, to make national summaries of land use patterns and changes for national policy formulation, and to prepare environmental impact statements and assess future impacts on environmental quality, to assess and manage areas of critical concern for environmental control such as flood plains and wetlands, energy resource development and production areas, wildlife habitat, recreational lands, and areas such as major residential and industrial development sites, local Government (Public works/ infrastructure management (roads, water, sewer), planning and environmental management, property records and appraisal),Real Estate and Marketing (Retail site selection, site evaluation),Public safety and defense (Crime analysis, fire prevention, emergency management, military/defense),natural resource exploration/extraction (Petroleum, minerals, quarrying),Transportation(Airline route planning, transportation planning/ modeling),health management (Health Systems, Health Centers, Management Beds),Public health and epidemiology, the Geospatial Industry(Data development, application development, programming).

GIS is a good tool to produce spatial information as maps that can be fed into planning processes. One advantage is that data like digital maps and statistics can be combined to derive new data. Also raster data can be transformed using different algorithms to create new data. Thus, it is not the input data that is most useful, but the derived new data that did not exist before. In many cases, planning professionals using GIS see the lack of data as a problem (e.g., ULI 2008). However, I believe that the data often exist, but the planners are not skilled in innovative and advanced analysis (Göçmen and Ventura 2010, ULI 2008) that would enable them to obtain this data. This problem calls for education of planning professionals in relation to different data analysis methods, and making planners aware of the possibilities with GIS as a general tool.

The most important elements of success in terms of GIS use indicated that, the organization management must be positive, data must be stored in bases which are accessible for the whole organization, and there must be a clear IT-strategy where GIS is a part. Geographic Information Systems could be applied in Rwanda in planning, map production, environment, utilities, real estates, traffic, transports, and water, forestry, education, sports, tourism, geology, health and social care, IT services, rescue, and agriculture.

The largest obstacles for a continuous development of GIS are the cost for data and systems. Other obstacles are the lack of knowledge within the personnel and the interest and understanding for the usefulness of GIS within the organization. The largest perceived benefit of using GIS is improved quality of analysis, presentations, and decision support.

The Geographic Information Systems (GIS) can be used briefly in Rwanda in urban and regional planners, civil engineers, geographers, spatial economists, sociologists, environmental scientists, criminal justice professionals, political scientists, and alike. "The Application of Geographic Information Systems" presents research findings that explain GIS's applications in different subfields of social sciences. With several case studies conducted in different parts of the world, the book blends together the theories of GIS and their practical implementations in different conditions. It deals with GIS's application in the broad spectrum of geospatial analysis and modeling, water resources analysis, land use analysis, infrastructure network analysis like transportation and water distribution network, and such.

Geographic Information Systems is Software systems with capability for input, storage, manipulation/analysis and output/display of geographic spatial information. Geographic Information Systems is a potential tool to improve, enhance the effects of physical environmental growth, plan for better management of resources, adding new values-added services, perform analysis on spatial and non spatial components, fast recall of data, offer ability for complex analysis, recall of non spatial data through object location, display of information in a different light/view, produce multiple scenario in planning can be performed easily management tasks.

One of the most significant challenges to the GIS and remote sensing technologies is the environment monitoring and change prediction at the practical operational costs. This is particularly important in developing countries, where limited resources are available. To achieve a sound cost/benefit ratio, the technological development must focus on the provision of operational benefit to the local management, where the adequate technical support should not be expected. It is therefore extremely important for a successful implementation to package the technology to assist the low-level users in their daily

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