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# The Need and Use of Geographic Information Systems for Environmental Impact Assessment

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**Abstract:** ***Environmental impact assessment (EIA) is a process of evaluating the likely environmental impacts of a proposed project or development, taking into account inter-related socio-economic, cultural and human-health impacts, both beneficial and adverse. Although legislation and practice vary around the world, the fundamental components of an EIA would necessarily involve the Screening, Scoping, Assessment and evaluation of impacts and development of alternatives, Reporting, Review, Decision-making, and Monitoring, compliance, enforcement and environmental auditing. World have experienced untold environmental degradation and ecological deterioration in the past century, with little or no real solution to alleviate many of these concerns. Poorly planned human interference has been the major cause. Adequate information and appropriate technology are limiting factors for effective environmental management. Hence, efforts to improve, conserve and protect the environment will include not only the resolution of political policies but also the application of a state-of-the-art scientific approach to planning and implementation. The process of Environmental Impact Assessment (EIA) was developed as an effective planning tool. The genuine conduct of this process will go a long way in reducing environmental deterioration. Because of the dynamic characteristics and multivariate nature of the environment, it has often been difficult to collate, analyze and interpret its data sets. This great complexity can be overcome, however, with the innovation and application of a system of computer tools such as the Geographic Information System (GIS) and related technology. Geographic Information System can be used and applied extensively for environmental impact assessment issues prevalent in many other developing nations. Some areas where GIS will be useful include: Storage, analysis and display of large data sets, Database creation, documentation and management; Environmental impact modeling, Environmental data and EIA analyses, Habitat Suitability Index. Habitat quality for wildlife population has a spatial component across large geographic areas, Aid in decision-making or policy formulation, Environmental Impact Auditing, Environmental Impact Mapping and Analysis, GIS can be used to map the sensitivity of the environment and its components to proposed projects. It also has the capabilities of carrying out various analyses on both locational and non-locational data. GIS analyses include statistical analysis, trend analysis, overlays, buffering, distance analysis, cost analysis and many more.***

**Keywords:** Environmental Impact Assessment, Geographical Information System, Environmental Impact Auditing and Environmental Impact Mapping.

## 1. Environmental Impact Assessment (EIA)

### 1.1 What is EIA?

EIA is a relatively new planning and decision-making tool first established in the United States in the National Environmental Policy Act of 1969. It is a formal study process used to predict the environmental consequences of any development project and its environmental management. The EIA tool is used worldwide as an instrument for developmental planning and control. It is an effort to anticipate and quantify the socio-economic and biophysical changes that may result from a proposed project. It assists decision-makers in considering the proposed projects' environmental costs and benefits. When benefits sufficiently exceed the costs, a project can be viewed as environmentally justified. Some future measures may be required to reduce anticipated environmental degradation.

Before starting a major project, it is essential to assess the present environment without the project, and the likely impact of the project on that environment, when completed. Therefore, an Environment Impact Assessment has to be started before project initiation. For analysis of environmental impacts, many professions and disciplines have to be involved. EIA is a management tool for officials and managers who make important decisions about major development projects.

### 1.2 Definition of EIA

EIA can be defined as a process for identifying, predicting, evaluating and mitigating the biophysical biological, hydrological, ecological, meteorological, noise, economical, social, and other relevant effects prior to development, then using the conclusions as a tool in planning and decision-making. In other words, impact assessment, simply defined, is the process of identifying the future consequences of a current or proposed action.

### 1.3 Purpose of EIA

Environmental assessment enables us to carry out an environmental cost-benefit analysis of projects at an initial stage. It is a precursor to detailed analysis of environmental impacts, which are taken up only if a need for the same is established. It gives a view of the actors involved in the development environment linkages. This is required in view of the fact that the community at large is always at a loss in terms of deterioration of living environment that accompanies industrial development. Based on Environmental Impact Assessment, regulatory measures can be identified and the roles of agencies concerned defined for achieving more efficient environmental management. EIA is a process with several important purposes. Its general purposes are (IAIA, 1999):

1) To ensure that environmental considerations are explicitly addressed and incorporated into the development decision-making process;
2) To anticipate and avoid, minimize or offset adverse significant biophysical, social and other relevant effects of developmental proposals;
3) To protect the productivity and capacity of natural systems and the ecological processes which maintain their functions; and
4) To promote development that is sustainable and optimizes resource use and management opportunities.

### 1.4 EIA framework

Several countries have over 20 years experience in applying EIA (e.g. USA, Australia, Canada and New Zealand). Recently, the number of countries with an active EIA process has increased rapidly, possibly to more than 100 countries. The environmental assessment process has been defined differently in different countries. In fact, it appears that no two countries have defined it in exactly the same way. General blanket

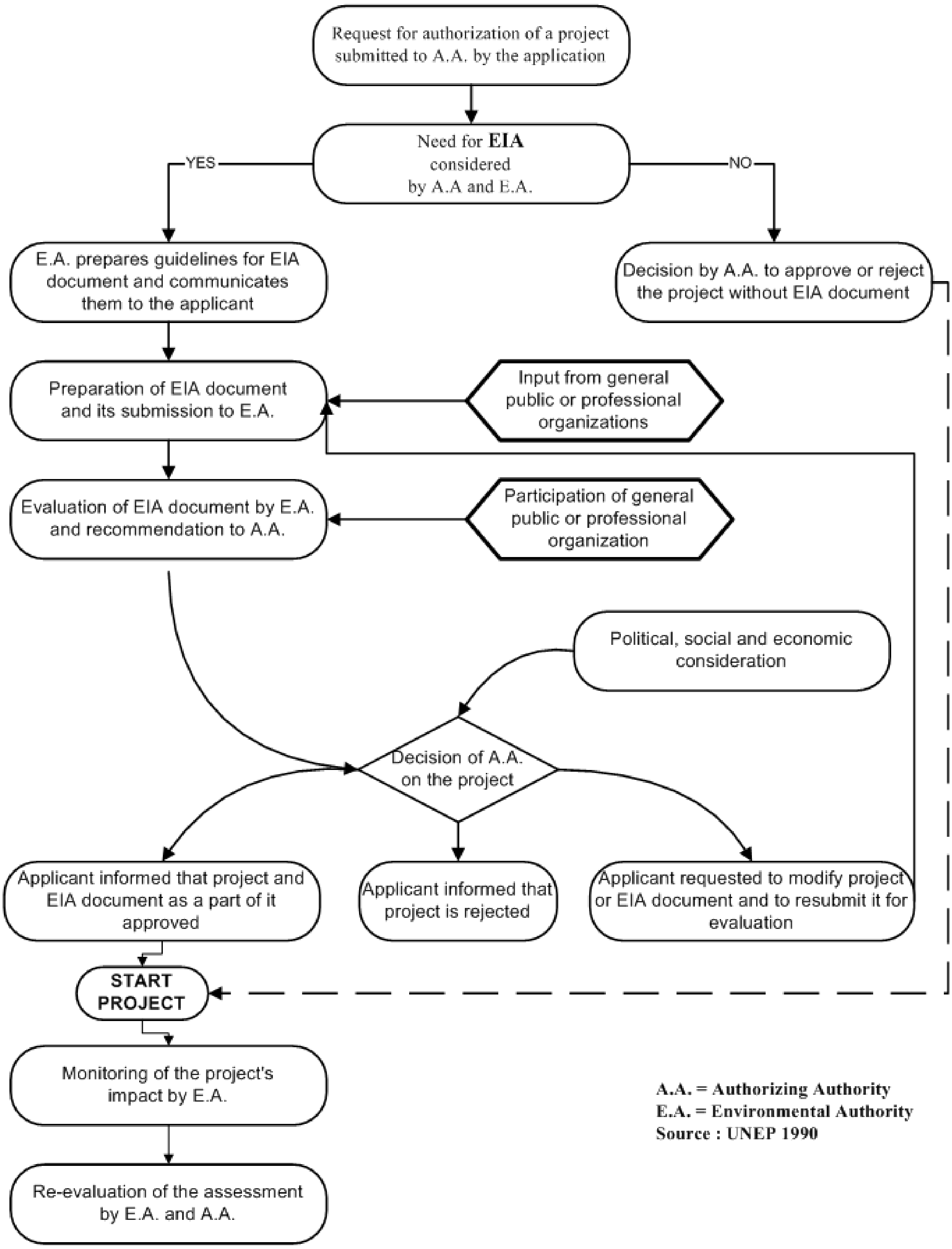


**Figure 1:** The international process of EIA (modified from UNEP, 1990)

statements are often made that developing countries all lag behind the industrial countries in terms of environmental issues (Goff and Goff, 1997). The United States was the first country to legislate for EIA. It is interesting to note that the

Philippines have required EIAs for certain projects since 1977. In addition to the different approaches to the process, there are wide varieties of formats for EIAs available. Generally, studies of physical, chemical, biological and socioeconomic impacts are carried out for an EIA. These parameters are differently defined in different countries, using different EIA evaluation criteria. Matrices, checklists and flow charts are the most commonly used techniques for impact identification. The Geographical Information System (GIS) and overlay maps can give a good evaluation of environmental impact. In addition, monitoring is important for checking the results of an EIA, but is very difficult to develop for economical and technical reasons.

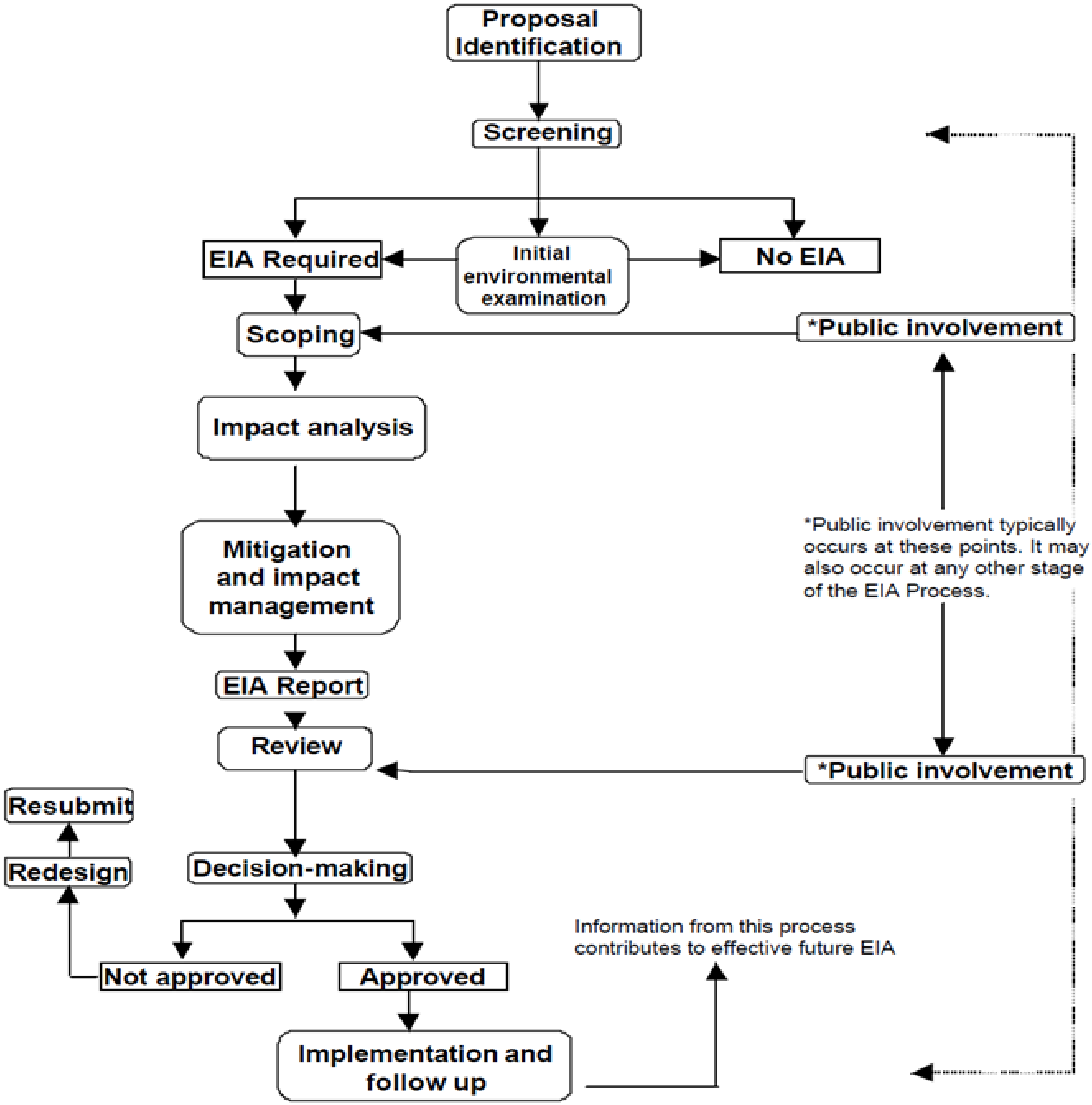


**Figure 2:** The Generalize EIA Process

Following are the steps involved in a systematic EIA of an environmental project:

1) **Project definition**: The importance and need of the project and its relation with regional and national developmental activity will be mentioned in this section.
2) **Screening:** Screening is done as per the statutory notification. Screening criteria are based upon:
    a) Scales of investment;
    b) Type of development; and
    c) Location of development.
3) **Scoping**: Scoping is a process of detailing the terms of reference of EIA. It is done by the consultant in consultation with the project proponent and guidance, if needed, from Impact Assessment Agency. Quantifiable impacts will be assessed based on

magnitude, prevalence, frequency and duration and non-quantifiable impacts (such as aesthetic or recreational value).Significance is commonly determined through the socioeconomic criteria. After that the areas, where the project could have significant impact are identified and the baseline status of these will be monitored and then the likely changes in these on account of the construction and operation of the proposed project will be predicted.

4) **Baseline information**: Baseline data describes the existing environmental status of the identified study area. The site-specific primary data is monitored for the identified parameters and supplemented by secondary data if available.
5) **Impact prediction**: Impact prediction is a way of mapping the environmental consequences of the significant aspects of the project and its alternative. Environmental impact can never be predicted with absolute certainty and this is all the more reason to consider all possible factors and take all possible precautions for reducing the degree of uncertainty.
6) **Evaluation of impacts and alternative criteria**: For the project possible alternatives are identified and environmental attributes are compared. These alternatives cover both project location and process technologies. Alternatives consider number of project also. Alternatives are then ranked for selection of the best environmental option for optimum economic benefits to the community at large.
7) **Management plan**: This section of the EIA will describe about the mitigation measures to reduce the harmful effects of the proposed project. Particularly, it will also contain the provision for rehabilitation of the people affected and displaced by the project.
8) **Public participation**: Law requires that the public must be informed and consulted on a proposed development after the completion of EIA report. Public participation can be assured by:
   a) Consulting the public directly affected by the proposed project and the voluntary groups like NGOs or pressure groups having a concern with a specific aspect of the environment.
   b) Conducting direct interviews with the sample from public or by sending questionnaire to the people from public.
   c) Publishing the summary of EIA report for objections and suggestions from people.
9) **Decision making**: Decision making process involves the consultation between the project proponent (assisted by a consultant) and the assessment authority (assisted by an expert group if necessary). The final decision on acceptance, rejection or clearance is arrived at through a number of steps including evaluation of EIA and environmental management plan.
10) **Monitoring Plan**: Monitoring should be done both during construction and operation phases of a project. Monitoring will enable the regulatory agency to review the validity of predictions and the conditions of implementation of the Environmental Management Plan.

**Geographic Information System (GIS)**

GIS is a set of computerized tools (including both hardware and software) for collecting, storing, retrieving, transforming, and displaying spatial data. GIS is essentially a marriage between computerized mapping and data base management systems. Anything that can appear on a map can be encoded into a computer and then compared to anything on any other map, using longitude-latitude coordinates. GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information to their locations. GIS technology can be used for scientific investigations, resource management, and community education.

Maps have been used for thousands of years, but it is only within the last few decades that the technology has existed to combine maps with computer graphics and databases to create GIS. In other words, GIS can be regarded as the high-tech equivalent of a map. An individual map contains a lot of information, which is used in different ways by different individuals and organizations. It represents a means of locating ourselves in relation to the world around us. Maps are used in diverse applications; from locating telephone wires and gas mains under our streets, to displaying the extent of deforestation in the Brazilian Amazon and the thawing of a glacier in Iceland. Maps are static and 0, is used to display and analyze spatial data which are tied to databases. This connection is what gives GIS its power: maps can be drawn from the database and data can be referenced from the maps. When a database is updated, the associated map can be updated as well. GIS databases include a wide variety of information including geographic, social, political, environmental, and demographic.

GIS uses layers, called "themes," to overlay different types of information, much as some static maps use Mylar overlays to add tiers of information to a geographic background, etc. Each theme represents a category of information, such as roads, vegetation, settlements, forest cover, etc.


**Figure 3:** Overlapping of several layers of GIS

Geographic Information Systems (GIS) have reached worldwide applications in EIA. Comparing to the manual process of overlaying thematic maps, through the use of GIS, the overlay analysis is much more powerful and accurate. Eedy (1995) and Antunes *et al.* (1996) have pointed out the advantages of the use of GIS in EIA, considering as an integrative framework for impact prediction and evaluation for decision support. GIS is also effective for impacts communication, however it is important not to overweight this property in detriment of the main purpose of identifying and quantifying impacts.

GIS provides the facility to extract different sets of information from a map and use these as required. This provides great flexibility, allowing a paper map, which exactly meets the needs of the user, to be quickly produced. However, GIS goes further, because the data are stored on a computer and analysis and modeling become possible. For example, one might point at two buildings, ask the computer to describe each from an attached database (much more information than could be displayed on a paper map) and then to calculate the best route between these. So when making decisions about site selection for new facilities, creating or developing a new geothermal site or power plant, protecting wetlands, directing emergency response vehicles, designating historic neighborhoods, carrying out EIA projects or redrawing legislative districts, GIS plays a significant role. GIS combines previously unrelated information into easily understood maps and can perform complicated analytical functions and then present the results visually as maps, tables or graphs, allowing decision-makers to virtually see the issues before them and then select the best course of action.

**Technical GIS Procedure**

The general methodology to obtain, process and analyze vegetation and land use GIS (ESRI, 2008) maps is shown in figure 4.

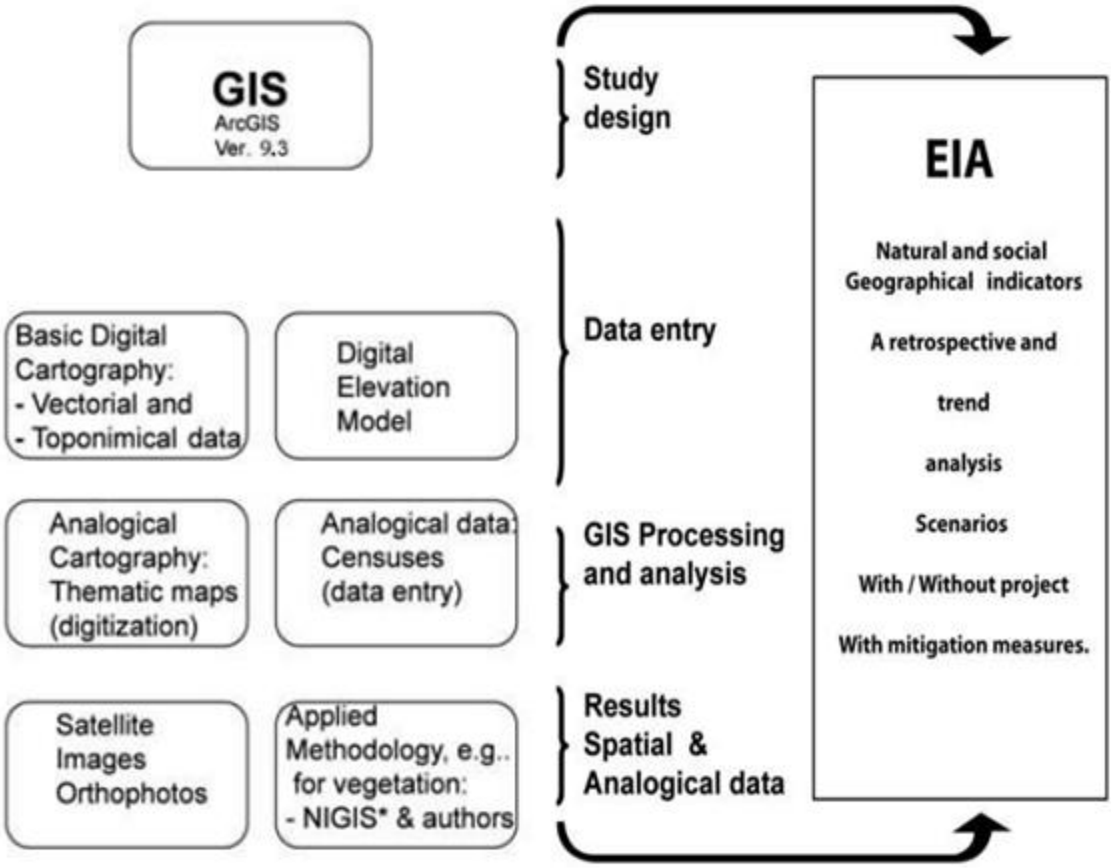


**Figure 4:** Technical GIS Procedure

**The Integration of GIS into EIA**

Geographical information systems can be applied at all EIA stages. EIA is a decision process, which aims to both identify and anticipate impacts on the natural environment. The interface between these two components produces several effects, which will generate specific impacts. GIS can also be explored within the EIA process to improve different features, mainly related to data storage and access, to the analytical capabilities and to the communicability of the results. The development of such a system will allow a more realistic approach to the environmental descriptors and a better of their interrelationships. GIS will bring to the EIA process a new way of analyzing and manipulating spatial objects and an improved way of communicating the results of the analysis, which can be of great importance to the public participation process.

The use of GIS in the EIA process, where public participation is of great importance, requires the development of applications allowing a better understanding of spatial phenomena. During the EIA process many different variables and phenomena presenting complex interrelationships, which vary in space and time are considered. These procedures involve technical analysis that includes changing assumptions and priorities and descriptions of significant visual and audible impacts.

GIS are tools for collecting, storing, retrieving at will, transforming, and displaying spatial data for a particular set of purposes (Burrough and McDonnell, 1998). Given the spatial nature of many environmental impacts, GIS can have a wide application in all EIA stages, acting as an integrative framework for the entire process, from the generation, storage, and display of the thematic information relative to the vulnerability/sensitivity of the affected resources, to impact prediction and finally their evaluation for decision support (Antunes et al., 1996).

Eedy (1995) stresses the advantages of the use of GIS in EIA, namely for data management, overlay and analysis, trend analysis, as sources of data sets for mathematical impact models, habitat and aesthetic analysis, and public consultation. According to a survey undertaken by Joa˜o and Fonseca (1996), GIS were used for all EIA stages. The most frequent use was for the presentation of results, followed by analysis/modelling and data preparation. GIS have also been used for the presentation of environmental baseline information and project description, through the preparation of thematic maps for the several environmental descriptors. Also, the overlay of baseline information maps with project layouts is frequently used for impact identification (Joa˜o and Fonseca, 1996).

The prediction of the magnitude of impacts is often undertaken by the application of simulation models (Fedra, 1993). The obtained result will most often be a map of the value of a given environmental descriptor (e.g., concentration of an air pollutant) at any location within the study area. The extension of environmental impacts can therefore be estimated from the spatial distribution of environmental quality values predicted for each alternative.

GIS also enable the use of a set of simple operations (such as overlay, classification, interpolation, aggregation of spatial information) that can generate additional information to support impact prediction. For instance, impacts on occupation of agricultural soils, disturbance of ecologically sensitive areas, watercourses disruption, and accessibility changes can be directly predicted from information stored in the GIS by overlaying the project layout with thematic data.

The use of GIS to support tasks besides presentation of results has been less explored. However, there are already some examples of simplified impact valuation and visualization methodologies based on the use of GIS. Most of these approaches are aimed at producing impact maps, for the spatial identification and evaluation of impacts, through the overlay of baseline information with project characteristics and effects.

For example, GIS have been used for the assessment of impacts in specific environmental components, namely for the evaluation of landscape impacts, where GIS are used to generate views from particular points of the scenery for the project alternatives, to perform visibility analysis for structures such as electricity poles, or to evaluate effects of alternative routes for high tension lines (Davidson1992). Schaller (1992) uses a GIS to produce a visual representation, named ‘‘annoyance mountain,’’ which combines population data with the noise levels expected with the installation of a new airport in Munich.

A similar approach is presented in Szergo (1994), where the influence calculation technique is applied to generate impact maps by the overlay of an external influence (such as air pollution) with population data in an urban area. Sankoh (1996) and Sankoh et al.(1993) applied two EIA methods (ecological risks and utility values analysis) to generate space resistance maps, which allow the identification of the route alternatives that present minimum conflict with the environment.

Rivas et al. (1994) present a methodology for the evaluation of impacts of land-use plans, based on the computation of impact indices obtained by the overlay of the proposed land uses with thematic maps. Smit and Spaling (1995) refer several studies where GIS have been applied for the evaluation of cumulative effects through time series analysis.

The importance and potential of using GIS to adopt a spatial approach to economic valuation of the environment, namely through the preparation of ‘‘economic value maps’’ has also recently been acknowledged (Eade and Moran,1996; Martinho et al., 1998). This type of approach has a very strong potential to increase the practical application of cost–benefit analysis, and therefore to enhance the role of economic valuation on environmental impacts assessment. Bateman et al. (1995) describe preliminary results for woodland recreation demand valuation and Wang (1996) and Martinho et al. (1998) for the assessment of recreation suitability.

Although the methodologies and applications described above present valuable contributions to the use of GIS within EIA, in this paper it is considered that they can play a more important role, acting as a framework to support the development of all tasks. Particularly, for impact evaluation, the information generated by the use of GIS in previous EIA stages can be used more thoroughly in the assessment of impact significance, contributing to increase the credibility of the evaluation, and therefore to improve the effectiveness of the whole EIA process.

**Use of GIS in EIA**

1) **In Project definition**: During project identification and definition, the project proponent conducts feasibility studies and defines the usefulness of the study. GIS can be very well used for defining the project by showing the location of the project and its need can be established with respect to other geographical identities like source of raw material, market for selling, source of labourer, climatic conditions favorable for the project etc.
2) **In evaluating environmental and visual impacts**: Using GIS various types of visual impacts can be evaluated like, how a road will look like? How much portion of the road will be visible from a particular point? By using DEM we can calculate and visualize the impact on ground levels either in filling or cutting and area of quarries etc (Oterholm, 1999).
3) **In scoping system**: GIS can serve as a basis for scoping of environmental effects. Once the basic databases are available, a GIS based system may provide better-targeted guidelines for EIS. A centralized institutional scoping structure, where by EIS guidelines are issued by a single entity, is found to be important for the operation of such a system as it can enjoy the economies of scale and scope involved in setting up and

operating a GIS system for scoping purpose (Haklay etal., 1998).

4) **In impact significance determination**: A spatial impact assessment methodology based on the assumption that the importance of environmental impact is dependent, among other things, on the spatial distribution of the effects and of the affected environment. For each environmental component like-air, water, biological resources etc., impact indices are calculated based on the spatial distribution of impacts (Antunes et al., 2001).

### GIS & Environmental Impact Mapping and Analysis

GIS can be used to map the sensitivity of the environment and its components to proposed projects. It also has the capabilities of carrying out various analyses on both locational and non-locational data. GIS analyses include statistical analysis, trend analysis, overlays, buffering, distance analysis, cost analysis and many more. In relation to EIA, Eedy (1995) has identified the following analyses which are appropriate to GIS:

1) Site Impact Prediction
2) Wider Area Impact Prediction
3) Corridor Analysis
4) Cumulative Effects Analysis and EA Audits
5) Real-Time Environmental Impacts Prediction

### GIS & EIA-Methodologies

There are many methodologies available for evaluation and assessment of environmental impacts. Most of the methods suffer from excessive dependence on subjective-judgment and are weak in predicting and quantifying the impacts of the project on the environment, but the development of computer-based modeling techniques using GIS promises the bridging of the existing gap (Sinha, 1998). Some of the main methods adopted individually or in combination are mentioned below-

#### 1) Overlay Method

It requires physical or computerized overlays of individual maps of social and physical attributes of the project area. The data it uses include topological data, air dispersal patterns, land and resource use data, wildlife, surface and ground water intakes. Such data may be obtained from aerial photography and satellite remote sensing. This method thrives on graphical display of data, but it is limited in that it lacks analytical capabilities. GIS is the ultimate tool for overlay EIA.

#### 2) Checklist Method

It can be a very simple or complex list of environmental components, attributes and processes, which are categorized under disciplinary headings such as geology, vegetation and air. GIS provides a computer platform for organizing, storing and analyzing these checklists.

#### 3) Matrix Method

It is a modification of Checklist, facilitates relating specific project activities to specific types of impacts. Matrices are required because they emphasize only direct impacts. They force consideration of impact of each aspect of a proposal for a range of environmental concerns and they consider both the magnitude and importance of impacts. Again, GIS provides a powerful tool for organizing, analyzing and storing matrices.

#### 4) Network Methodology

It is defined a network of possible impacts that may be triggered by project activities and that require the analyst to trace out project actions and direct and indirect consequences. From the network methodology, direct, secondary, tertiary and other higher order impacts of action may be traced out. This method cuts across disciplinary lines and it forces the identification of site-specific factors and conditions necessary for the establishment of a proposed cause-effect relationship. This technique however requires that the analyst be knowledgeable in the various types of environmental components and dynamics.

GIS importance is based on the possibility of transforming data bases and carry out spatial analysis. That includes transformation in the coordinates system to enter data in layers (Burrough, 1986). Other possibilities are related to converting vector to raster models, extract and overlay data to analyze the closest neighbors for creating influence and buffer zones for the EIA analysis. This digital information can be combined with information coming from aerial photograph and satellite imaginary. Resulting images can be used to analyze previous or future changes in the coverage, for example of land use. Besides, conventional cartography methods give clear boundaries ignoring natural features, therefore one technique to deal with uncertainty on geographic processing is the diffuse logic, recently used to analyze distribution and changes in environmental features.

In summary, the capabilities of GIS in EIA are:

1) It is possible to store large amounts of different kinds of data. The access to these rich databases allows the performance of dynamic queries based on real world representations.
2) Concerning the analytical capabilities, some potential functionality can be added such as the use of interactive video and digital sound associated with zoning maps, to help planners and decision-makers to visualize and better evaluate the impact of a new infrastructure. Other capabilities are related to the integration of spatial simulations associated with real images and to stereoscopic aerial photographs in order to get an improved visualization of the phenomena and their evaluation in real time.
3) The results of EIA correspond to compressed information to synthesize in a small number of descriptors the complex and diversified universe that has been analysed. In a GIS, the improvements in the communicability of the results are associated with the use of images, which represent information in a compact way, of easier comprehension.

The development of GIS for EIA requires the analysis of this process in order to identify the tasks that will be beneficial. To better understand the study area it may be necessary to view it from several different perspectives: aerial views, static and dynamic ground views. The aerial view corresponds to a combined flight through aerial photographs or satellite digital photographs, giving a perspective of the study area. This representation can be associated with the corresponding route of the flight over a map, allowing the interrelationship between the two spatial representations to be established.

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