Environmental Assessment Sourcebook
UPDATE

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Geographic Information Systems for Environmental Assessment and Review

Sustainable development and management of natural and economic resources depend on the ability to assess complex relationships between a variety of economic, environmental and social factors across space and time. Limited capacity and experience in gathering and managing data along these dimensions frequently inhibit the quality of environmental and developmental planning. As a result, information management is currently receiving growing attention. Geographic Information Systems (GIS) have emerged as a particularly promising approach in this regard, enabling users to collect, store and analyze information that has been referenced to its geographic location.

This EA Sourcebook Update offers an overview of what GIS is and presents how it may be applied in environmental assessment (EA). Since GIS was not discussed in the Sourcebook, the Update does not replace any existing material.

What is GIS?

In the broadest terms, GIS is a systematically designed, spatially indexed approach for organizing information about places or regions in order to facilitate analysis of relationships between different social, economic and environmental variables. For example, a set of maps or overlays of a given area, with different levels of resolution and types of data—topography, hydrology, land use patterns, demography, planimetric features and so forth (see figure 1)—is one type of GIS that does not necessarily require complex computerized data systems. At the other end of the spectrum is a more technology-based application of GIS, as reflected in the following definition by the U.S. Federal Interagency Committee on Digital Cartography (*A Summary of GIS Activities in the Federal Government*, 1988): "[a] system of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, ... and display of spatially referenced data for solving complex planning and management problems."

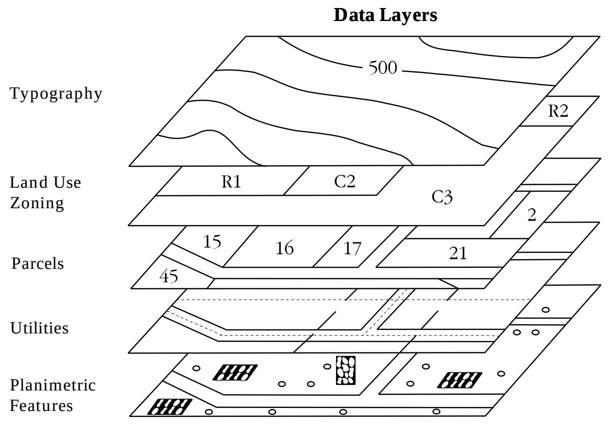
This Update aims to introduce GIS as a concept, or organizing principle, rather than as a specific set of technologies. A forthcoming Update will discuss how in-country technological and institutional GIS capacity can be built and applied, for both individual projects and long-term environmental planning.

Advantages of GIS

Most situations that would benefit from GIS capability can be categorized as long term or short term. The long-term category is where economic and environmental management on a national, regional or local level is called for—in other words, institutional or programmatic applications. The short-term category usually involves specific project situations, for example EA work. The basic equipment, software and human resource skills required may be similar for both categories, but the design, implementation and operation implications may be different. In some instances, what starts as a project-specific application may evolve into a permanent program.

GIS may be particularly useful in cross-sectoral and regional development, for example, in coastal zones, watersheds, large urban or metropolitan areas, or multipurpose development schemes within a given administrative region. Determining a region's vulnerability to soil erosion, for instance, requires the consideration of such factors as soil structure and chemistry, seasonal fluctuations in rainfall volume and intensity, geomorphology, and the type of land management regime in place. Assessing the feasibility of a soil conservation program in an area requires further information on the economic status of inhabitants, the types of crops grown, and the responsiveness to incentives for soil conservation. Then, select-

Figure 1. Layers of spatially related information in a GIS database



ing the appropriate soil conservation or land rehabilitation models requires information on land capability and its suitability for different uses.

GIS technologies handle both the spatial and non-spatial properties of data-sets, thus providing an extension to other statistical methods that disregard the spatial nature and variations of environmental information. The advantages of using GIS in environmental assessment include the following:

- It encourages a more systematic approach to environmental information collection;
- it can reduce the overall costs and institutional overlap of environmental information collection and management;
- it increases comparability and compatibility of diverse data sets;
- it makes data used in EA preparation accessible to a wider range of decision-makers; and
- it encourages the spatial analysis of environmental impacts that would otherwise be more easily ignored because of analytical difficulty or cost.

GIS applications in EA

Until recently, the use of GIS for EA has been reserved for evaluating very large and geographically extensive projects such as hydroelectric power, national forest management and large-scale urban developments where high land values justify expenditures on elaborate information systems. For many smaller projects and associated EA activities the cost of system acquisition and data collection has not always justified GIS development. However, progress in the development of data collection systems (especially satellite-based systems) and information management techniques (PC based systems) is making GIS an increasingly cost effective instrument.

While it is impossible to define a single GIS blueprint for all environmental assessment and review, a number of basic characteristics for such a system can be identified. These include the following features or capabilities:

- Description of the condition and geographic distribution of natural resources and areas of concern;
- identification of the nature, sources, magnitude, and location of environmental stress present in an ecosystem or reporting unit;
- description of an ecosystem's current and potential level of exposure to a given stress
- assessment of the actual response of an ecosystem to existing or potential stresses; and
- assistance in the evaluation of the risk posed as a result of that exposure (that is, the probability that an impact of a given magnitude will occur).

The GIS approach may thus be useful in EA requirements such as collecting and systemizing baseline data, estimating impacts (particularly cumulative impacts), and managing data during monitoring. GIS can also be a powerful tool to identify and analyze project alternatives in terms of geographic location, overall design and technology choices. All of these applications are important components of EA under OD 4.01.

GIS as a tool for supporting resource inventories and baseline surveys

The EA Operational Directive states that baseline data in a project-specific EA Report should contain an "assessment of the dimensions of the study area and description of relevant physical, biological, and socio-economic conditions.." (Annex B of OD 4.01, para 2). GIS was developed precisely to gather, manage and use such information in a spatially indexed fashion; and using GIS to collect and analyze baseline data may not only reduce costs and time but also enhance overall EA quality as well, especially in countries where GIS capacity is already present. In countries where GIS has not yet taken root, introducing a package for a specific project or a full-scale national resource information management program—in the form of a set of appropriate technologies, institutional arrangements and training—may reap the same qualitative benefits, at low to moderate additional cost (see box 1).

One field where GIS frequently has been used as a tool for building inventories of natural resources and baseline environmental conditions is land resource management. In the forestry sector, for example, satellite remote sensing has been applied to document the composition and distribution of vegetation types, classify ecological system types, identify marketable timber species and volumes, perform agro-ecological zoning, detect vegetative stress (for example, rates of deforestation), monitor pest infestation, and predict fire hazards. However, while satellite imagery has proven effective for broad forest reconnaissance surveys, it has generally not been helpful for detailed assessments.

Aerial photographic techniques combined with terrestrial (ground) surveys have proven extremely effective in

Box 1. Resource survey and land-use mapping in the Philippines

In developing a lending strategy for the Philippines, the World Bank recognized the need for more current and accurate resource information about the country in order to identify a set of interventions to help manage—and use in a sustainable way—land and water resources. The Bank then undertook a study, as part of its regular economic and sector work, to identify significant natural-resource and environmental management issues in the country. To support the study, the Bank together with the Swedish Agency for International Technical and Economic Co-operation) created an information base from which it could prepare development strategies. Up-to-date information about resources and land use was required within a relatively short time. Because conventional approaches and techniques for resource and land-use surveys are typically time consuming and costly, an alternative approach using SPOT satellite imagery was applied to assess and map land-use practices and vegetation cover.

Ground truth information and other data from primary and secondary sources were used to assist in the assessment and mapping work. Based on the satellite and ancillary information, forty-three maps at scale 1:250,000 were produced representing twenty-two land cover classes and two marine classes identifying coral reefs and silted waters. From these maps, provincial, regional, and national level statistics were derived summarizing land use and vegetation cover.

Complete national coverage and land-use mapping at the 1:250,000 scale was accomplished in less than one year and at a cost of approximately $1.7 million, or about $5.65 per square kilometer. The database was established within the Philippine National Mapping and Resource Information Authority (NAMRIA) and serves as a baseline of resource and environmental information. The database has subsequently been used to assess land-use change and to help plan project activities that have environmental impacts.

supporting engineering feasibility studies, optimal routing analysis, and impact prediction for roads, hydroelectric facilities, pipelines, and other major infrastructure. In particular, the science of aerial photogrammetry (making maps on the basis of aerial photography) and photo interpretation from large-scale stereo-photos allows detailed computations of topography, drainage characteristics, land cover, erosion hazards, and so forth. Forest management specialists are now developing ways to link traditional forest planning and timber management techniques (such as linear programming and forest stand growth modeling) with GIS and artificial intelligence to achieve habitat protection objectives.

A recent study in China used GIS to assess the agricultural potential of soils in different areas, by combining data on soil characteristics with other local site factors. The World Bank has used GIS technology to integrate physical models of soil erosion potential with models of soil conservation costs in order to assess the approximate cost of erosion to the local economy in Java, Indonesia. Box 1 provides an example from the Philippines, where GIS was used to produce and analyze baseline data.

GIS can also be used for generating and managing baseline data in an urban environmental planning context, as box 2 illustrates.

GIS for impact assessment and analysis of alternatives

GIS modeling techniques allow complex interrelationships to be evaluated within comprehensive spatially referenced databases. Techniques such as network analysis, proximity buffering and digital terrain modeling are routinely applied in engineering and environmental applications throughout North America and Europe, and are beginning to be used in developing countries as well.

Through the services GIS can provide in impact assessment, the identification and analysis of design and site alternatives can be enhanced. By offering a single and consistent framework for impact analysis across space and time, GIS promotes objective analysis of alternatives and provides decisionmakers with better information about their options. Once a decision is made, the information already generated will be useful in designing mitigative measures. Risk assessment applications such as hazard identification, risk characterization, and risk minimization planning are other examples where GIS has been effective.

GIS for environmental monitoring

The use of GIS for environmental monitoring during project implementation and thereafter should be considered early on during project preparation. If GIS has already been used for baseline surveying and impact assessment, applying

Box 2. Urban base-map from satellite data

In Dar es Salaam, Tanzania, a panchromatic SPOT image in map sheet format at 1:50,000 scale was used to quickly collect information on the growth of the city. The primary objective was to produce an up-to-date base-map, to be used together with the image map for strategic environmental planning. The present extent of built-up areas and roads also provide vital information for the initial planning of major infrastructure rehabilitation.

The maps were produced by visual interpretation of the photographic prints and traced on easily reproducible transparent overlays. The first overlay contained features for location, including coast line, trunk roads, railways, major drainage channels, and the extent of built-up areas. Another contained only road delineations. A number of such overlays on different themes will be produced where information from the image, available maps, and other sources are compiled in a common format. In this way, a "manual GIS" is developed for the analysis of environmental issues. When capacities for computer processing become available in the future, a large part of the costly database development will already be in place.

Box 3. National information system for environmental monitoring in Nigeria

Building on the strategy paper "Towards the Development of an Environmental Action Plan for Nigeria - 1990" (prepared jointly by the World Bank and the Federal Government of Nigeria), an Environment Management Project (EMP) was approved on September 1991. The project aimed at strengthening Nigerian environmental institutions (particularly the Federal Environment Protection Agency - FEPA) and helping them implement their programs; establishing a national environmental information system, based in large part on GIS, to monitor environmental change over time; and conducting a complete series of sector investigations and studies to redress environmental degradation.

The project's support to the environmental information system included technical assistance, training, provision of equipment and services, and financing of recurrent costs on a declining basis. Four sectoral information nodes were established: (a) vegetation and land use, managed by the Forest Department; (b) soils and lands, managed by the Department of Land Resources; (c) water quality and quantity, managed by the Ministry of Water Resources; and (d) air quality, managed by FEPA. In addition, the project established a central node, managed by FEPA, to ensure information flow between the sector entities.

The system has provided key data to a number of studies. For example, the recently completed study of land use and vegetation changes between 1978 and 1995 (based in large part on the vegetation and land use node) provided precise information about the consequences of population pressure and unsustainable land use practices in different regions of the country. Large areas of the country are experiencing land degradation due to extensification of agriculture and removal of trees and shrubs for fuelwood. In the southern coastal areas, removal of mangrove vegetation and urbanization are causing increasing salt water intrusion and disappearance of marches and tidal flats. In the north, once stable sandy areas are subject to increasing problems of desertification and soil erosion. The results of this study were presented at a national workshop to agree on a strategy, based on current and reliable quantitative information, to overcome these problems and mitigate the damages.

Upon completion of the other nodes and associated studies (water, land and air) it will be possible to produce digital overlays and combine them with a socio-economic layer to study relationships between environmental and socio-economic trends, the impact of policies on environmental quality, and the cumulative effects of environmental changes across media (vegetation, land, water and air).

Since its establishment, the information system has allowed large quantities of environmental and resource information to be collected in compatible spatial and temporal formats to fit into an integrated GIS network. The data is being freely exchanged between agencies for environmental and natural resource management.

GIS for monitoring does not require much additional effort. Sometimes countries decide to develop a permanent environmental monitoring program based on GIS, rather than a case-by-case approach (see box 3).

When monitoring environmental impacts during and after project completion, databases with multiple attributes—often dynamic in nature—must be integrated. GIS can help structure and integrate this diverse information ranging from water quality to soil productivity to habitat data. Specific GIS technologies that are useful in monitoring include remote sensing, which can be applied to monitor for example sewage disposal sites, effluent discharges and coastal wetlands for example. The use of aerial photography is still the preferred technology to date, but satellite-based imaging systems are gaining ground as spatial resolution increases.

One clear advantage of GIS in monitoring is flexibility, which allows specialists to create a wide range of reports, maps and statistical summaries suitable for public briefings as well as technical analysis. GIS may thus help increase transparency and broaden the scope of public participation in project implementation.

For further reading

Several publications are available that provide more in-depth information on GIS. The following documents are recommended for further reading:

Antonucci, J. 1991. *GIS: A Guide to the Technology*. Von Nostrand Reinhold. New York.

Burrough, P. A. 1986. *Principles of Geographic Information Systems for Earth Resources Assessment*. Clarendon Press. Oxford.

Hassan, H. M., and C. Hutchinson. 1992. *Natural Resource and Environmental Information for Decisionmaking*. World Bank. Washington, D.C.

Paulsson, B. 1992. *Urban Applications of Satellite Remote Sensing and GIS Analysis.* World Bank. Washington, D.C.

This *Update* was prepared by Hassan Hassan and Olav Kjørven. The *EA Sourcebook Updates* provide up-to-date guidance for conducting EAs of proposed projects and should be used as a supplement to the *Environmental Assessment Sourcebook.* The Bank is thankful to the Government of Norway for financing the production of the *Updates.* Please address comments and inquiries to Olav Kjørven and Aidan Davy, Managing Editors, EA Sourcebook Update, ENVLW, The World Bank, 1818 H St. NW, Washington, D.C., 20433, Room No. S-5139, (202) 473-1297. E-mail: eaupdates@worldbank.org.