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Land use planning and environmental impact assessment using geographic information systems

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11.1 INTRODUCTION

Land use planning consists of making decisions about the use of land and resources (Food and Agricultural Organization 1993). It is conducted primarily to achieve the best use of land, and its implementation is often driven by current and future people's needs in terms of productivity and environmental sustainability. Land use planning may not be as important in sparsely populated countries and communities. In sparsely populated countries or communities, the land use planning is straightforward and is usually aimed at finding the best locations for each of the potential land uses at hand; in other words, it is reduced to a land evaluation (FAO 1976; Rossiter 1996). In highly populated communities, however, land use planning consists of a more elaborate analysis due to conflicts between competing uses (Brinkman 1994). In this case, planning activities are tailored primarily to making the optimal uses of the limited land and associated resources.

Land use planning may be conducted at different levels or scales of decision-making: national, district, local, farm, or field level. The national level is concerned primarily with national priorities as driven by land use policy and legislation. In some countries, land use planning consists of a multi-year program detailing goals at every step of the action plan. Land use planning at a district level often deals with development projects. Local planning may be carried out at the community or watershed level. Farm-level land use planning involves determining best management practices for different fields in the farm. The land use planning process differs from project to project depending on the goals and availability of data. Most projects involve sequential organization of thoughts, evaluation and comparison of alternative land uses in terms of their suitability and impacts to the environment, and finally design and implementation of the plan. While the Food and Agriculture Organization (FAO) land use planning process (Figure 11.1) emphasizes the regional and nationwide planning, that of the United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) is primarily concerned with conservation planning and nutrient management at the farm level (Figure 11.2).

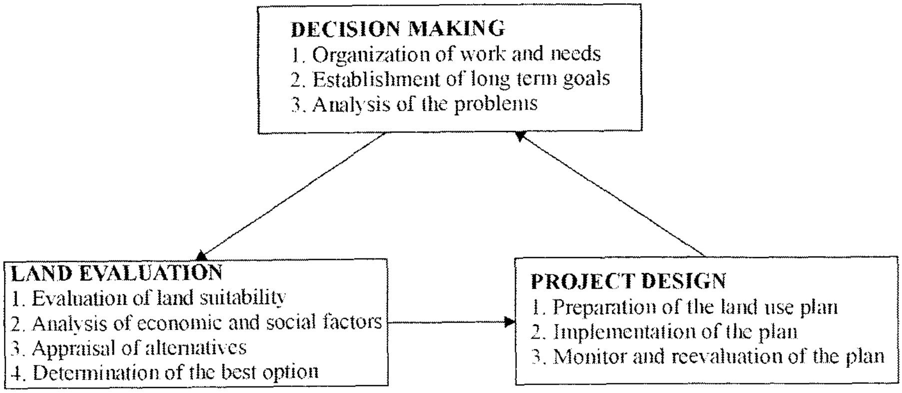

Figure 11.1: Relationships among different tasks of the FAO land use planning process.

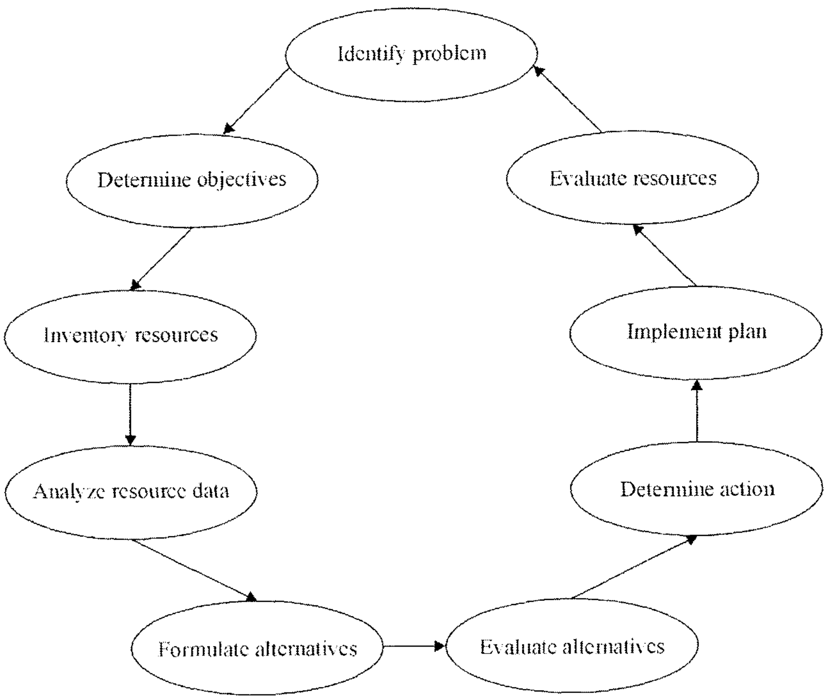

Figure 11.2: The USDA-NRCS farm planning process.

Environmental impact assessment (EIA) is performed in land use planning activities to determine the effect a potential land use would have on the environment (e.g. soil and water pollution, air pollution, ecosystem health and functions, drinking water availability). The type of impact to be evaluated varies depending on the nature of the proposed land use and its potential consequences on the immediate environment. Results of this analysis are intended to help planners to suggest appropriate and sustainable management practices. Only cost-effective land uses that cause the least harm to the environment are retained for further analysis.

Geographic Information System (GIS) technology was originally developed as a tool to aid in the organization, storage, analysis and display of spatial data. The ultimate goal, however, was its application in geographical analysis. Such analyses include land use planning, as well as land use and cover monitoring and management. GIS has been linked to environmental models, decision support systems and expert systems in order to make these tools applicable in spatially-explicit environmental planning and decision-making. The objective of this chapter is to describe ways by which GIS is being or can be used in various aspects of land use planning and associated activities.

11.2 GIS IN LAND USE PLANNING ACTIVITIES

GIS is used for improving the efficiency and effectiveness of a project where geographical information is of prime importance (Burrough 1986). The information within a GIS consists of two elements: spatial data represented by points (e.g. well locations), lines (e.g. streams, road networks), polygons (e.g. soil delineations of soil mapping units), or grid cells, and attribute data or information that describes characteristics of these spatial features. The spatial data are referenced to a geographic spatial coordinate system and are stored either in a vector or raster format (Burrough 1989).

The availability of data sources in a digital form such as digital elevation models (DEM), spatial databases (e.g. soils) and remote sensing imagery, and the increased capability of computers to handle large volumes of data in recent years has increased the applications of GIS in land use planning. In this context, GIS has been used primarily in land evaluation (FAO 1976; Rossiter 1996), a procedure aimed to determine the suitability of land evaluation units for current and alternative uses and the potential impact of each use on the environment.

The development of spatial decision support systems, a type of application software, is one of the reasons GIS is used in land use planning and are defined as interactive computer-based systems that help decision-makers use spatial data and models to solve unstructured problems (Sprague and Carlson 1982). They evolved from decision support system types of decision-making software programs that were developed for business applications including strategic planning, investment appraisal and scheduling of operations (Densham 1991). The goal is to improve the quality of the decision-maker's work, have all the spatial data analysis and modelling capabilities required such that a user, with little or no limited computer and modelling expertise, can quickly access and evaluate the data.

Spatial decision support systems differ from traditional GIS and linear programming models because they provide selection tools via a customized graphical user interface to design and model alternatives, select and evaluate these alternatives, and subsequently display results in maps, tables and/or diagrams. In most straightforward applications, the interface and utility modules are built using the programming facilities offered by various GIS packages. However, spatial decision support systems often combine GIS technology with modelling and programming facilities of computer programming languages such as C, FORTRAN, and Pascal (Petersen *et al.* 1995). For these reasons, GIS have become effective and efficient technologies for scientists, managers and other decision-makers that need to address multi-disciplinary and complex land use planning and management programs. In contrast, GIS-based expert systems provide, not only spatial input data and decision-making information, but also expert knowledge and reasoning rules to manipulate and evaluate that information (van der Vlugt 1989) (see also Chapter 2 – expert system models are classified as deductive-knowledge based models). Unlike a spatial decision support system, an expert system gives potential solutions to the problem.

11.3 SOURCES AND TYPES OF SPATIAL DATA SETS

Data sets commonly used in the land evaluation and EIA can be grouped into two categories: socio-economical and biophysical factors. Socio-economic factors are concerned mainly with the location of the land in relation to essential infrastructures (e.g. markets, major roads, schools, hospitals), social restrictions of the community (e.g. sites of historic value), and economic value of the land use. Biophysical factors, on the other hand, deal with the immediate surface and subsurface environment around the land area of interest. This section deals with sources and types of some of the spatial data commonly used in land evaluation and EIA. Data on soils, vegetation and landform across landscapes are particularly important to GIS-based land use planning activities because they are:

(1) Often available in GIS format as spatial databases
(2) Used to provide spatial input data for assessing and modelling the impact of current and alternative land uses on the land, and
(3) Used to compute land productivity often needed in land evaluations.

11.3.1 Land topography

GIS-based land evaluations can be enhanced by the use of digital topographic data. Contour lines on topographic maps have to be digitized and processed for every area of interest, a tedious and time-consuming process. DEMs are efficient and convenient sources of this information. The US Geological Survey (USGS) produces and distributes DEMs of different resolutions for the entire US The 7.5 minute DEMs are produced from the 7.5-minute quadrangle maps using 30 m grid cells and are referenced horizontally on the Universal Transverse Mercator (UTM) coordinate system (see Chapter 4).

DEMs appear as geo-referenced arrays of regularly spaced elevations of the land surface and are compatible with GIS. Slope gradient and aspect, and curvature (concave, convex and linear) are some of the most important parameters calculated from DEMs (see also Chapter 9) that are relevant to land use planning.

Most GIS packages contain algorithms that automatically compute these topographic characteristics. The slope gradient is one of the key parameters often used in earlier stages of land evaluations to set limits on where a given land use type is possible or not. For example, clean-tilled cropland is generally limited to slopes of less than 18 per cent unless carefully planned management practices are adopted. Slope also affects water infiltration, drainage, storm water runoff, nutrient losses and erosion from croplands. As a result, it is an input data layer to hydrologic, soil productivity, crop growth, and water quality models often used in land evaluations and EIA. Furthermore, a map of slope gradient classes is important to the overall land use planning because it helps locate stable and unstable landscapes for selected potential uses (Marsh 1991). The slope form affects the distribution of water, soils and vegetation and is often used to decide which type of crops should be grown in an area.

11.3.2 Soils

In the US, soil maps have commonly been prepared manually for areas of interest from county soil survey reports. The process is difficult and expensive particularly for large areas, and boundaries between mapping units in these reports are often inaccurate. In addition, thematic consistency is difficult to achieve, because adjacent surveys were typically conducted at different times and with different legends. Today, the process of digitizing soil delineations based on orthophoto quadrangles or topographic maps somewhat corrects these inaccurate boundaries; at least mechanically the boundaries match. This automated processing of soil maps and related attributes allow more efficient handling and display of soil information.

Geographic soil databases are perhaps the most important data source in GIS-based land evaluations. They are developed to organize soil attributes in a coherent manner for efficient storage and handling by users. Early non-digital soil databases consisted of tabular information on soil properties held in a generalized form. An example is the USDA-NRCS map unit interpretation record (MUIR). The use of this type of database, however, is limited due to its poor flexibility when querying data for different, and particularly intense, spatial analyses. Furthermore, soil boundaries have to be redrawn manually every time new data analyses are performed for different interpretative maps (Burrough 1991). Geographic soil databases evolved in order to include both spatial and non-spatial descriptions and were particularly designed to work exclusively within a GIS.

Geographic soil databases have been developed by countries, at a regional or international level or scale. For example, the USDA-NRCS has developed three national soil geographic databases: Soil Survey Geographic (SSURGO), State Soil Geographic (STATSGO) and National Geographic (NATSGO) databases. Each database is composed of soil map units that are linked to attribute tables of chemical and physical properties, and interpretative data (Reybold and TeSelle 1989). SSURGO, the most detailed one, is used primarily in natural resource planning and management at the farm, watershed and county levels. STATSGO was designed for use in statewide and regional environmental assessments (Bliss and Reybold 1989). They are made at the 1:250,000 scale using 1-by 2-degree USGS topographic quadrangles as map bases and are distributed as complete coverage for each state. NATSGO is a broader scale soil database and was designed primarily for regional and national planning. The boundaries between map units are those of the major land resource areas (MLRA) and regions are developed primarily from general state maps. Thus, map units are mainly associations of dominant soil series. The NATSGO soil map was made at a scale of 1:7,500,000 and is distributed as a coverage for the entire US. Similar soil databases have been developed only in a few other countries: Canada, The Netherlands, and France. A major constraint to land evaluation practice in other countries is the lack of reliable digital soil maps.

11.3.3 Land use/cover

Land use and land cover distributions have generally been derived from aerial photographs and land cover maps. Delineations of different land use/cover types on photographs are made from visual interpretations of characteristics (e.g. tone, texture and colour) aided by optical devices. Digital maps of these classes are created by digitizing and processing boundaries between land uses or by scanning photographs covering the area of interest and screen-digitizing their boundaries. These maps have to be geo-referenced and registered before they can be used in GIS analyses. Remote Sensing (RS) imagery is another source of land use/cover information for use in land use planning. Detailed information on satellites presently in orbit is provided in Chapter 3.

While aerial photography and land use maps are effective and appropriate for small area analyses, satellite remote sensing offers tremendous advantages when planning for large areas such as river basins and regions, as it usually allows for relatively easy and reliable differentiation of existing land uses (e.g., wetlands, new subdivisions, degraded landscapes). The knowledge of the extent and location of land cover obtained by classifying remote sensing imagery is crucial to the development of land use plans because it serves as a basis to which other potential land uses can be compared. Land use/cover distributions are input to GIS and GIS-based hydrologic/water quality models commonly used in EIA. They are also important to other aspects of land use planning such as the development and implementation of zoning ordinances, tax assessment, conservation activities, farmland preservation, and ecosystem and wildlife habitat assessments.

Repetitive coverages and the broad-scale perspective of polar-orbiting satellites offer also the possibility of monitoring the land cover changes over time, data which cannot be provided as quickly and efficiently by conventional mapping procedures. Gathering information on land cover at several time intervals is particularly important in the monitoring and re-evaluation stages of a land use planning. Factors such as plant stress, growth and yields that serve as measures of the effectiveness of an existing plan can rapidly be estimated following digital processing and analysis of remote sensing imagery. Remote sensing has been used in many instances to monitor soil degradation and salinity, differentiate geologic formations and locate surface geologic features such as lineaments, etc. (Agbu and Nizeyimana 1991). Although remote sensing cannot fully replace field mapping of land cover and land use, it supplements and provides information not otherwise available to land use planners.

Recent advances in GIS applications have promoted the development of high-resolution spatial technologies that will enhance the land cover assessment and planning in the future. Some of these are the global positioning system (GPS) and digital orthophoto quadrangles (DOQ). GPS allows the user to record accurately and rapidly geographic coordinates of any location in the field with precisions ranging from several tens of metres to a centimetre (Petersen *et al.* 1995). Soil, terrain and land use attributes observed or measured can then be input to a GIS along with their precise locations and extent. Digital orthophoto quadrangles, on the other hand, are digital images of aerial photographs that were corrected to remove relief displacement and distortion caused by the camera angle (Kelmelis *et al.* 1993). Digital orthophoto quadrangles acquired at different times can be used to monitor the magnitude of changes in land cover and land use over time. The relationship between GIS and remote sensing as related to land use planning is illustrated in Figure 11.3.

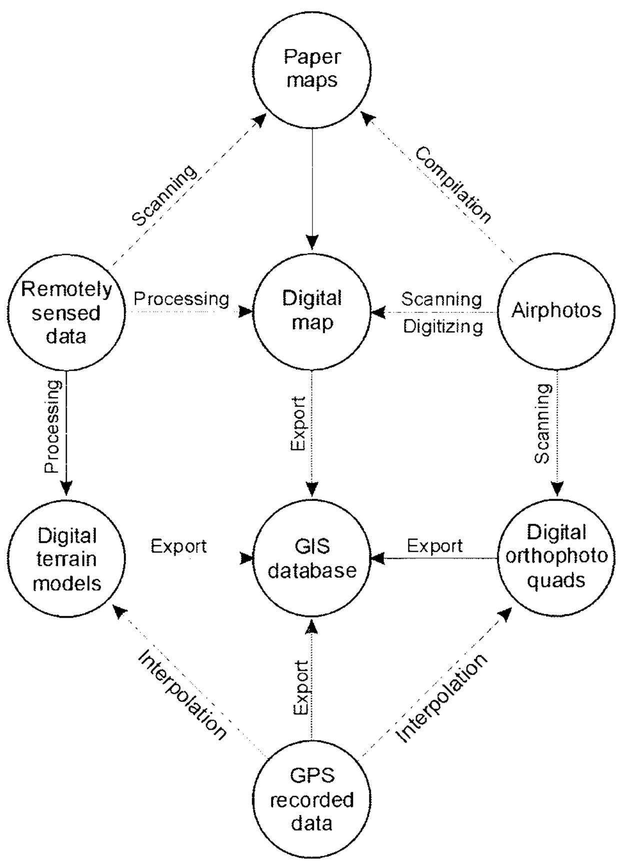

Figure 11.3: Relationships between GIS and remote sensing.

11.4 LAND EVALUATION METHODS

Land evaluation has been defined as the process of assessing or predicting the performance of land for specific purposes (FAO 1976). Potential land uses are analyzed in terms of their ability to provide commodity benefits based on the biophysical, economical, and social factors characterizing the land. Land evaluation is the most important part of the land use planning process (Whitley and Xiang 1993). The land evaluation is performed using conventional or quantitative approaches. In conventional land evaluations, the suitability or limitations for specific uses are generated using ranges of environmental land characteristics including soil properties, landscape-derived data, etc. The resulting classification scheme is often part of national soil surveys and many spatial soil databases. Quantitative approaches, on the other hand, consist of computer-assisted modelling of land qualities. This section deals primarily with biophysical aspects of land evaluation in agriculture and related activities.

GIS is often used in land evaluations for land use planning. In this case, land attributes and qualities are derived from geographic databases and are used to determine land suitability, limitations or ratings for various uses. These databases and associated attribute data may be part of a GIS, a GIS/model linkage, spatial decision support system or expert system. The analysis results may be presented in tabular or graphical form and are intended to provide key information necessary for a land user or planner making meaningful decisions about land management and conservation and/or land use planning. For a theoretical framework of land evaluation approaches, see Rossiter (1996); for a historical survey of land evaluation see van Diepen *et al.* (1991).

11.4.1 Conventional approaches

11.4.1.1 Soil management groupings

Soil management groupings are developed using numerical and descriptive soil information from soil surveys. These interpretations are arranged into classes of relative soil suitability or limitations for a specific use (Soil Survey Division Staff 1993). Several soil interpretative generalizations have been developed for use in agricultural land use planning and management. They are often part of soil survey reports and geographic soil databases. Soil and landscape interpretation systems have been developed in many countries including Great Britain (Morgan 1974), Canada (Canada Land Inventory 1970) and the Netherlands (Vink and van Zuilen 1974). The most well-known examples, however, are perhaps the land capability classification of the USDA-NRCS (Klingebiel and Montgomery 1961) and the fertility capability classification of the FAO (Sanchez *et al.* 1982).

The land capability classification system was developed to assist farmers in planning crop rotations and soil management practices for different fields in the farm (van Diepen *et al.* 1991). In addition to soil properties, the procedure also incorporates information on landform (slope gradient), climate, erosion risk, etc. It consists of eight land capability classes varying from most suitable (I) to least suitable (VIII) soils for agricultural production. Soils occurring in the same class have the same limitations and risks when used for crop growth and therefore should respond similarly to soil conservation and management needs. Each class contains subclasses that indicate the type of limitation (e.g. erosion hazard, wetness). Each subclass may also have several units.

In its original application for conservation farm planning of typical family farms in the US, it has been successful.

The fertility capability classification clusters soils that respond similarly to similar soil management practices (McQuaid *et al.* 1995). However, it is a soil fertility-based ranking system that assigns condition modified according to each soil mapping unit (e.g. low cation exchange capacity, acidity, salinity). Classes are defined according to the number of chemical and physical limitations soils have for proper plant growth. The fertility capability classification is part of the FAO/United Nations Educational, Scientific and Cultural Organization (UNESCO) digital soil database and has been also used in conjunction with country-wide and local soil survey systems.

11.4.1.2 Soil productivity ratings and indices

Soil management groupings described above have been used in some instances as measures of soil productivity (Liu and Craul 1991). However, the productivity of a farm or farm fields for specific crops and plants is commonly evaluated using soil productivity ratings. Soils are compared on a relative scale (0–100) based on predicted yields of a specific crop as a percentage of standard yields taken as 100 per cent (Soil Survey Division Staff 1993). The approach has some advantage since ratings for several crops and different soils can be combined to produce a general rating for a large area. Most county soil survey reports in the US contain soil productivity ratings for major crops and common trees in that county. These data may be entered into a GIS and can be retrieved and used in land evaluations just like any other attribute data.

The level of agricultural productivity for different tracts of a farm can also be determined using ranking/indexing classifications of soil mapping units based on soil properties known to affect crop growth. In this type of classification, soils are ranked in terms of their relative productivity based on a combination of soil properties and qualities relating to productivity potential. As a result, productivity indices are not affected by changes in technology compared to productivity ratings, which are based on plant yields. A soil productivity index model can be multiplicative, additive or a combination of both. In any of these models, a soil parameter is given ranges of values with corresponding ratings that show its suitability for crop production. These are multiplied or added for each mapping unit to create a single index value.

A well-known example of a soil productivity ranking system is the Storie Index (Storie 1937). This index was programmed in FORTRAN as the soil ratings for plant growth (SRPG) model (Sinclair 1996). SRPG is a multiplicative index aimed at classifying soils in terms of their ability to produce fibre, vegetative growth and grains for commodity crops. Soil properties used in the model are derived from soil databases and include organic C, bulk density, clay content, available water capacity, pH, calcium carbonate, CEC, texture, rock fragments, etc. Soil climatic data (moisture and temperature regimes) and landscape features were also incorporated in the final stages of SRPG calculations. The resulting classification is a relative index of land 'quality' for each soil series. Results can be graphically displayed on a farm, county, state or national basis using GIS. This is essentially a multiple-regression approach (i.e. an empirical inductive as described in Chapter 2) to predicting land performance. The resulting apparent precision is attractive, but care must be taken not to over-fit the model (Gauch 1993).

Another example of an often used soil productivity ranking/indexing model is the Productivity Index (Pierce *et al.* 1983). The index rates soils in terms of their suitability for root growth and development. It assumes that crop yields are a function of root growth. The model is a multiplicative function that predicts long-term soil productivity changes due to long-term soil erosion based on soil parameters (pH, available water capacity, bulk density) from the soil interpretation record (SIR) SOILS-5 data set. The model was developed for the north central US region but it can be applied to other areas after proper calibration of its variables.

11.4.2 Quantitative approaches

Quantitative methods used in biophysical land evaluations generally consist of regression and crop growth simulation models. Statistical methods are used to develop empirical models of crop yields (see also Chapter 2). Model coefficients are computed for a specific land location by regressing a sample of yields to corresponding climate (e.g. temperature, rainfall, radiation) and soil characteristics known to affect crop yields. An example of a statistical model relevant to land evaluation is that of Olson and Olson (1986). The authors evaluated various parameters and found that the best fit regression model of yield estimates for areas in the state of New York was a function of rainfall, number of growing degree days, basic cation status and organic C content of soils. Regression models are site-specific and should be calibrated for new land areas. In addition to simple and multiple regression, crop yields may be estimated using more complex statistical approaches such as multivariate and principal component analysis.

During the past few years, scientists have simulated physical and economic land suitability. The modelling approach to land evaluation in land use planning efforts offers some advantages over conventional and statistical methods because the effect and cost associated with temporal changes in land and/or climatic attributes can also be determined. Potential land uses can be compared to crop yields predicted under future climate changes, long-term soil degradation, etc. Similarly, those factors known to affect the socio-economic aspects of land evaluations, such as future population growth and technology changes, can be used to predict the capacity of the land to sustain future food demands.

A number of process-oriented crop simulation models that have potential for use in land evaluation are aimed at simulating crop yields from agricultural lands. The use of models in land evaluations has been very limited particularly due to the large volume of input parameters required and the time involved in compiling them and parameterizing the model, particularly for large areas. The integration of these models with GIS, however, may involve significant processing time.

Sharifi and van Keulen (1994) have developed spatial decision support system for land use planning at the farm level. In this system, planning, crop simulation and linear programming models were integrated into a GIS. A Decision

Support System for Agro-technology Transfer (DSSAT) has been developed by the International Benchmark Sites Network for Agro-technology Transfer which includes many US universities (e.g., University of Hawaii, University of Florida) and the University of Puerto Rico (IBSNAT 1992). The system integrates data from crops, soils, and weather in one standardized input data with several crop models to simulate multi-year yields under different crop management strategies at farm and regional levels. Two GIS-based interfaces, the Agricultural and Environmental Geographic Information System (AEGIS) and AEGIS/WIN were also developed jointly by the University of Florida and University of Puerto Rico and linked to the DSSAT (Engel *et al.* 1993; Luyten and Jones 1997). The AEGIS consists of databases, crop models, ES and GIS (Figure 11.4).

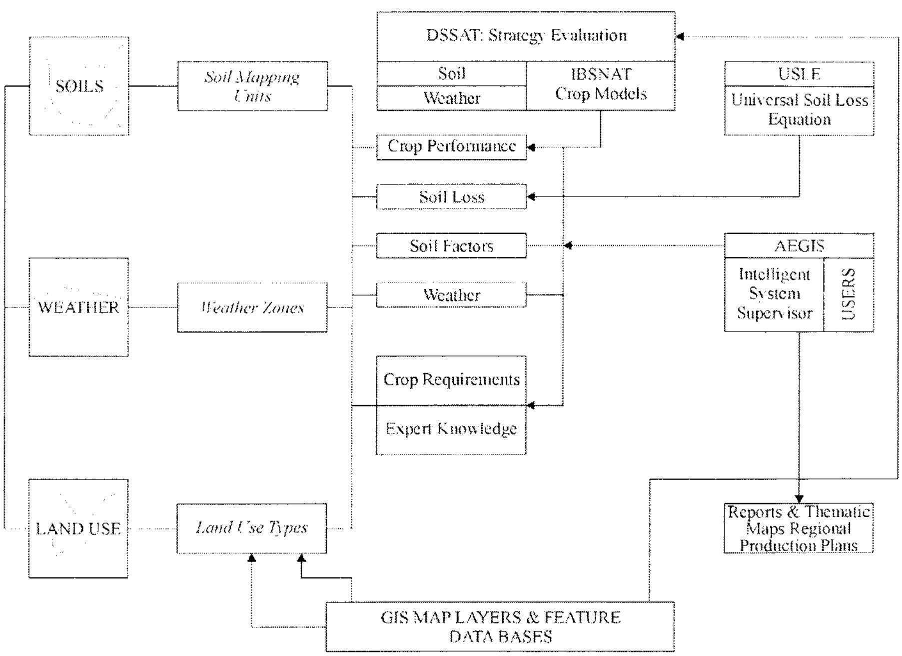

Figure 11.4: AEGIS decision support system (adapted from IBSNAT 1992).

11.4.3 Site suitability analysis

A site suitability analysis typically involves the assessment of the level of affinity a specific land has for a particular land use. Soil information available in soil databases are rarely enough for site evaluations. In addition to soils, the analysis often integrates local information landforms, current land uses, the relative location of the land and associated social and political restrictions. The proposed use may have additional limitations that should be taken into account. For example, an analysis for suitable sites for land application of sewage sludge should, for example, consider the physical, chemical and biological properties of the waste in soils and water.

Sites for various activities have been selected using GIS. Firstly, site-specific analyses often require many and detailed data sources. Secondly, GIS overlay features, logical operations and display functions are tailored to speed up data processing and therefore allow efficiently suitability class assignment and graphical display of results. A good example is the use of GIS for locating appropriate sites for forest land application of sewage waste (Hendrix and Buckley 1992). The authors derived physical site suitability ratings for an area in Vermont based on EPA guidelines (USEPA 1981) and merged them with social and political restrictions of the state and counties to derive a land applicability classification. Similar GIS-based approaches have been used to locate sites for solid waste disposals (Weber *et al.* 1990; Karthikeyan *et al.* 1993).

11.4.4 Standard land evaluation systems

Standard land evaluation systems contain two procedures: biophysical and economic. The biophysical suitability analyses use any of the land capability classification schemes, agricultural productivity ratings or modelling approaches described above. Biophysical land suitability classes may also be derived using land qualities (e.g. erosion hazard, soil water storage) or locally measured/observed land characteristics from sources such as soil databases, remote sensing, geologic maps and DEMs. In this case, numerical values are assigned to suitability ranges of each relevant parameter and land quality. These are combined to yield the overall rating. Suitability classes for ranges of various soil, landscape and hydrologic properties can be found in manuals such as the National Soils Handbook (USDA 1993) or derived by the user based on the knowledge of specific soil behaviour and other land parameters. An economic suitability analysis, on the other hand, includes an evaluation of a land's location in relation to major highways and urban land, and social and economic restrictions of the municipality, county or state.

Many systems have been developed over the years in the agricultural community and in many parts of the world to assist in the land evaluation. An example of such a system is the USDA-NRCS Land Evaluation and Site Assessment (LESA) (Wright *et al.* 1983). LESA was developed to aid planners and public officials at the city, township, county or state level in determining the agricultural quality and economic viability of a farm (Dunford *et al.* 1983; Stamm *et al.* 1987). The land evaluation portion of LESA determines soil productivity levels, farm size and agricultural sales volume; the site assessment portion deals with factors such as location, amount of non-agricultural land, zoning restrictions, etc. (van Horn *et al.* 1989; Daniels 1990). GIS-based LESA systems have also been developed and implemented at county and state levels (Williams 1985; Ferguson *et al.* 1991). LESA and similar systems have been incorporated into many county, state and national programmes in the US, such as the Purchase of Agriculture Conservation Easement programme (PACE) (Christensen *et al.* 1988; Clayville 1994). PACE has been used in farm prioritization programmes such as farmland preservation, taxation and real estate valuation.

A GIS-based land evaluation system, the Comprehensive Resource Inventory and Evaluation System (CRIES), has also been developed (Schultink 1987). The CRIES system uses a grid cell approach to delineate agro-ecological production zones within a GIS and estimates crop production for existing and alternative land uses. It has two inter-linked components: the geographic information system (CRIES-GIS) and the agro-economic information system (CRIES-AIS). The CRIES-GIS component has modules for model parameterization, result display, and other routine GIS-based analyses. The CRIES-AIS has modules for water balance modelling, yield predictions, and linear programming, among others. The system was developed primarily for land use planning applications within the framework of farming systems in developing countries.

Other systems that are commonly used in land evaluations are the Automated Land Evaluation System (ALES) (Rossiter 1990) and the Land Evaluation Computer System (LECS) (Wood and Dent 1983). Both systems are based on the FAO framework of land evaluation. ALES is a PC-based computer program designed to allow land evaluators to build their own expert systems based on the local knowledge of the land. LECS has been implemented in the FAO's Agricultural Planning Toolkit (APT) (Rossiter 1996) and the Integrated Land and Watershed Management Information System (ILWIS) (Elbersen *et al.* 1988) of ITC, The Netherlands. Land evaluation systems may also be part of an SDSS or ES, systems that are designed to aid in the decision-making process.

11.5 LAND USE PLANNING ACTIVITIES AT REGIONAL AND GLOBAL SCALES

Several GIS-based systems have been developed in different countries and regions for land evaluations. In addition to databases, GIS functions and associated programming tools, some systems have modelling capabilities and decision-making tools useful in land resource assessment and evaluations. The FAO Agro-Ecological Zones is an example of such a system (Figure 11.5). Various GIS layers in the agricultural ecological zones are developed from database attributes and combined on a per-grid cell basis to derive model input data for yield simulations, land suitability and productivity evaluations (Koohafkan and Antoine 1997).

Another aspect of regional and global land use planning is the assessment of land quality for use in land and ecosystem assessments and management. Traditional methods for assessing and mapping land soil quality (e.g. soil erosion, soil salinity, and organic matter depletion) are based on observations and laboratory data collected at field and/or watershed scales. Furthermore, measures of composite land qualities such as erosion risk, and the Universal Soil Loss Equation

(USLE), were designed originally to operate at field scales. Today, however, characteristics used in land quality assessments evaluation and subsequently in land use planning can be mapped for large areas using existing digital soil and terrain databases, remotely sensed data and other data sources (Nizeyimana and Petersen 1997). These databases are typically developed by extrapolating field- and watershed-collected data to larger mapping units or by providing links between the spatial data and tables containing interpretation records (Petersen *et al.* 1997).

Results of land quality analyses assist national and international agencies involved in land use planning to understand the regional and global scope of environmental problems such as land degradation (Bliss and Waltman 1994).

A number of countries have developed nationwide geographic soil databases for use in land use planning. In the US, two soil databases described earlier, STATSGO and NATSGO, were designed for use in regional and nationwide environmental resource assessment and planning (Bliss and Reybold 1989), respectively. Soil-based land qualities such as available water storage capacity, organic C storage, acidity, etc., have been mapped using ranges of attribute values from STATSGO (Miller and White 1998) and NATSGO (Kern 1995; Bliss *et al.* 1995) for the entire country. These GIS-derived maps serve to provide a general view of the distribution of limiting or suitable soil attributes to agricultural production in the country. Geographic soil databases have been developed for similar applications in Canada (Kirkwood *et al.* 1996), the Netherlands (DeVries and Denneboom 1993) and Australia (Bui *et al.* 1996). In the latter case, the authors used a regional geographic soil database to determine regional salinization risk resulting from forest clearing in the North Queensland area.

At the continental scale, a soils map of Europe (1:1,000,000 scale) previously compiled and prepared by Tavernier (1985) has been digitized under the Coordinated Information on the European Environment (CORINE) program (Platou *et al.* 1989). The program's objective is the creation of a spatial database on the environment and natural resources of the European communities (Jamagne *et al.* 1996). Its legend is similar to that of the FAO world soil map. Each mapping unit is linked to a soil topological unit that identifies the main soil type whose attribute data are in a relational database. Soil and terrain parameters from this database were used, for example, to generate GIS maps of soil erosion risk for the southern region of the European Community (Bonfils 1989).

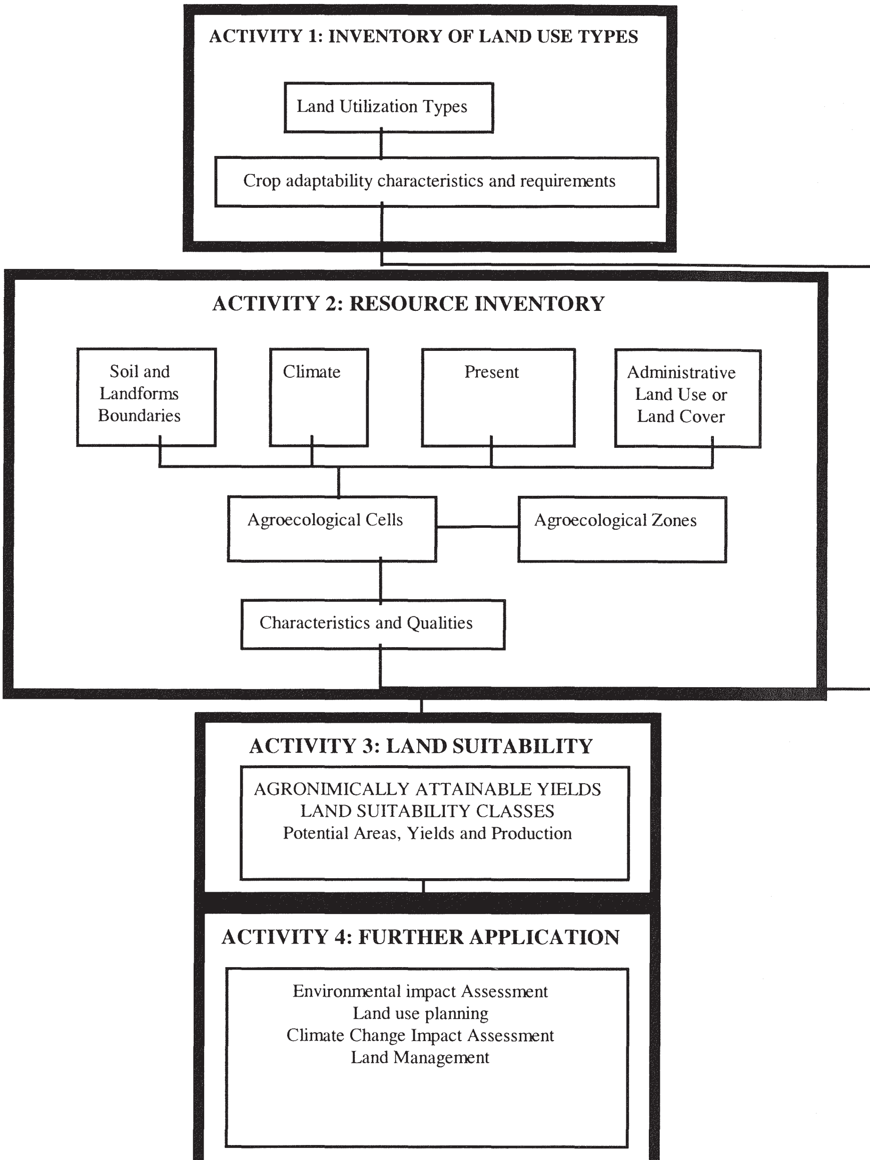

Figure 11.5: Methodology of the FAO Agro-Ecological Zoning (AEZ) core applications (adapted from Koohafkan and Antoine 1997).

At the global scale, a digital soil database has been developed for the entire world (1:5,000,000) by digitizing the FAO/UNESCO soil map of the world (FAO 1995). This GIS coverage consisting of 4930 different map units, has been used to derive land qualities (available water storage, soil productivity potentials, soil degradation potential, etc.) for the US (Kern 1995) and Africa (Eswaran *et al.* 1997). In a similar vein, the development of a more detailed digital database, the World Soils and Terrain (SOTER), has begun under the auspices of the UN/FAO, the International Society of Soil Science (ISSS), and the International Soil Reference and Information Center (ISRIC 1993). SOTER was designed at the 1:1,000,000 scale and accommodates most soil classification systems. Map units in the database are described by one to three terrain components and one to three soils whose characteristics are presented in separate attributes files (Baumgardner 1994).

Owing to the present need for assessing human-induced land degradation, a Global Assessment of Soil Degradation (GLASOD) map that uses SOTER soil and terrain attributes was produced at a scale of 1:10,000,000 through a collaborative project between the United Nations Environment Program (UNEP) and ISRIC (Oldeman *et al.* 1990). GLASOD indicates the geographic distribution of severity of water erosion, wind erosion and physical deterioration such as soil compaction. The information provided by GLASOD is crucial to policy- and decision-makers for establishing priority programs. Other regional and global databases are described in Chapter 4.

11.6 AVAILABILITY AND DISTRIBUTION OF SPATIAL DATA SETS

A number of land information delivery systems have been developed in recent years to make spatial data available to users for application in various aspects of land use planning. These systems are usually designed in a way such that many users can access them at the same time. Some have been linked to the World Wide Web (WWW) for quick and easy access. The data sets may be spatial or in tabular form and are often intended for use in regional or global analyses. An example is the multi-layer soil characteristics data set for the conterminous US (CONUS-SOIL) designed primarily for use in regional climate and hydrology modelling (Miller and White 1998). CONUS-SOIL is based on the STATSGO data and provides soil physical and hydraulic properties including soil textural and rock fragment classes, depth-to-bedrock, bulk density, porosity, rock fragment volume, particle size fractions (sand, silt, and clay), available water storage capacity, and hydrologic soil groups (HSG). Data in CONUS-SOIL are vector or raster (1 km grid resolution) formats and are available for downloading via the Internet or FTP.

During the last few years, scientists have created land resource information systems to develop and update spatial and non-spatial databases and distribute data sets and associated attributes (terrain, land use, etc.) to users. These systems are developed using popular database design software such as INFORMIX and ORACLE, and/or GIS software. GIS-based land resource information systems are multi-purpose systems that integrate geographic databases and GIS tools to analyze, retrieve, record, report and display relationships between data. The type of data in these databases and the complexity of GIS analyses in a land resource information system depends on the intended use of the system. Databases contain data from different sources and scales of application but possess same coordinate system and reference datum for easy integration by users. Table 11.1 shows some of the most recent land resource information systems and their primary functions.

Table 11.1 Most recent land resource information systems and their primary functions.

Land resource information system	Origin	Objectives	Scope	Source
Canadian Soil Information System (CANSIS)	The Centre for Land and Biological Resources Research, Canada	Develop and update spatial soil databases; provide data exchange and distribute digital land resource data	Regional	MacDonald and Valentine (1992)
National Soil Information System (NASIS)	USDA-Natural Resources Conservation Service (NRCS)	Manage and maintain soil data and its dissemination to users	Regional	Soil Survey Division Staff (1991)
ISRIC Soil Information System (ISIS)	International Soil Reference and Information Centre (ISRIC), the Netherlands	Develop soil databases and disseminate soil data	Global	Van der Ven *et al.* (1995)
Global Land Information System (GLIS)	US Geological Survey	On-line descriptive information on the availability status of soils, land cover, terrain data and remote sensing imagery	Global	US Geological Survey (1991)
Land Information Systems (LandIS)	Soil Survey and Land Research Centre, England	Develop and update soil, land cover and related data and its dissemination	Regional	Hallett *et al.* (1996)

11.7 RELIABILITY OF GIS-BASED LAND USE PLANNING RESULTS

GIS analyses for land use planning and EIA have grown in recent years. GIS is particularly attractive in these areas because it allows overlay of spatial data sets and the merging and analysis of attribute data from different sources. The resulting data are obtained using data from digital and paper maps of different scales and/or projections and from data acquired at different resolutions such as in the case of DEMs and remote sensing imagery. The combination of such data layers may produce unrealistic model data and consequently lead to erroneous predictions. The question is how reliable are these results when used for developing land use and management plans. Accuracy of land cover and land use maps, as well as management plans, may be assessed (Skidmore 1999), and the propagation of error and uncertainty in GIS-based analyses is also possible (Heuvelink 1998).

The accuracy of GIS-based land evaluation and EIA is a function of the quality of attribute data and maps, as well as the type of model or assessment scheme used in the analyses. Various algorithms for assessing the quality of GIS results are part of popular GIS and image analysis software (e.g. Arc/Info, ERDAS Imagine), but these tools are frequently not used by GIS practitioners. Similarly, models vary depending on how each represents various processes of the system. Lumped models (see Chapter 2) and indexing/ranking schemes are used mostly in land evaluations because they are easy to parameterize. However, these models ignore spatial variations of parameters throughout the field, watershed or region of study. Furthermore, models originally designed for fields and watersheds are often applied to regional analyses, thus adding some level of uncertainty in modelling predictions. For example, most land use planning programs use conventional methods of land evaluation. Each land parameter is given ranges of values with corresponding ratings showing its suitability to crop production. These indexes are added or multiplied to create a single index that is used to rank land units.

The method is simple but carries a high uncertainty because breaks between two ranges or ranks are subjective.

The effect of map scale and resolution on environmental assessment and modelling output data has been subject to many studies, as illustrated below using DEMs. Raster-based GIS systems require that a grid cell size be defined prior to the analysis. However, as pixel size increases above the resolution of the original data, the spatial variability decreases. This causes a decrease of the predictive power of generated input parameters, particularly for small land areas. An example is the evaluation of DEM cell resolution on hydrologic model input parameters, predicted runoff and peak discharge in watersheds (see also Chapter 9). Studies by Jenson and Domingue (1988) showed that the accuracy and details of watershed boundaries and overland flow paths derived from DEMs depended on the resolution and quality of the DEMs. Chang and Tsai (1991) found that watershed slope gradient decreased gradually as the DEM resolution was varied from 20 to 80 m and differences concentrated in areas of steep slopes. Isaacson and Ripple (1990) reported that slope gradients derived from three arc-second DEM (100 m-DEMs) were lower than those that were determined from 7.5minute DEM for 70 per cent of the total pixel count. Similar results were obtained by Jenson (1991) by comparing ETOPO5, 30 minute-DEMs, and 3 arc-second DEMs. Zhang and Montgomery (1994) and Wolock and Price (1994) showed that increasing the coarseness of the DEM resulted in a decrease in depth to water table and increase in peak flow predicted using TOPMODEL, a topography-based watershed model.

11.8 SUMMARY AND CONCLUSIONS

Environmental scientists provide the information needed to address land use and degradation problems. As the population increases and land becomes a scarce commodity in many parts of the world, carefully planned land uses must be undertaken to accommodate conflicting people's needs and preserve/protect the environment. The decisions about the use of land are made based on analyses of each potential use in terms of its economic and biophysical suitability to the specific tract of land and possible impact to environmental degradation. The definition of the FAO land use planning process has also been extended to include conservation planning and nutrient management planning activities commonly done in the US at farm and watershed levels.

GIS and related technologies (e.g. remote sensing, GPS) have proven to be a valuable tool in land use planning and EIA. The GIS approach is important in these areas because it provides powerful analysis and relational database facilities to modify and/or integrate spatial data from different sources and resolutions. GIS has been coupled to a variety of models (e.g. for crop growth, yield predictions, hydrology and water quality simulations) and is an important component of the spatial decision support system, expert system and land resource information system. In these systems, GIS enhances model flexibility and efficiency. As a result, decision makers and land use planners in local governments, state and regional agencies are using GIS to develop spatial environmental databases, perform land evaluations, and analyze and manage resources.

The demand for GIS and GIS-based analysis systems in land use planning and EIA will increase in the future as more detailed digital environmental data sets become available. Detailed spatial data sets combined with remote sensing, GPS, geostatistics using high capability computers to handle large volumes of data will increase GIS applications in land use planning and management, particularly at scales finer than the farm level.

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