TOWARDS THE USE OF GEOGRAPHIC INFORMATION SYSTEMS FOR EFFECTIVE MONITORING AND EVALUATION OF LAND AND MARINE RESOURCES IN SMALL ISLAND DEVELOPING STATES

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The rationale for the effective management of natural resources in SIDS has been a subject of discussion in many fora in the last decade. The relatively fixed quantity and exposure of these resources to natural and human degradation are major concerns to the population at large. In an attempt to manage these resources in rational and sustainable ways, efforts have rightly been focussed on the development of legislative and policy instruments. These instruments have shown little-known results and their impact is sometimes difficult to assess.

Improvements in information technology, in the last decade, have tremendously improved the capability of geoinformatics as a data acquisition, data analysis and data management tool. The introduction of high-resolution satellite imagery and high-precision Global Positioning Systems along with increased data processing power of GIS has provided efficient tools for resource management.

This paper will review technological advancements that could improve the management of natural resources. Particular attention would be paid to the use of Geographic Information Systems (GIS) as a data analysis and modelling tool for a variety of spatial analyses and management. The paper concludes by proposing a strategic development plan for the effective use of GIS in land and marine management in SIDS.

Keywords: *GIS, Land and Marine Resources Management, Caribbean*

1. Land and Marine Resources Management in the Caribbean

Land, being fixed in supply, is a primary resource that has multiple functions and hence competing claims for its use. There is a complex interplay between public policies and public actions on the one hand, and land use, development and conservation on the other. This interplay is heightened greatly in Small Island Developing States [SIDS] of the Caribbean where the scarcity of land resources is even more critical, the competing claims more strident and the impacts of land use on the marine environment more acute. The determination of the best use for any given area of the natural resources requires an integrated approach to the formulation of land and marine resources policies, land use planning and management. With such an approach, resources can be utilized to the fullest, whilst at the same time, minimizing its degradation.

Most Caribbean countries have stated policy objectives that address the maintenance and improvement of the biotic productivity of the land and marine resources, whilst balancing other socially desirable competing claims on their use. These policy objectives have been

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stated in several documents and fora and have been specifically articulated in the Barbados Declaration of Small Island Developing States Conference held in 1994, in which a Programme of Action [POA] was developed. The POA specified policies, actions and measures to be taken at the national, regional and international levels to enable SIDS to achieve sustained development. The POA is divided into 15 areas, 2 of which speak specifically to coastal, marine and land resources.

In 1999, in preparation for a special session convened by the United Nations General Assembly to discuss the implementation of the POA, a survey was carried out on the implementation status of the Caribbean countries that were signatories to the Barbados Declaration. The survey found that with respect to coastal and marine resources, most countries had undertaken some measures to encourage improved coastal zone management by the establishment or strengthening of coastal zone management institutions, and the creation of administrative and legal structures and programmes for coastal zone management. Many countries have also initiated feasibility studies and implemented projects to encourage integrated coastal zone management as well as designed research, monitoring and awareness programmes for integrated coastal zone management. However, in many cases, notably Trinidad and Tobago, the national capabilities to ensure sustainable harvesting and processing of fisheries are not well established. In Barbados and Jamaica, management strategies for coastal and marine resources are well developed and include fiscal and economic instruments, enabling legislation, regulations, non-binding guidelines and public participation. New systems have been established or existing ones strengthened for integrated coastal zone planning and management, and the use of Environmental Impact Assessments [EIA] and GIS as decision-making tools are also well established.

Land use planning is the systematic assessment of land and water potential, based on the evaluation of alternative uses and the economic and social conditions surrounding their use, in order to select the best options. The purpose is to select and implement those land uses that will best meet the needs of the people, while safeguarding the resources for the future. In doing this, full account must be taken of the issues of the impact of land-based activities on the marine resources.

In almost all of the countries, the approaches to land use planning, development and conservation of the land and marine resources are fractured and segmented. Current land use and management approaches in the Caribbean tend to focus on the utilization of a single resource, without adequate consideration of the other resources that may have a negative or positive impact on it. Moreover, sectoral plans are made with little knowledge of the extent of the physical resources.

Effective resources management hinges on the integration of information and knowledge of the conditions and processes that affect the extraction and use of those resources. It requires a comprehensive inventory and appraisal of those resources, monitoring of their status and their re-evaluation at periodic intervals.

This requires timely, accurate and up-to-date data on land and marine resources and the interactions between these resources. Such data can derived from remotely-sensed images, global positioning systems and field surveys. The data can then be stored, manipulated and analyzed with Geographic Information Systems. However, these data are relatively expensive to obtain and maintain given the scarcity of human, financial and institutional capacity evident in the Caribbean.

2. Geographic Information System

GIS is an organized collection of computer hardware, software, geographic data, and personnel, designed to efficiently *capture, store, update, manipulate, analyze,* and *display* all forms of geographically referenced information [1]. Geographical information plays an important role in activities such as environmental monitoring, management of land and marine resources, and real estate transactions. According to Olędzki (2004), this technology enables the current monitoring of those phenomena which cannot be investigated and estimated in any other way, as well as the modeling of spatial (geographical) phenomena.

The areas of GIS applications are numerous and growing. Listed below are major areas of applications that have benefited from developments in GIS [2]:

- Management of natural resources
- Environmental Impact Analysis (EIA)
- Hazardous or toxic facility siting
- Groundwater modelling and contamination tracking
- Wildlife habitat analysis
- Zoning, subdivision plan review
- Land acquisition
- Maintenance of ownership

The increasing use of GIS in the varying professional fields has produced both tangible and intangible benefits that are enough to sustain its use into the future. The following benefits have been advanced for the use of GIS natural resource management [3] [4] [5]:

- It provides integrated data storage and data retrieval capabilities.
- It encourages a more systematic approach for the collection of data.
- It can reduce the overall costs of data collection and management by facilitating data sharing among users.
- It increases comparability and compatibility of diverse data sets.
- It makes data accessible to a wider range of decision-makers.
- It encourages the spatial analysis of environmental impacts that would otherwise be more easily ignored because of analytical difficulty or high cost.

GIS has over the years, evolved as a powerful tool for spatial decision making and support systems. Due to this fact, a new era of GIS applications, which have proved to be supportive in the case of SIDS, has emerged. Vihar (2003) asserted that Geoinformatics, which includes remote sensing, satellite photography and information technology, is indeed finding increased application in agriculture, forestry and hydro-geology. More specifically, in the past five (5) years, GIS technology has been utilized in diverse new areas in Small Island Developing States. These main areas include:

- Tourism potential and logistics
- Hydrology and water resource management
- Flood control in flood-prone areas
- Development of Urban Land Information Systems

Over the past three years, computer hardware and software constraints to GIS development have been reduced. Data acquisition still remains a challenge even with advances in sensor technology and the decreasing cost of acquisition. The removal of the intentional error in GPS readings and the availability of sub-5metre resolution satellite imagery have provided some relief to these constraints. The recent commercialization of the IKONOS satellite imagery with the 1-metre panchromatic and 4-metre multi-band resolution is revolutionizing the use of GIS for natural resource management.

3. GIS and Land and Marine Resources Management

The use of GIS technology has greatly extended the ability to analyse data on Land and Marine resources for gap analysis and modelling and decision support systems. The increasing capacity of GIS to integrate data from a variety of sources allows for more sophisticated analysis. In this section, examples of how GIS is being used in applications relevant to land and marine resources management are provided.

3.1 GIS as a tool for Water Quality Monitoring and Ground Water Resource Management

The use of GIS in water resource management is gaining increasing support. Turner and Kolm [6] developed a 3-dimensional GIS for groundwater modelling of regional aquifer systems in areas with complex geologic and climatic conditions. Kilborn et. al. [7], integrated ground water models with GIS, thus providing spatial visualization for the output of the models. Mullen [8] demonstrated the use of GIS in the assessment of ground water, in particular, analyzing the spatial distribution of atrazine contamination in wells along with soil leachability data. Tucker et. al. [9] integrated water quality database with a GIS in order to highlight the spatial and temporal dimensions of the database and to undertake more sophisticated analysis. As a data acquisition tool, Richie and Cooper [10] utilized Landsat MSS digital data in a GIS environment to estimate surface suspended concentration over Enid Reservoir in North central Mississippi. Shih and Jordan [11] integrated remote sensing techniques with GIS to assess regional soil moisture conditions over a 208 354 ha. site in southwestern Florida. Maruo (2004), with the assistance of point data spatial analysis, was able to produce groundwater level maps, and water quality maps.

Special purpose water quality modelling software may be interfaced to GIS for a fully integrated modelling environment. Such an interface would lead to a reduction in data input problems and foster integrated analysis and visual result presentation. This becomes important when the results of water quality analyses are to be displayed in map form as opposed to graphs or bar charts. GIS will provide such a mapping environment.

Fundamental to the successful development of GIS support for water quality management is the development of environmental digital databases for the entire management area. The databases would provide support for the qualitative and quantitative analyses of hydrological queries. Attempts are currently being made by the Water Resource Agency, WASA, to develop such databases for the island of Trinidad.

3.2 GIS as a Tool for Environmental Monitoring

The single most important threat to surface and subsurface drinking water resources is nonpoint source (NPS) pollution. Agriculture, which is the most viable form of meeting the demands for food, is threatened by nonpoint source pollution. GIS is being used to estimate the spatial distribution of nonpoint source pollution such as nitrogen, phosphorous, zinc, lead, BOD and sediment. The ability to accurately assess present and future NPS pollution impacts on the ecosystems at a local and global scale would provide an invaluable tool to environmental stewardship and future human activities.

The interfacing of GIS to a nonpoint source pollution model may be used to estimate the success of an attempt to reduce pollution loads and the ability to improve water quality. To assess NPS pollution is an integrated process. It comprises a number of complexities of scale and position, thus drawing from different fields of science and applied in a spatial context. In the case of NPS pollutants, Corwin et al. [12], used a mathematical model within the context of a GIS that describes the appropriate chemical, physical and biological processes involved in the transport of a solute through the vadose. Endreny and Wood [13] in central Oklahoma used Topographically-based Land Atmosphere Transfer Scheme (TOPLATS), a GIS-based watershed model, in a water table-driven VSA hydrology routine to identify runoff zones in a specific area of agricultural watershed. Steve Carver et al. [14], evaluated the field-base GIS methodology for environmental characterization, modelling and decision support and noted the following advantages of the use of GIS:

- The improvement of environmental models through interactive field verification procedures
- Greater confidence in data gained through direct involvement in the data collection process
- The operation of positive feedback mechanisms
- The input of local knowledge and Experience

Duguay et al., [15], discussed environmental modelling and monitoring with GIS. They stated that "remote sensing imagery and ancillary data from GIS are important sources of information for input to ecological and climatic models of seasonal and long-term change (p. 219)." One of the goals of the United States Long-term Ecological Research (LTER) program is to systematically monitor and study patterns and controls within a variety of natural ecosystems at various spatial and temporal scales. The goal of this study is to "monitor changes on the earth's surface as a result of natural and anthropogenic processes. Within LTER, the integration of remote sensing and GIS data sets will be critical toward linking established and detailed ecological studies at plot and landscape levels to regional scale interpretations through ecological simulation and modelling."

Recent cases of drinking water contaminated by pathogens, have underscored the importance of preventing livestock waste from entering surface water. It is to this end, that analytical tools are needed to identify sub watersheds or livestock operations that contribute disproportionately to contamination. A GIS-based transport model (SEDMOD) is used as an index of pathogen loading potential to streams using key transport parameters [16]. The transport model together with a livestock density GIS layer, explained 50% of the variation in average faecal coliform discharged from sub watersheds. Though not perfect in the quantitative predictions, the model is useful for predicting the relative contribution of diverse livestock operations within a varied landscape, hence watershed managers can prioritize sites for nonpoint source pollution control.

Included also in Environmental Monitoring Systems, are Environmental Impact Analyses (EIAs). Chakrabarti (2004) utilized GIS and Geo-environmental mapping to depict the results of EIAs spatially. In relevance to SIDS, the operational combination of Remote Sensing and GIS technologies plays a facilitator role in the collection and visualization of up-to-date spatial data, as well as integration and analysis of the same with aspatial database. This is done in order to generate application specific 'strategic datasets' for structural and non-structural means, towards environmentally sound landuse and land cover practices, minimizing the adverse effects of natural hazards (e.g. droughts, floods, bank failure) and land degradation to their predominantly coastal environments.

3.3 GIS as a Tool for Land Resource Inventory: SALIS

Guided by the need to efficiently and effectively manage land resources, the Cabinet of the Government of Trinidad and Tobago in 1993 directed the Ministry of Agriculture, Lands and Marine Resources (MALMR) to undertake the following tasks:

a. Compile a full inventory of all agricultural state lands in Trinidad and Tobago
b. Conduct a survey of the utilization of all such lands, and
c. Verify the compliance of such tenants with the terms and conditions of leases and agreements.

In response to these directives, the MALMR initiated a GIS parcel-based State Agricultural Land Information System (SALIS). The objectives of SALIS are as follows:

a. To design and develop an automated land information system that could be used to collect, store, retrieve, manipulate, analyze, manage and share land-related data required for the management of state agricultural land in Trinidad and Tobago.
b. To implement the use of such system on a phased-basis in all agricultural districts in Trinidad and Tobago.
c. To evaluate the strategies and resources required for full implementation on all State lands in Trinidad and Tobago.
d. To integrate SALIS with other natural resource databases existing in Trinidad and Tobago e.g. soils rainfall, elevation databases.
e. To integrate SALIS with other property management databases existing in other land-related agencies.

Maps, such as that shown in Figure 1, are produced as a result of analysis using SALIS.

The SALIS stores for each parcel of State agricultural land, information on the following themes. Other data types, as may be required for land management, can be added into the system.

a. Land parcel definition
b. Official record of tenure
c. Field investigated tenure
d. Information on occupier
e. Information on rent
f. Information on land use and level of utilization

g. Agricultural commodity on land
h. Information on water supply

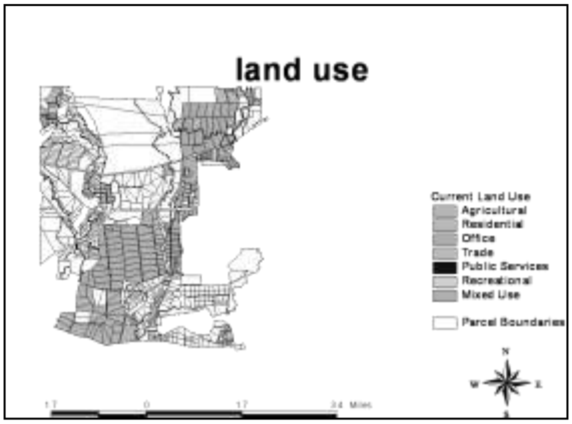

FIGURE 1: Current Land Use derived from SALIS

SALIS is being used to perform the following land management activities:
a) Area and commodity development planning
b) Natural resource management
c) Land rent collection and management
d) Land valuation processes
e) Land use planning and management
f) General estate management
g) Land tenure regularization
h) Determining water needs for agricultural development

3.4 GIS as a Tool for Evaluating the Carrying Capacity of Land Resources: Sustainable Tourism Development in the North Coast of Trinidad.

The North and Northeast coasts of Trinidad constitute 10% of the area of the island. The watersheds in this area are vitally important for the supply of potable water. The area, consisting of beaches, scenic rugged terrain, forests and scattered rural communities, is very popular for recreational activities. For this reason, the area is targeted for the development of sustainable tourism activities. An evaluation of its potential for tourism requires analysis of the physical, ecological, social, economic and cultural aspects of the area. The overall objectives of the Carrying Capacity study were:

- To assess the ecological, physical, infrastructural, socio-cultural, economic and land use context of the study area for sustainable tourism use and development.
- To determine the optimum amount and location of activity and development for the area.

The analysis was efficiently implemented using GIS. GIS spatial analyses were conducted to objectively identify developable sites for tourism activities. In order to minimize disruption to the ecosystem of the area the following criteria were imposed for a land site to be qualified for physical development. A developable site must:

- Be on slopes less than 20 degrees (Category 4)
- Not be located on prime agricultural land and steep forested slopes
- Not be on ecologically sensitive sites
- Not be within Forest Reserves
- Not be within existing human
- settlements
- Not be within designated National Parks and Protected Areas
- Be on state lands

The GIS data used for the analysis were:

- Ecologically sensitive sites (Bird and turtle nesting habitats along beaches)
- Human settlements
- Land tenure
- Forested areas including Forest Reserves
- Designated National Parks and Protected areas, Scientific Reserves
- Agricultural Land capability classes
- Scenic landscapes, National Landmarks
- Watershed boundaries

The analysis was done for each of the twelve watersheds using the GIS overlay process. For each watershed, the selected developable sites, as shown in Figure 2**,** met the stated criteria. The selected sites were subsequently used to derive hotel and guesthouse accommodation based on the total daily carrying capacity of beaches and trails in proximity to the developable sites.

FIGURE 2: Maracas watershed: Developable sites selected using criteria for hotel site selection

3.5 GIS as a Tool for Sustainable Fisheries and Coastal Zone Management

In recent times, SIDS have seen the use of GIS and Remote Sensing (RS) in aiding the implementation of sustainable fisheries management and supporting and strengthening regional fisheries management organizations such as the recently established Caribbean Regional Fisheries Mechanism (UNCOSA, 2007). This mechanism has utilized remote sensing data for sea surface temperature, marine environments and algal bloom on the reefs. More recently also, Geoinformatics technologies are increasingly been utilized by SIDS of the Caribbean and Pacific Islands in overall coastal management, in the context of the United Nations Environment Programme (UNEP). Here, RS and GIS tools serve as decision making tools for policy makers and environmental managers alike in the development of forecasting models.

4. Towards Effective Use of GIS in the Caribbean

In order for the SIDS of the Caribbean to effectively benefit from the many advantages of GIS, there is a need to develop a strategic development plan. Critical to the plan are the following elements:

- Consistent data collection programme
- Efficient data management plan
- Capacity building
- Consistent data models and integrated analysis

Consistent Data Collection Programme: The effective use of GIS for land and marine resource management requires consistent flow of data on the extent and status of these resources. Spatial analyses and resource monitoring programmes can be rendered ineffective with data gaps and incompatible data. A programme of regular data collection on the status of natural resources is imperative. The use of satellite imagery has made the undertaking of such a programme more affordable to SIDS.

Efficient Data Management Plan: In addition to a consistent data collection programme is the need to develop an efficient data management plan. The high investment in data collection may go to waste if the data is not managed efficiently. Data management plans should include data sharing and data dissemination protocols, cost recovery programmes and development of data standards.

Capacity Building: An important element in the effective use of GIS is the availability of trained and experienced personnel. Whereas the SIDS of the Caribbean have invested in GIS hardware and software in the past 10 years, very little investments have been made towards the training and retraining of resource persons required to design, build, use and manage a GIS. A renewed effort is therefore required in building a structured (formal and informal) training programme. An investment in human resources will ensure the sustainable use of GIS.

Consistent Data Models and Integrated Analysis: GIS provides for integrated analysis of land and marine resources. Impact analysis and cause-effect models can be efficiently built for different land use scenarios. To be able to undertake such analysis, it is important that a consistent data model be built for the different natural resources in the SIDS of the Caribbean. Land use classification, ecological or ecosystem classification, soils and geological properties need to be modelled so that cross-island analysis can be undertaken. The absence of such a model will perpetuate the current situation of island-based analysis.

5. Conclusion

The many opportunities provided by the reducing cost of satellite remote sensing imagery and the powerful functionalities of GIS have made it the technology of today for the SIDS of the Caribbean. The era of planning without information on the nature and stress of the natural resource is fast coming to an end. A programmatic and strategic investment in GIS is required for the effective and efficient management of land and marine resources.

References

[1] Opadeyi, J. (1992) "Concepts, design and applications of geographic information systems for water resource management", in *Proceedings of the Caribbean Workshop on Water Resources Management and the Environment,* Trinidad, 1992.

[2] Goodchild, M.F. and K.K Kemp (Eds.) (1990) *Introduction to GIS*, NCGIA Core Curriculum, University of California, Santa Barbara, California.

[3] Dale, P. F. and McLaughlin, J. D. (1988*) Land Information Management.* Oxford University Press, New York.

[4] Star, J. and J. Estes (1990) *Geographic information systems: an introduction* Prentice Hall, New Jersey.

[5] Aronoff, S (1989) *Geographic Information Systems: a management perspective*. WDL Publications. P.O. Box 585, Station B, Ottawa, KIP 5P7, Canada.

[6] Turner, A.K. and K.E. Kolm (1991) "Three-dimensional geoscientific information systems for ground-water modelling" in Proceedings ACSM-ASPRS Annual Convention, Baltimore, Vol.4, pp 217-226..

[7] Kilborn, K. et al. (1991) "The integration of ground water models with geographic information systems (GIS)", in Proceedings ACSM-ASPRS Annual Convention, Baltimore, Vol.4, pp 150-159.

[8] Mullen, M. P. (1991) "A GIS technology for ground water assessments", in Proceedings ACSM-ASPRS Annual Convention, Baltimore, Vol.4, pp 243-252.

[9] Tucker, D.F. et al. (1991) "Spatial and temporal dimensions of water quality at Indiana Dunes National Lakeshore", in Proceedings ACSM-ASPRS Annual Convention, Baltimore, Vol.4, pp 654-661.

[10] Ritchie, J.C. and C.M. Cooper (1991) "An algorithm for estimating surface suspended sediment concentrations with Landsat MSS digital data", in Water Resources Bulletin, Vol. 27 No. 3, pp 373-379 AWRA.

[11] Shih, S.F. and J.D. Jordan (1992) "Landsat Mid-infrared data and GIS in regional surface soil-moisture assessment", in Water Resources Bulletin. Vol. 28, No.4, pp 713-719 AWRA.

[12] Corwin, D. L. Loague, K. and Ellsworth, T. R. (1999) “Advanced Information Technologies for Assessing Non-point Source Pollution in the Vadose Zone: Conference Overview”. Journal of Environmental Quality. 28:357-365.

[13] Endreny, T.A., and E.F. Wood, “Distributed watershed modeling of design storms to identify non-point source runoff,” *Journal of Environmental Quality* 28 (2): 388-396, 1999.

[14] Carver, S., Heywood, I., Cornelius, S. and Sear, D. (1996) “Evaluating Field-Based GIS for Environmental Characterization, Modelling and Decision Support”. In *GIS and Environmental Modelling: Progress and*

Research Issues. Eds. Michael Goodchild, Michael Crane and Sarah Glendinning. GIS World Books, Fort Collins, CO, USA. pp 43-48.

[15] Duguay, C. R. and Walker, D.A. (1996) Environmental Modeling and Monitoring with GIS: Niwot Ridge Long-term Ecological Research Site. In *GIS and Environmental Modelling: Progress and Research Issues*. Eds. Michael Goodchild, Michael Crane and Sandi Glendinning. GIS World Books, Fort Collins, CO, USA. pp 219-223.

[16] Fraser, R. H., Barten, P.K. and Pinney, D. A. K. (1998) "Predicting Stream Pathogen Loading from Livestock using a Geographical Information System-Based Delivery Model". Journal of Environmental Quality. 27:935-945.

[17] United Nations Coordination of Outer Space Activities (2007), "Sustainable Development Of Small Island Developing States", Action items in the Plan of Implementation (A/CONF.199/20, Resolution 2) UNCOSA, 2007-01-08. Website: http://www.uncosa.unvienna.org/pdf/wssd/WSSD_list_nat_island-states-15.pdf Accessed: 2008-05-13

[18] Maruo, Yuji et al (2004), "Application of Geographic Information System (GIS) for Groundwater Resource Management": *Practical Experience from Groundwater Development & Water Supply Training Center* International Ground Water Conference in Ethiopia; United Nations Conference Center, Addis Ababa, Ethiopia, May 2004 Website: http://www.uneca.org/groundwater/Docs/Application%20of%20GIS-%20JICA-%20NO-12.pdf Accessed: 2008-05-13

[19] Chakrabarti, Parthasarathi (2004), "Geoinformatics for Natural Resources Management vis-à-vis Environmental Justice" Government of West Bengal. Website: http://www.isprs.org/istanbul2004/comm7/papers/83.pdf Accessed: 2008-05-12

[20] Oledzki, J (2004) "Geoinformatics – An Integrated Spatial Research Tool" Warsaw University Miscellaneous Geography Publication, Warsaw.

[21] Vihar (2003) "New Areas of GIS Application" India Cartographer Website: http://www.incaindia.org/technicalpapers/CD3_6.pdf Accessed: 2008-05-13