Sustainability and decision tools for coastal areas

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Introduction

A region's sustainable development involves all the systems integrated in it, each with multiple, and sometimes conflicting, objectives and without any clear hierarchy. Modelling of a system requires the use of advanced analysis tools; the GIS (geographic information system) is selected, considering the geographic scope of the components involved.

The management of sustainability is focused on the existing demand of natural resources by human activities. The competitive demand for these resources and their allocation creates a conflict between the needs of the environment and humans. The feasible solutions defined by sustainability are based on negotiations: trade-offs between various objectives, without maximizing individual objectives but finding an efficient and acceptable balance between the stakeholders' requirements and resource availability. It is thus necessary to define and quantify the trade-off between the conflicting objectives, determined by resource availability and socio-economics. Nowadays, computer-based systems can be developed to help managers make such decisions. These are called DSSs (Decision Support Systems) and, in the case of territorial analysis, they are developed using GIS software functionalities.

In the Goa case study, human activity is focused on tourism, as this area is one of India's main tourist destinations. The natural resources demanded by tourism are water and land and, as mentioned earlier, these demands lead to a conflict with the environment. In the context of the current project, instead of a complex DSS, a flexible and multipurpose set of tools has been designed to facilitate a decision-making process necessary for the sustainable development of tourism and allied activities.

Decision Support Systems

The DSSs are closely involved in the information revolution; they have emerged to solve the challenge of extracting useful information from large amounts of data, thus complementing human decision-making capability with a computer's immense capacity for data processing (Clyde and Andrew 1993). The DSSs have had a great impact on organizations, which are searching for systems to guide and support them in decision-making.

According to a well-known definition (Silver 1991), a DSS is a set of programmes and tools that allows the user to obtain, when necessary, information required in decision-making in an unsure environment, since it combines data, sophisticated analytical models, and software in a unique and powerful system.

The objective of a DSS is to give support to the decision making-process, starting from the systematic generation and evaluation of different alternatives or decision scenarios (Ralph and Hugh 1986). Since there are numerous and different factors involved in the process, the decision-maker has to bear in mind that experience is the key element since any decision has to be made according to a very complex reality with a great number of variables. The DSS does not solve any problem by itself (that onus lies on the decision-maker) but provides effective support to the process.

A DSS can overcome technological obstacles and facilitate better, swifter decision-making at lower costs. The expected benefits of implementing a DSS are as follows.

- Enhanced quality of decision-making
- Improvement in communication
- Reduction in costs
- Increase in productivity
- Saving of time
- Increased satisfaction of end-users.

Basic principles of multi-criteria decision analysis techniques

Through the 1990s, serious attempts were made to develop applications focused on environmental management, incorporating

MCDM (Multi-criteria Decision-Making) techniques. The resulting system, generically named the MCDSS (Multi-criteria Decision Support System), has been the most innovative contributor in the development of DSSs (Jankowski 1995).

The MCDSS can be defined as an interactive computer system, designed to support decision-makers in solving difficult problems, while taking into account numerous objectives. It has four main components: (1) an end-user (decision-maker), (2) a preference structure, (3) a dynamic alternatives group (potential actions), and (4) a criteria set to be considered in the alternatives evaluation.

To consider a determined number of alternatives, taking into account a group of objectives in conflict, is the basic goal of MCDM techniques. Multi-criteria decisions analysis is understood as a series of concepts, models, and processes to help decision-making by describing, inventorying, classifying, and evaluating alternatives according to fixed criteria.

The basic methodology of work requires a definition from the so-called 'Concordance Matrix', the mathematical representation of objectives, where the different criteria are allocated positions in columns and the alternatives are allocated positions in rows. The value of each matrix cell, known as scoring of criteria, represents the value of the aim for each alternative and criterion.

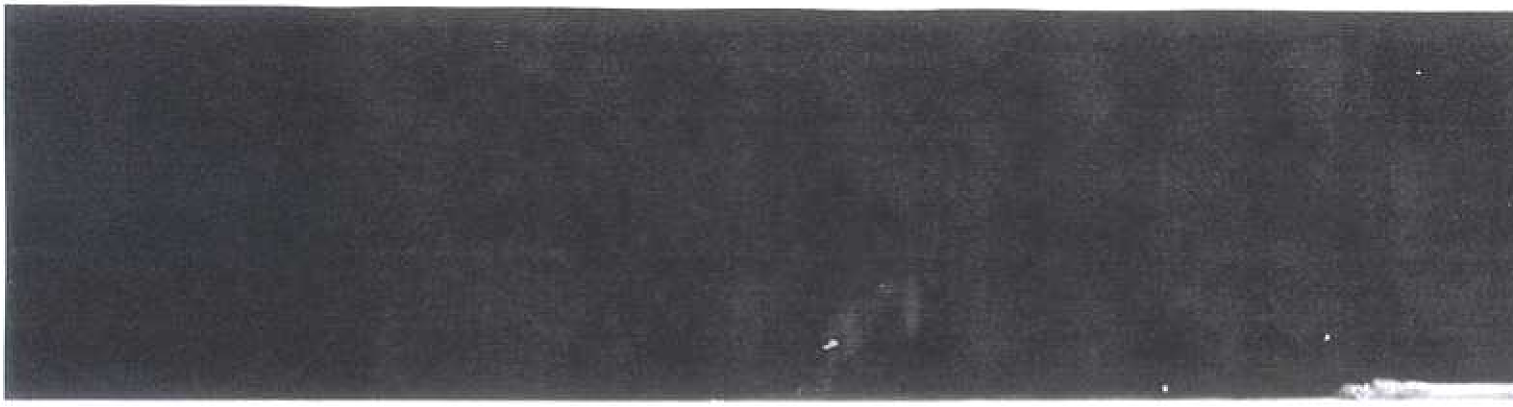
This structure makes it evident that it is very important to assign the different criteria scores for each alternative to obtain real results. The onus for this always lies on the experts and planners. The basic elements involved in the process of multi-criteria decision are criteria, weights, and decision rule.

Criteria: factors and constraints

The bases for decision-making are the criteria. In general, one can consider the existence of two criteria categories: factors and constraints.

A factor is a criterion, which maximizes or minimizes alternatives value according to each evaluation. This is to say that some values establish measures over a continuous scale, i.e. the application of factors from minor to major vulnerability according to distance.

The constraint criterion may be classified into two groups: restrictive and obligatory. In the first, availability of alternatives is restricted; they directly exclude some data from the evaluation, for example, natural landscapes from the evaluation to define new areas



to construct infrastructure. In the second, any alternative has to be accomplished with this value and is called a goal.

Weights

For each evaluation, it is necessary to establish a hierarchical system for the involved criteria. It is called weights, if expressed quantitatively, and hierarchies, if expressed qualitatively. With these values, one can establish, if necessary, a matrix of priorities, showing different points of view or priorities (environmental, tourism-related, and so on).

Evaluation: decision rule

To carry out the evaluation process, criteria are combined using the decision rule, which can be very simple (use of one criterion) or very complex (integration of a larger set of criteria). The decision rule is furnished from the criteria but structured according to objectives defined by the decision-maker and created expectations. There are two main procedures to coherently integrate the different criteria, beginning with defined decision rules and multi-criteria techniques.

1 Selection function
2 Heuristic function

The first one establishes an alternative classification (optimization) starting from a mathematical rule, which implies the evaluation of all alternatives. The second one, being simpler and easier to apply, is more common. It establishes a procedure for searching across a small selection of alternatives. To make the evaluation, the present arithmetic–statistic multi-criteria are different and may be as simple as linear addition, arithmetic operations or as complex as the analysis of the ideal point, linear programming, optimization methods, etc.

Once the decision rule is established, the method consists of applying it to the criteria set to evaluate it and produce the decision alternative.

GIS and Multi-criteria Decision Support Systems

MCDSSs have been developed essentially to face the increasing complexity in environmental decision-making (Carver 1991). Due to the strong spatial component of problems related to MCDM, they have evolved with close links to the use of GIS as a development platform, specifically around analysis modules and spatial modelling.

Spatial analysis gathers a set of techniques, depending directly on the localization of analysed objects. These tools may be simply descriptive or complex statistic techniques, which allow forecast and scenario generation, impact analysis, and adequate policy definition. For this process to be effective, it is necessary to identify the adequate analysis algorithms as well as choose some territorial units as frames of spatial evaluation.

The main process that can be decided in spatial modelling is the capacity to add value to the information, i.e. the generation of new data reckoning from existing data, beginning with previously established processes and models that describe the behaviour in the real world under determined conditions. In this way, results or solutions to complex spatial problems can be achieved.

Goa case study decision support tools

To define, design, and implement a system with such features in the Goa case study, the general objectives must be specified in the first step. Afterwards, according to these objectives, data analysis plans and procedures as well as the systematization of its capture, modelling, storage, and management (see Chapter 16) have to be set in a way that can be useful in a DSS (Figure 1).

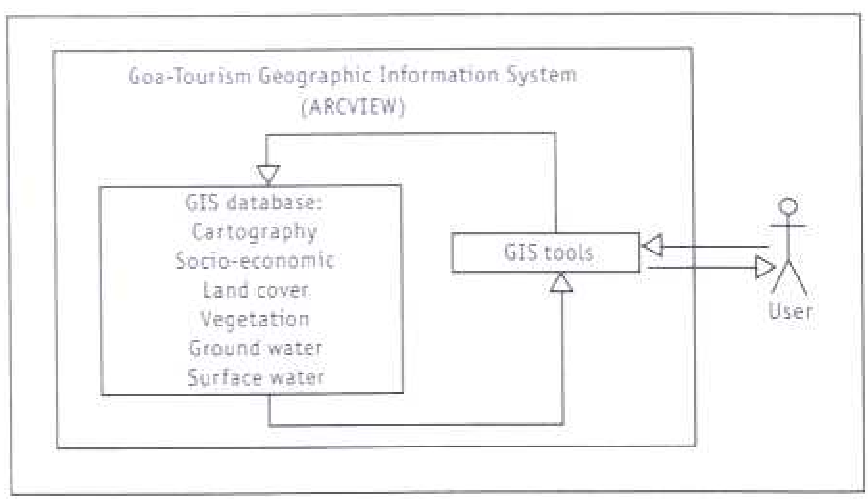
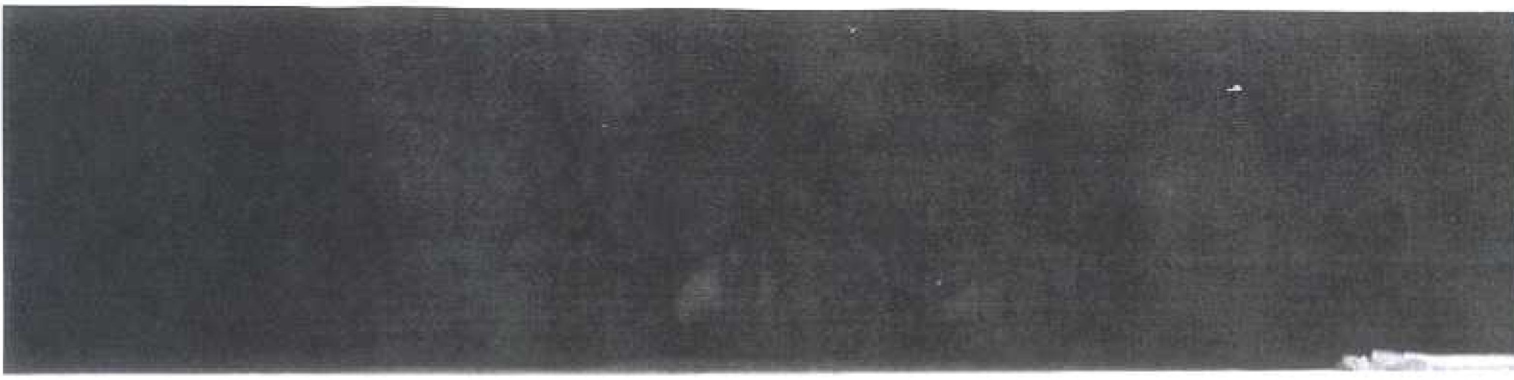


Figure 1
Basic system architecture



With the established general objective being sustainable development study in coastal zones, the first step is to determine the factors involved in its achievement. Coastal systems are dynamic and complex; research is necessary to understand, enumerate, and evaluate the basic behaviours and interactions inside the ecosystem and also with human activity.

It is unfeasible to implement a system capable of managing all possible variables, indicators, and models implied in the real system. A simplified model of the system should be defined by determining the most significant variables and indicators such that the final system is highly representative. The system simplification may be focused from two different points of view.

1 *To determine the driving force or human activity, which promotes the area's development*
   If this factor can be established, the interaction between human activity and the environment can be significantly simplified. In the Goa case study, one may clearly see that the main socio-economic driving force is tourism development.

2 *To specify those natural resources that are more significantly impacted by human activity*
   Additionally, if the main human activity has been determined, it will be easier to know its consequences and be aware of the pressures on the natural environment. In Goa, resources subjected to strong pressures are water and land, due to the increasing demand.

This approximation allows the definition and analysis of a simple system to model different established relations and facilitate the task of incorporating, structuring, and analysing all the generated information in such a way that can be easily managed by a set of tools that support decision-making. So, the searching plan has to identify the functionality principles of a coastal system where the main driving force is tourism and pressures on natural environment affect water and land cover.

To reach a good system operation, it is advisable to organize the different indicators in accordance with their effects and/or the status they represent.

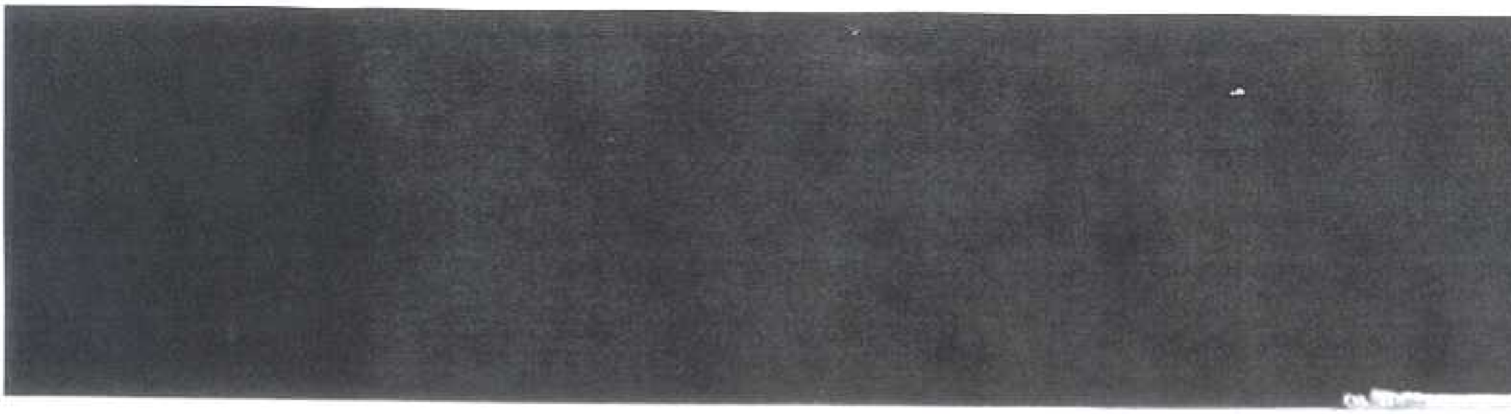
- *Status indicators* These describe the status of the present system in the environment and socio-economic level. Some indicators have been generated to describe and classify the status of natural resources and their possible actions against the different pressures they can receive. For instance, they enable knowledge of water quality and its vulnerability.
- *Previous status indicators* These describe the status of the system in previous periods. Using these indicators, the evolution of socio-economic pressures as well as the variation in the land cover typology in recent years has been established for the study area.
- *Pressure indicators* These describe the pressure that tourism-related development places on the environment.
- *Description indicators of future scenarios* These are based on a simulation serial concerning future predictions and alternatives established, starting with socio-economic and ecological models.

The incorporation of a socio-economic data set has allowed the formulation of a group of indicators that point out the result of tourist development policies and, at the same time, estimate the pressures on the environment. This group also allows the incorporation of data about perceptions that a society shares about the benefits, problems, and needs that tourism generates. All these aims act as indicators or tendencies, which can be of help when defining possible policies to adopt in order to improve tourism expectations, quite like environmental indicators warn of the main dangers of allowing uncontrolled rise in tourism. Attempting to balance these controversial objectives will allow the desired definition of sustainable development.

Based on the set of indicators, DSSs have been defined, using the Goa case study as a model. The set of decision tools could be classified into three main groups: visualization tools, spatial analysis tools, and advanced analytical modelling tools.

Visualization tools

The purpose of visualization tools is to make accessible and visualize the entire available data in the GSD (Goa Spatial Database) (see Chapter 16), on the same interface. This allows deeper insight into the coastal zone and provides valuable support to social agents for analysing sustainable tourism development.



A customization of GIS functions and tools has been done to manage the GSD: thematic data load and viewing, preparation of the system of symbols and legends to visualize and print data, etc. Tools, based on GIS capabilities for data management and presentation, enable integrated data management and viewing. These functionalities allow us to do the following.

- Select, choosing data to be used from different datasets
- Classify, setting up categories for attributes in the datasets [This can be done by unique values, based on the grouping, defined by the user or based in basic statistical analysis.]
- Symbolize, assigning a representation to each one of the defined categories
- Prepare map compositions, defining the output maps in order to show the dataset information in the most appropriate manner.

These tools allow the visualization of the study area conditions from different perspectives, the definition of the main biophysical characteristics of the coastal zone, the emphasis on similarities and differences, the understanding of some direct cause–effect relationships, and the establishment of bases for the present status. A set of predefined views has been built to facilitate the visualization of GSD (Figures 2 and 3), gathering the following indicators.

- Socio-economic data
- Estimated pressures
- Household and tourism survey
- Land cover data
- Groundwater data
- Surface water data.

Spatial analysis tools

The spatial analysis tools are based on GIS functionalities to manipulate spatial datasets.

1 *Vector functionalities*
   - Transferring attributes from one feature to another
   - Adding 'x, y' coordinates to attribute tables
   - Combining attribute table fields
   - Calculating area and perimeter
   - Geometric overlay functions
   - Logical overlay functions

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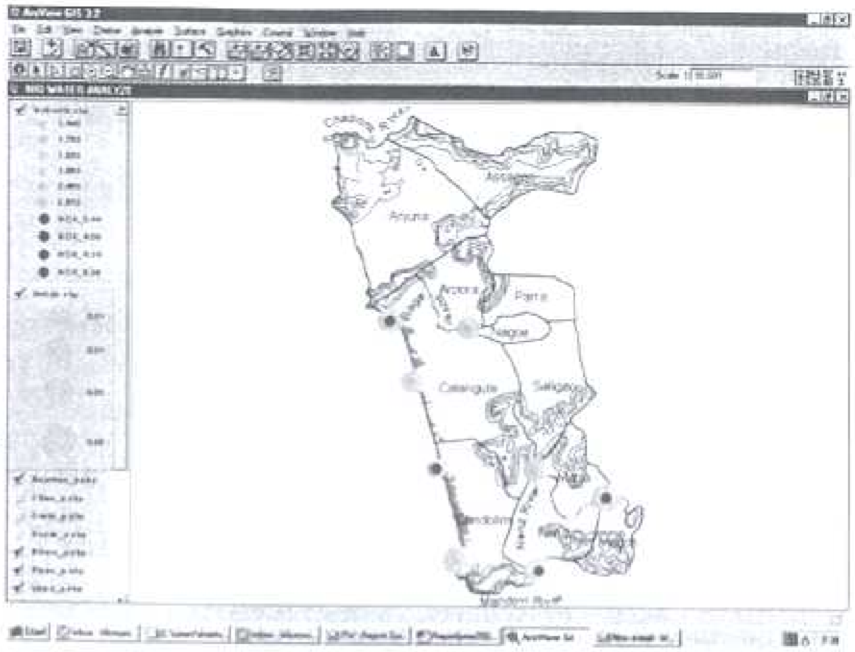
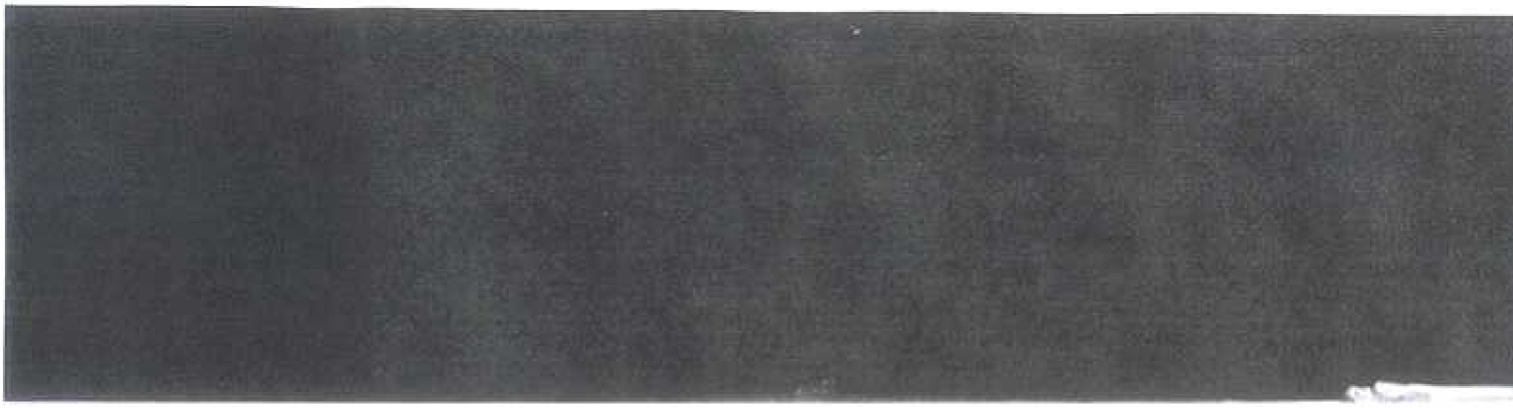


Figure 2
General view of Arcview GIS interface and symbolization process: surface water contamination

Figure 3
Example of map composition from the Goa Spatial Database: groundwater data and socio-economic data



- Arithmetic overlay functions
- Neighbourhood functions

2 *Raster functionalities*
- Vector-to-raster conversion and vice versa
- Raster algebra
- Interpolation functions
- Neighbourhood functions
- Reclassification
- Time series analysis.

These tools are used to create fresh data as a result of combining existing datasets, using their spatial and attribute relations. It is possible to operate with datasets with vector data model, raster data model, or both. A subset of a vector dataset, obtained as a result of a query, or the dataset produced by applying spatial operators to a single or a combination of datasets, can be converted to raster and combined with other raster datasets using raster operators. This increases the analysis capabilities significantly.

For the Goa case study, these tools are focused on the establishment of spatial relationships between socio-economic datasets and water and land resources (Figures 4 and 5).

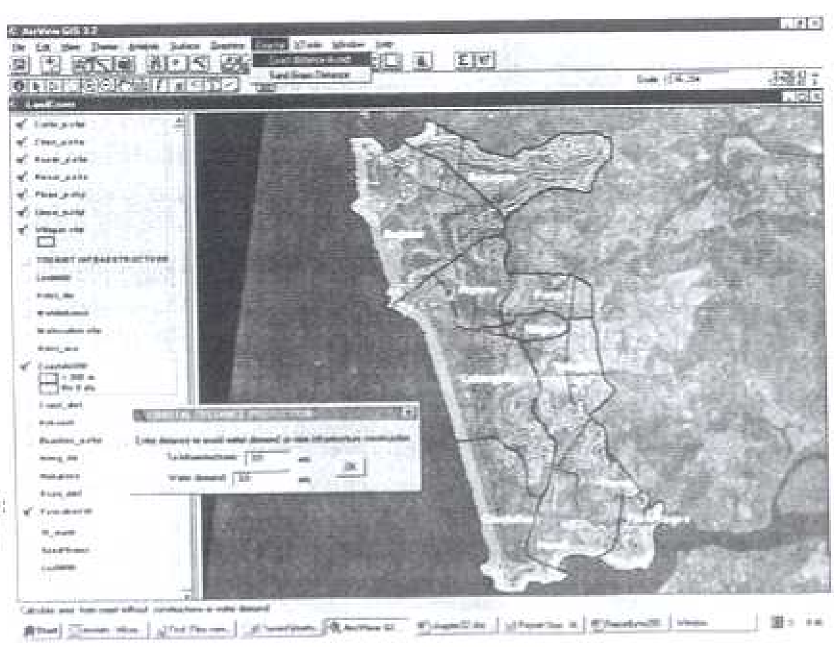


Figure 4
Goa study area: establishing a coastal protection perimeter

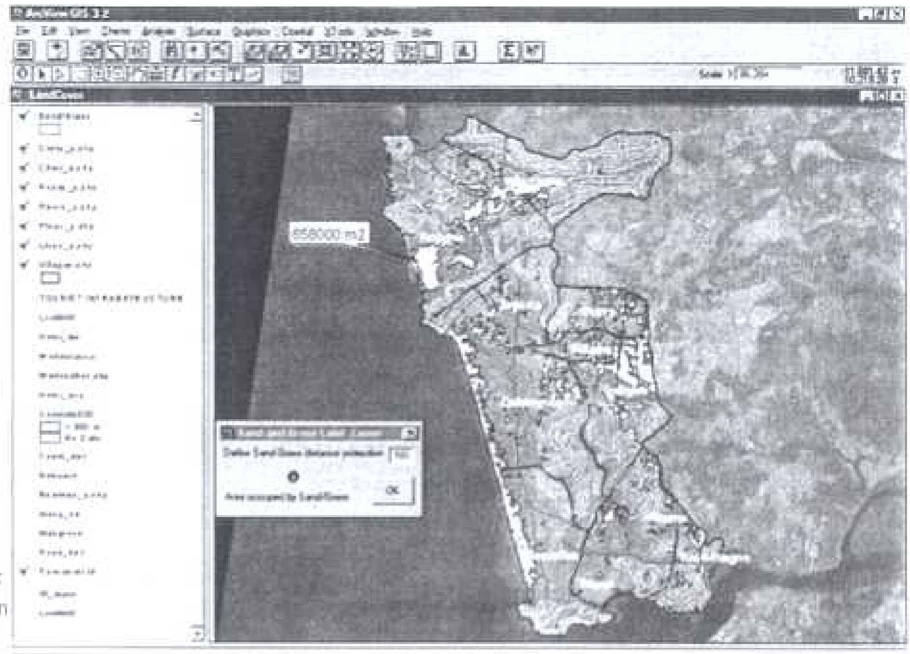


Figure 5
Goa study area: sand protection and area occupied

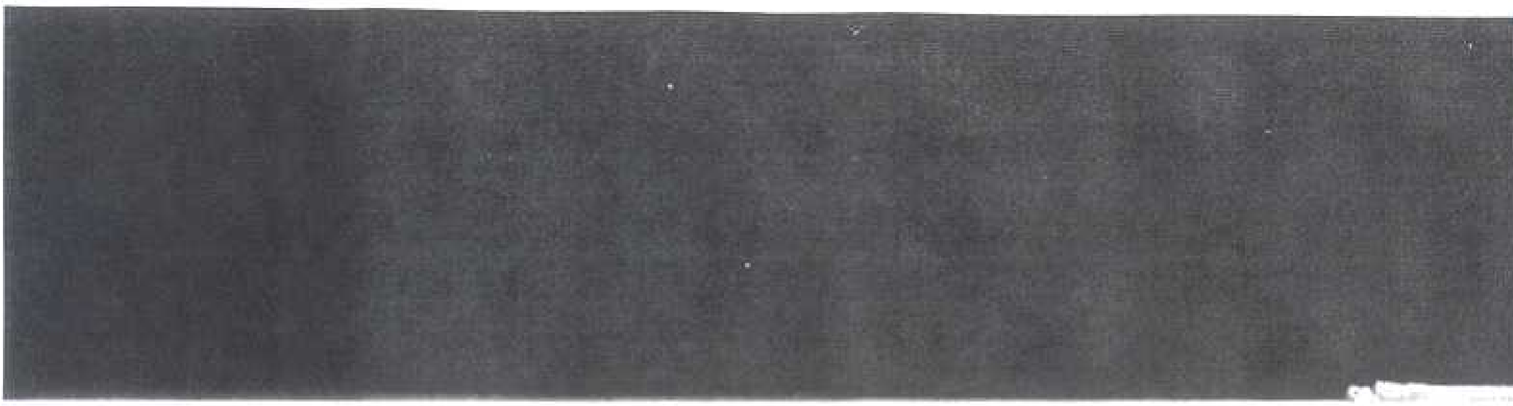
Advanced analytical modelling tools

The advanced analytical modelling tools are supported by GIS analysis capabilities, mainly mathematical functions and raster modelling capacities. These go a step forward from the simple spatial analysis tools, and are designed to answer specific questions about natural resource competition by means of models and scenario implementation.

They are complex tools specifically developed to provide optimal responses to defined goals, whether complementary or competitive, for the sustainability of the coastal area. The conceptual frame for implementation of these tools is MCDM.

The development methodological approach should be as follows.

1. Definition of objectives
2. Design and development of spatial database (Chapter 16)
3. Development and implementation of models
4. Definition of criteria and weights
5. Establishment of decision rules
6. Evaluation of alternatives
7. Presentation of results.



The objectives are related to tourism-related demands on natural resources. The main problems in coastal zones, which can be monitored, analysed, and evaluated, are as follows.

- Increase of land cost due to growth in demand (speculation)
- Disorderly infrastructure development, leading to conflict
- Danger to sensitive zones by overdevelopment
- Lack of planning for solid and liquid waste disposal, to provide required services to tourism.

To implement the models, it is necessary to identify the components, relationships, and behaviours of the entire system. In the Goa study area, the general relationships within the coastal system can be summarized as follows.

- *Drivers* The main considered driver is tourism activity.
- *Resources* The drivers generate a demand for the existing resources: water and land.
- *Effects* The demand for natural resources directly affects the ecosystem elements: surface water, groundwater, land cover, and coastal morphology.
- *Pressures* The above effects induce stresses such as water discharges, land reclamation, water extraction, sand extraction, and exploitation of wood.
- *Impacts* Finally, the pressures lead to impacts, such as loss of biodiversity, loss and degradation of the aesthetic beauty of the beaches, impairment of the quality of groundwater and surface water, shortage and salinization of freshwater, spatial conflicts, and destruction of coastal habitats.

A set of indicators about sociological, economical, and natural environment aspects has to be developed for the characterization, classification, and quantification of criteria involved in the behaviour of a coastal system.

Using the set of indicators, the priorities for competitive resource demand are established, so that the different alternatives and purposes can be evaluated taking into account the defined sustainability targets (Figure 6).

Figure 6
Example of spatial modelling to allocate optimum locations for tourism infrastructure, based on a set of rules

Advanced analytical modelling tools are the bases for the development of complex decision-making tools, which support model implementation and alternative generation. In the context of the Goa case study, instead of complex tools, an open and flexible set of tools to support decision-making has been developed.

Summary

The sustainable use of coastal natural resources necessitates integrated coastal management. The best approach to develop a set of decision tools for environmental management is the use of multi-criteria analysis techniques in a GIS context. However, it is very important to note the difficulty of applying decision analysis in environments of great ecological and social complexity, because of the impossibility to precisely define the system's behaviour and the lack of essential datasets.

The most significant result has been the demonstration of the possibility to design, construct, and develop a unique environment to manage data, which affects coastal zones either socio-economically or environmentally at different scales, local and regional.

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