6

Geographic Information System and Its Applications

6.1 INTRODUCTION

During the 1960s and 1970s, new trends emerged in the method of handling and using spatial data for assessment, planning and monitoring. While the concept of superimposing and manually overlaying different resource maps has been in vogue and has been a familiar feature for planners and resource managers, the concept of using computers for making maps and analyzing them was initiated with the Synagraphic Mapping (SYMAP) System (*SYMAP is a Greek term meaning to bring together*), developed by the Harvard School of Computer Graphics in the early 1970s (*Burrough*, 1986). Since then, several automated methods for handling different maps using computers have emerged.

Spatial data analysis is a multidisciplinary, activity concerning hydrology, water resources, geography, urban planning, and earth sciences. Spatial data sets are frequently heterogeneous, having data on soils, water rainfall, infiltration, landuse, topography, forestry, administrative boundaries, population, etc., and often are available at different scales, in different coordinate systems, at various levels of accuracy and areal converges for solving a variety of problems. These data sets may be derived from text, maps, charts, ground information, organizations, aerial photographs and satellite imagery. The management and analysis of such large volumes of spatial data requires a computer-based system called Geographic Information System (GIS) which can be used for solving complex geographical and hydrological problems (*Garg*, 1991).

GIS is defined as a system of computer hardware and software, designed to allow users to collect, manage, analyze and retrieve large volumes of spatially referenced data and associated attributes collected from a variety of sources (*Aronoff*, 1991). GIS is rapidly becoming a useful tool for management of resources (Fig. 6.1), and at present it is difficult to think of a resource planning or mapping without a GIS. Effective utilization of large spatial data volumes is dependent upon the existence of an efficient geographic handling and processing system that transforms this data into usable information.

The GIS is a database system for manipulating digital spatial and thematic data gathered from several sources. The major advantage of GIS is that it is an information system, therefore, the digital database which has been developed at any stage can also be used in future and any related information can be extracted conveniently and efficiently. New information layers/overlays can also be incorporated and maps with newly defined user conditions/constraints can be generated and updated (*Peuquet and Marble*, 1990).

Time series of vegetation or surface water information can easily be preserved in the GIS, to enable monitoring activities to be carried out. However, it is important to establish format and data exchange standards so that the database can be used effectively by agencies concerned with land and water management. Remote sensing is a powerful tool for the collection of spatial data, and GIS is a powerful tool for management and analysis of data required for any land developmental activity (*Garg*, 1991).

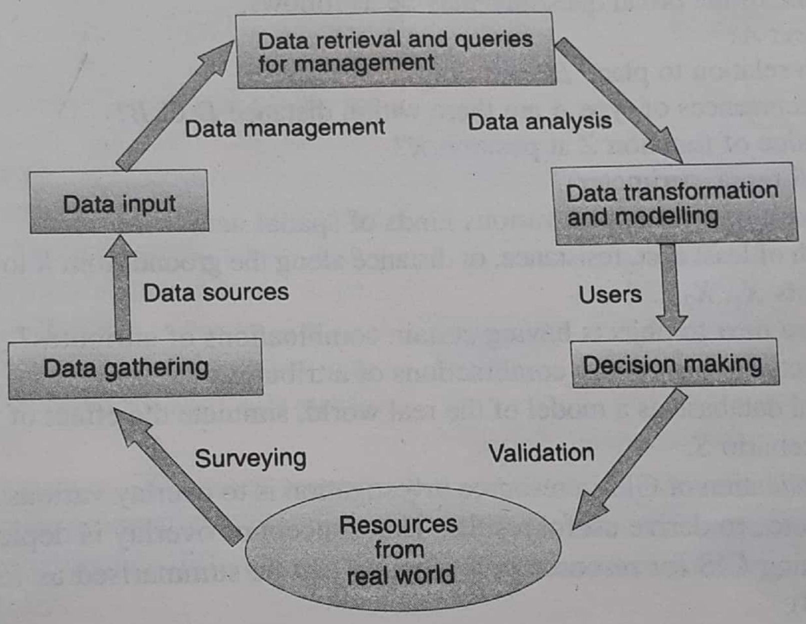

Fig. 6.1 Geographic information system as a management tool

6.2 COMMON APPLICATIONS OF GIS

Geographic Informations Systems have been adapted to many application areas. Some of these are listed below (*Burrough*, 1986).

1. Engineering mapping
2. Automated photogrammetry
3. Sub-division design (cut/fill, street layout, parcel layout)
4. Cadastral mapping
5. Highway mapping
6. Utility/facility mapping and management
7. Surface water mapping
8. Event mapping (accidents, crime, fire, facility breakage, etc.)
9. Census and related statistical mapping
10. Management of watershed and its prioritization
11. Landuse planning and management
12. Environmental impact studies

13. Natural resource mapping and management, including forest management, agricultural management, ecological and biological studies
14. Urban and regional planning
15. Route selection of highway/pipelines.

6.3 ADVANTAGES OF A GIS

The users of GIS can ask unlimited number of questions using combinations of data retrieval and transformation functions. Many of these questions may be extremely difficult to answer using the conventional methods. Some of the broad questions may be as follows.

(a) Where is object *A*?
(b) Where is *A* in relation to place *B*?
(c) How many occurrences of type *A* are there within distance *D* of *B*?
(d) What is the value of function *Z* at position *X*?
(e) How large is *B* (area, perimeter)?
(f) What is the result of intersecting various kinds of spatial data?
(g) What is the path of least cost, resistance, or distance along the ground from *X* to *Y* along pathway *P*?
(h) What is at points X_1, X_2,... ?
(i) What objects are next to objects having certain combinations of attributes?
(j) Reclassify objects having certain combinations of attributes.
(k) Using the digital database as a model of the real world, simulate the effect of process *P* over time *T* for a given scenario *S*.

The most useful application of GIS in resource investigation is to overlay various thematic maps such as rivers, roads, soils, etc., to derive useful results. This concept of overlay is depicted in Fig. 6.2. The other advantages of using GIS for resource investigation can be summarised as follows (*Garg*, 1991, *Meijerink, et al.*, 1994).

1. GIS is a powerful tool for handling spatial data collected from a variety of sources at different scales and resolutions .
2. Large quantities of data can be stored, maintained and retrieved at a greater speed and low cost.
3. GIS is able to manipulate and integrate different types of data in a single analysis which is otherwise an impossible task.
4. It can perform complex spatial analysis providing both qualitative and quantitative results.
5. GIS is extremely helpful in planning scenarios, decision models and interactive processes.
6. It also facilitates the following.
   (a) Overlays of data for the purpose of comparison
   (b) Updating of information to depict change with time
   (c) Change of scale for micro-analysis

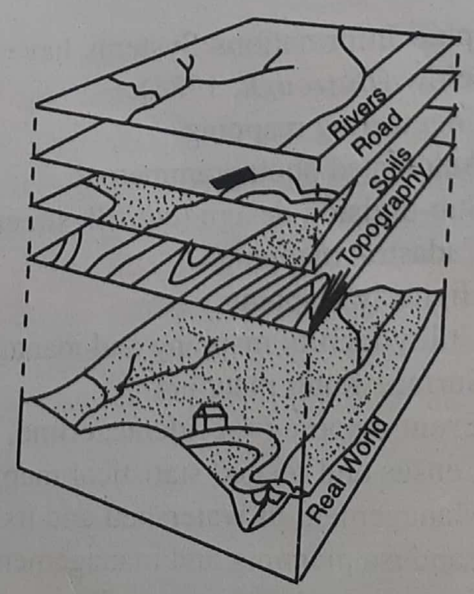

Fig. 6.2 The overlay concept of the real world

(d) Generation/interpolation of data through manipulation of known factors
(e) Incorporation of remotely sensed data for resource mapping, monitoring and management.

6.4 ESSENTIAL ELEMENTS OF A GIS

A GIS consists of two major elements namely hardware and software (*Burrough*, 1986).

6.4.1 Hardware Components

It mainly consists of the processing system and data entry/output system. The major hardware components of the GIS are (Fig. 6.3) as follows.

(a) *Processing unit* This takes care of all the computer-intensive tasks. The data is accessed by the processor from a disk which serves as a data storage unit. Present day platforms for a GIS range from low-end PCs to high-end workstations with a wide range of system capabilities in terms of performance, memory and storage capacity. An ideal PC-based system for a GIS would need to have minimum of 16 MB of memory and 1GB storage space on the hard disk.

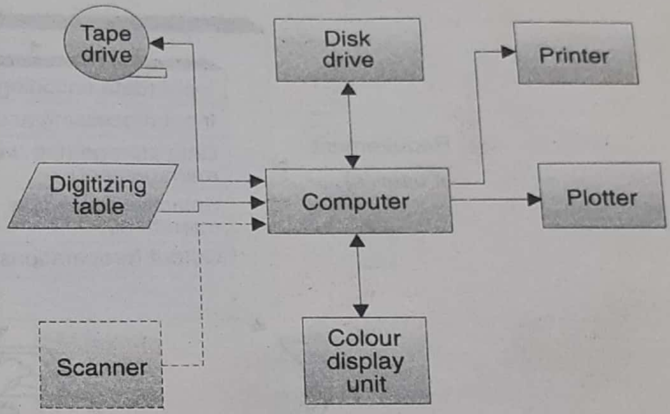

Fig. 6.3 Major hardware components of a GIS

(b) *Spatial data entry system* Digitizer, scanners, etc., are the basic tools for data entry. A wide range of digitizers and scanners are available commercially which are directly compatible with GIS packages. However, there is a considerable difference in the manual operation of digitizers as against the automation provided by scanners.

(c) *Graphic display system* This is the display system where the data can be viewed either while entering and editing or after analysis. Basically this serves as an interface between the user and the processing unit.

(d) *Plotter/printer* This is used for taking cartographic quality output in spatial format. However, a colour inkjet printer and laser printer could also provide output from a GIS.

Apart from the above, a tape drive (or CD drive) and a printer are also parts of the hardware, mainly for data back-up and printing reports, respectively.

6.4.2 Software Modules

Software modules are required for organizing the GIS database, integration operations and processing the output (Fig. 6.4). These modules of a GIS can be classified into following four categories.

(a) Related to data input and editing
(b) Related to database management
(c) Related to analysis/ transformation/ manipulation
(d) Related to data display and output.

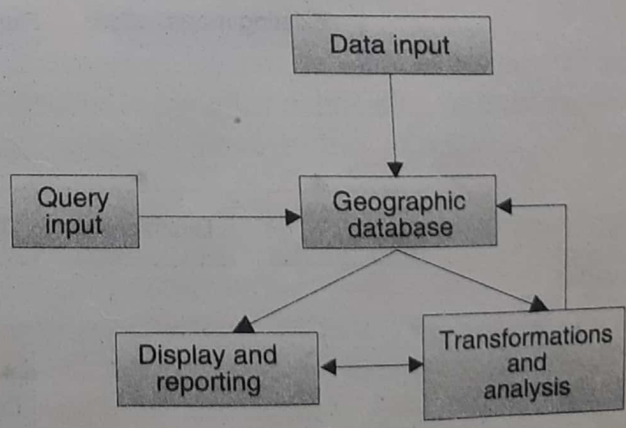

Fig. 6.4 Major software components of a GIS

Various subsystems of a GIS, are shown in Fig. 6.5, whereas above four categories are briefly explained below.

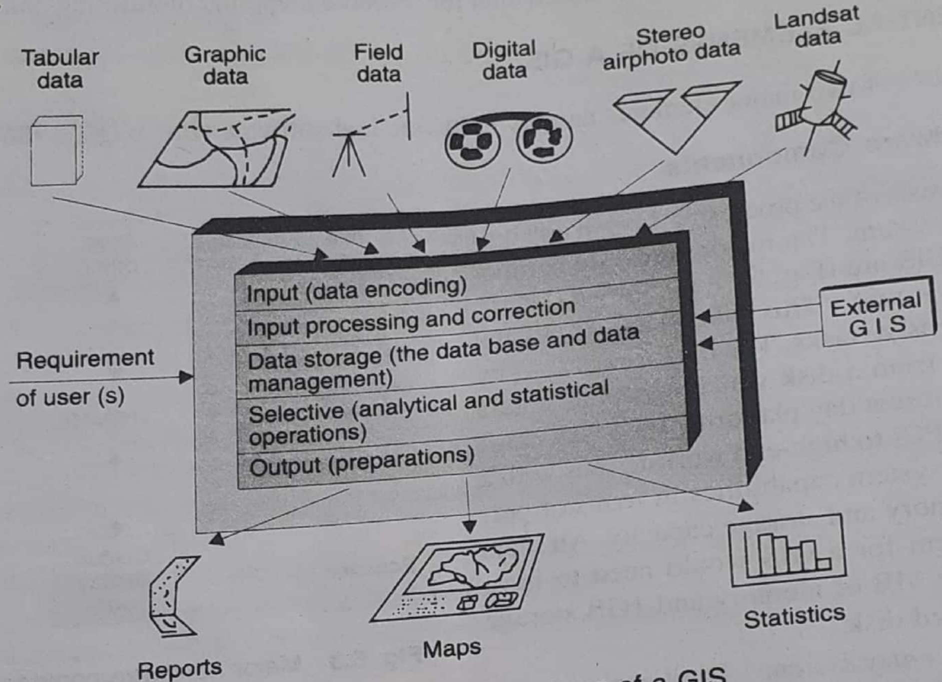

Fig. 6.5 Various sub-systems of a GIS

Data Input

Before any spatial analysis or modelling operations can be carried out in a GIS, it is necessary to feed it with the requisite data. Data input is the procedure of encoding data into a computer-readable form and writing the data to a GIS database. Data should be reliable, and should have information, such as date of collection, and the method used to collect and encode the data. It is essential that the data should be accurate and sufficiently comprehensive.

Broadly categorized, the Earth-surface data for any GIS application can be derived from various sources, as shown in Fig. 6.6. This data has two major components (*Aronoff*, 1991):

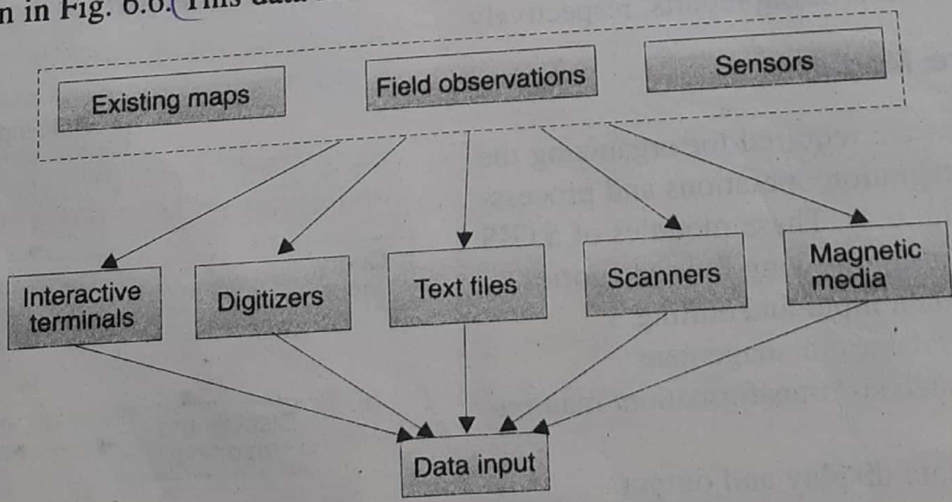

Fig. 6.6 Sources of data input

1. *Spatial Data* It consists of maps which have been prepared, either by field surveys or by the interpretation of remotely sensed data. Some examples of such maps are the soil map, geological map, landuse map, village map, etc. Many of these maps are available in analog form and some map information is available directly in digital format. Thus, the incorporation of these maps into a GIS depends upon whether it is in analog or digital format, each of which has to be handled differently. This data can be reduced to three basic topological concepts, as described below and as shown in Fig. 6.7.

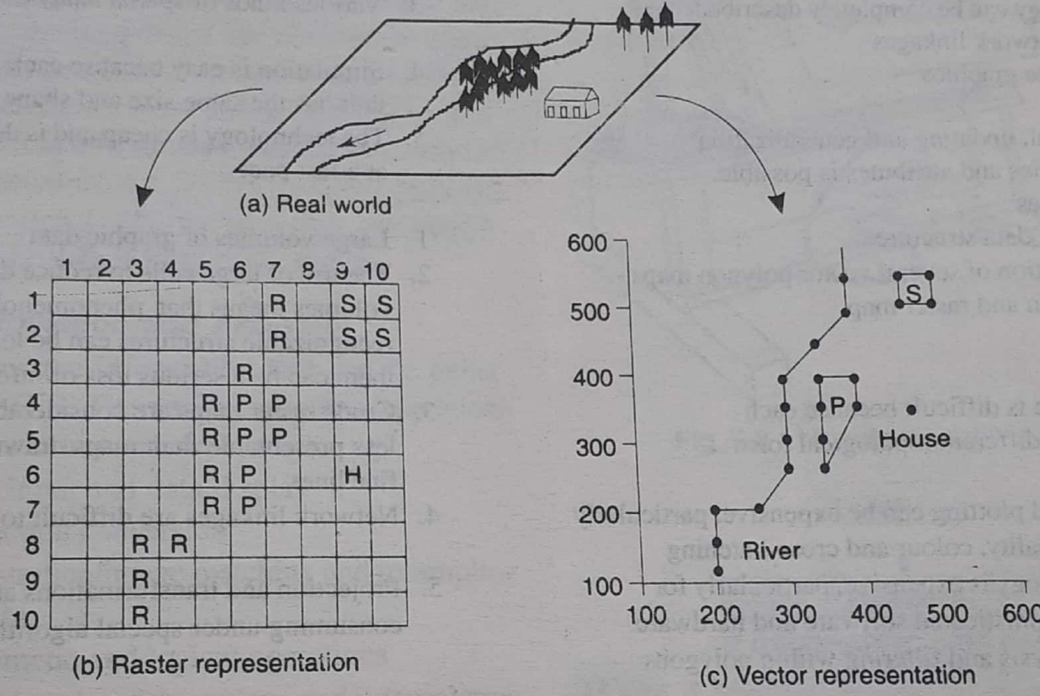

Fig. 6.7 Representation of point, line and aerial data in raster and vector form

(i) *Point data* It consists of observations that occur only at points, or occupy very small areas in relation to the scale of the database. Features such as wells, rainfall stations, buildings, etc. may be represented as point data.

(ii) *Line data* Line data is exemplified by features such as highways, rivers, elevation contours, pipelines or power lines. Vector-based GIS systems can show line data in fine detail, whereas raster-based systems depict a linear feature only as a chain of grid cells.

(iii) *Areal data* It includes soil, land cover, water bodies, vegetation and objects that occupy an area at the working scale of a GIS. Vector-based systems provide detailed delineation of boundaries of the classes, whereas the use of raster-based systems inevitably involves loss of information as the data is encoded at each grid cell.

Table 6.1 lists the advantages and disadvantages of features represented in both vector and raster forms.

2. *Non-Spatial Data* It consists of attributes that are complementary to the spatial data, and describes what is at a point along a line or in a polygon. The attribute usually represents the properties or characteristics of the spatial data which may include socio-economic characteristics from census or from other sources. For example, the attributes of a soil category could be the depth of soil, texture, erosion, drainage, etc., and for a geological category, they could be the rock type, its age, major composition,

Table 6.1 A comparison of vector and raster data

Vector data	Raster data
Advantages	
1. Good representation of phenomenological data structure	1. Simple data structure
2. Compact data structure	2. The overlay and combination of mapped data with remotely sensed data is easy
3. Topology can be completely described with network linkages	3. Various kinds of spatial analyses are easy
4. Accurate graphics	4. Simulation is easy because each spatial unit has the same size and shape
5. Retrieval, updating and generalization of graphics and attributes is possible.	5. The technology is cheap and is developing at a fast pace.
Disadvantages	
1. Complex data structure	1. Large volumes of graphic data
2. Combination of several vector polygon maps or polygon and raster map	2. The use of large cells to reduce data volumes means that phenomenologically recognizable structures can be lost and there can be a serious loss of information
3. Simulation is difficult because each unit has a different topological form	3. Crude raster maps are considerably less presentable than maps drawn with fine lines
4. Display and plotting can be expensive, particularly for high quality, colour and cross-hatching	4. Network linkages are difficult to establish
5. The technology is expensive, particularly for the more sophisticated software and hardware	5. Projection and transformations are time-consuming under special algorithms.
6. Spatial analysis and filtering within polygons is impossible	

etc. The socio-economic characteristics could be the demographic and occupation data for a village or traffic volume data for roads in a city.

The non-spatial data is mainly available in tabular records in analog form and needs to be converted into digital format for incorporation in GIS. The 1991 census data of the country is now available in digital mode and thus its direct incorporation in a GIS database is possible.

Maps or photographic data (spatial or non-spatial) can be fed to the GIS by converting it into a digital form, using any of the following devices.

(i) *Manual digitizing* Manual digitizing techniques involve the use of an electro-magnetic, electro-static device called a digitizer. The digitizer converts movements of a cursor or 'point locator' into electrically identified locations which are read directly into the computer. Digitizers are usually designed to be very accurate and can be interfaced with a minicomputer to capture data in varying formats of points, lines and polygons. The digitizer can record the position of each point, line, or polygon in either a point by point mode or by a continuous mode, incrementing by time or by distance moved by the cursor on the digitizing table. Figure 6.8 illustrates the line diagram of a digitizer.

(ii) *Digital scanning* Automated scanner technology typically operates in the form of raster scan, measuring binary (on/off) values of the points, lines, polygons, and textural data appearing on a map. A scanner is able to convert the image on paper, or any other such medium, to an electrical form which can be stored directly on the computer in digital values. This is made possible by the sensors installed in the scanner that scans the entire document by virtue of the light reflected by the document.

Database Management

A Database Management System (DBMS) comprises a set of programs that manipulate and maintain the data in a database (Fig. 6.9). DBMS manages the storing of data in an orderly manner and ensures that the integrity of the database is maintained. It acts as a central control over all interactions between the database and the application programs, which in turn interact with the user. One of the major benefits of a DBMS is that it provides data independence; i.e., the user does not need to know how the data is physically stored.

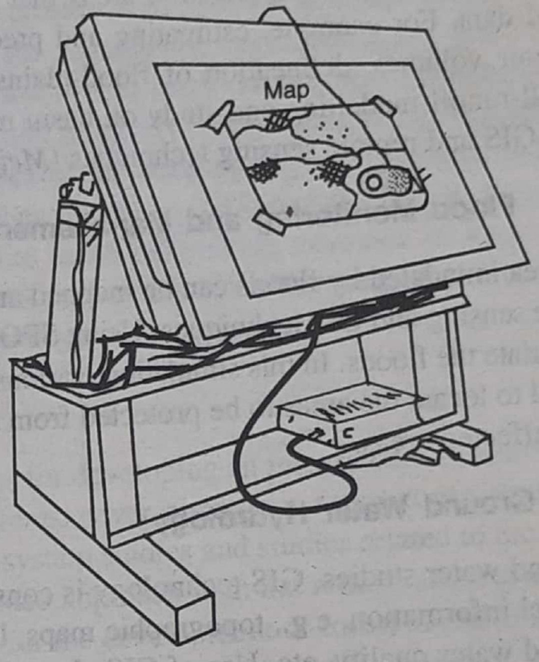

Fig. 6.8 Manual digitizer

Data Manipulation and Analysis

It determines the information that can be generated by the GIS. The various possible operations on a GIS are summarized below.

1. Data input and data display
2. Projection conversion
3. Registration/image matching and resampling of data
4. Arithmetic and logical operations
5. Neighbourhood operations and interpolation
6. Overlay analysis and area analysis
7. Proximity/corridor analysis
8. Vector-to-raster conversion
9. Windowing and clipping
10. Modelling operations

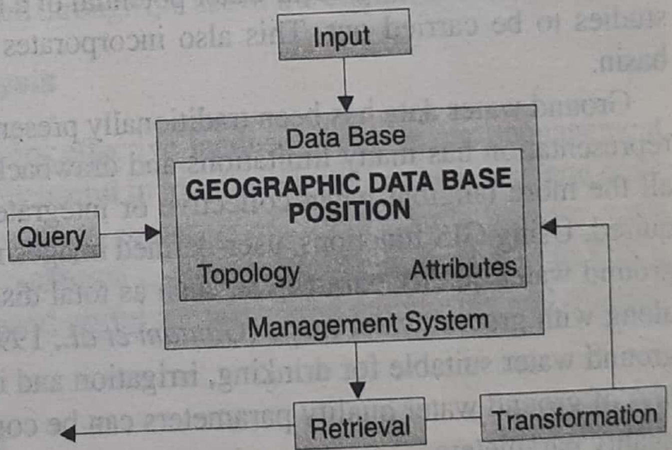

Fig. 6.9 Database management system of a GIS

Data Output

The processed output data from a GIS can be taken in several forms; hardcopy, softcopy or electronic (Fig. 6.10). Hard copy outputs are permanent means of display, and can be printed on paper, mylar, photographic film or others. Maps and tables are common output in this format. Softcopy output is the display as viewed on a computer monitor, such as text or graphics. Output in electronic format consists of computer compatible files. These files are usually stored on a magnetic medium, such as a floppy, magnetic tape compact disk.

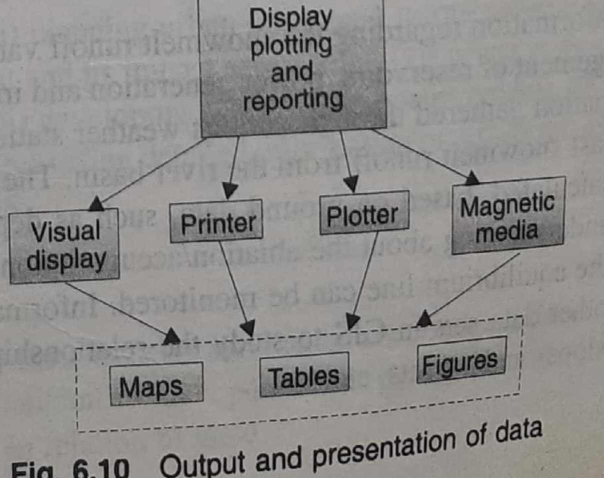

Fig. 6.10 Output and presentation of data

6.5.4 Wetland Management

A primary requisite to management and protection of wetlands is an accurate map and inventory. Any inventory necessarily includes the area and volume of the water body, vegetation types, patterns and water movement directions. Integrated GIS offers a useful tool to carry out this type of inventory because wetland studies are generally conducted for large and relatively inaccessible areas. An additional aspect of wetland management involves the study of the extent of dredging, lagoons, drainage and other man-induced changes that have an impact on the natural environment. GIS is well-suited to take inputs from remote sensing and to monitor these changes and to make preliminary estimates of the environmental impact (*Maidment*, 1993). The simulation capabilities of the GIS allow to predict any impact from developmental activities in the area and its surroundings.

6.5.5 Forest Management

Remote sensing has proved to be a very effective means for developing an integrated GIS which could meet the challenges of managing forests. The extent of forest cover, changes in forest cover, strategy for forest resource protection and conservation, forest eco-system studies and studies related to the forest's role in climate, all can be effectively studied by integrated approach with the remote sensing and GIS. Since climate and terrain have significant roles to play for the development of forest cover, GIS can be used to establish a relationship between these parameters. The extent of forest fires and the resulting damage, as well as preventive measures can be suggested through the use of the complete database in GIS.

6.5.6 Landuse and Land Cover Change Analysis

Timely and reliable landuse information is essential for effective landuse planning and management. GIS supported by remote sensing has proved extremely useful in monitoring the landuse and land cover changes, as well as to update the existing landuse maps (*Gautam, et al.*, 1994). Such landuse maps, combined with the slope, irrigation facility and soil condition can be overlaid and modelled in GIS to derive an optimal landuse plan. GIS has also been found useful for wasteland monitoring and management.

6.5.7 Urban Sprawl Mapping and Monitoring

Remotely sensed data has been found to be of great value in providing the latest information on urbanization and industrialization. This data base can be stored in GIS and can be used for (i) studying urban sprawl/growth trends, (ii) monitoring urban landuse, (iii) planning urban utility and infrastructural facilities, (iv) urban landuse zoning, (v) urban environment and its impact assessment, (vi) urban population estimation, (vii) studying urban hydrology, and (viii) developing urban management models. IRS PAN data with 5.8 m ground resolution is very useful in providing detailed information on urban related aspects, which shall be a major input for analysis in GIS.

6.5.8 Land Suitability Analysis

Land suitability analysis is done on the basis of similar characteristics and related economics and environmental implications and conditions with respect to suitability for a permanent productive task. Its evaluation is related to benefits obtained from the land in relation to yield.

The GIS approach which permits variables to be stored as layers of information provides a powerful mechanism for manipulating and modelling the variables to assess the potential of land. The suitability of land is determined by minimising or maximizing the parameters or through an iterative process in GIS (*Aronoff*, 1991). This analysis is extensively done in the field of agriculture to assess the suitability of land for a particular kind of use in terms of crops, kinds of irrigation and for management of land, etc. Land suitability analysis using remote sensing and GIS requires clear definition of the problem and a decision on the data requirement. Remote sensing and GIS techniques also provide an effective tool for monitoring the positive effects after the land suitability program has been implemented.

6.5.9 Land Degradation

Land degradation by water erosion, sedimentation and deterioration of water quality by point and non-point source pollution is a major issue of environment. The scope of GIS for soil erosion studies includes not only overlaying exercises but also analyzing the effects of topography, meteorology and environmental factors on erosion. The use of GIS and DEM provides the means to compute spatially referenced reservoir volumes, including loss of storage capacity due to sedimentation. A bathymetric contour map of a reservoir is converted to digital bathymetric surface using digitizing, vector to raster conversion and contour interpolation GIS techniques.

During the calibration of a ground water model, the GIS could be effectively used. Both point and non-point pollution sources may be overlaid with the intake and the discharge areas, as derived by ground water modelling. By overlaying maps of perennial drainage channels, marshy areas, agricultural fields, agrochemical loading and hydro-geological data, a composite map may be prepared, showing the position where pollutants enter the ground water flow system (*Meijerink, et al.*, 1994).

6.5.10 Watershed Management

Watershed monitoring and management has been found to be economical and faster with the usage of the capabilities of a GIS. Erosion and sediment yield from the watershed can be assessed using a suitable model in raster GIS (*Garg*, 1991). On the basis of erosion and other environmental parameters, watershed prioritization can be carried out in the GIS. Changes in various resources within the watershed can be effectively studied and the affected areas can be located on GIS derived maps. For better management of land resources, a composite land development index can be established within a GIS.

6.6 SALIENT FEATURES OF SOME GIS PACKAGES

At present, a number of GIS packages have been developed within the public and private sector. Some packages are application specific while others are more generic in nature. Figure 6.11 shows the connection between a GIS and other related application software. Users will often be able to apply existing systems directly to their applications, eliminating the need for costly system development work.

Development within the GIS field is a continuous process. This trend is challenging the question of GIS implementation from one of developing a system to meet user requirements, to one of selecting the best existing system or combination of systems that meets user needs. Table 6.2 lists some commercially available GIS software.

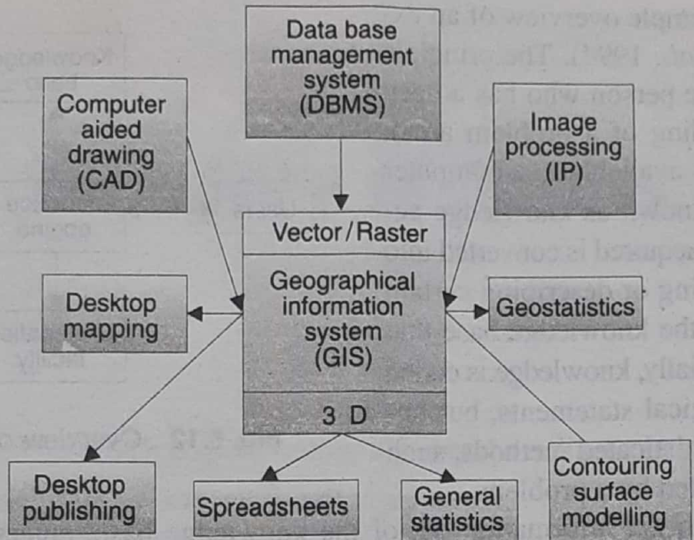

Fig. 6.11 GIS and other related software system

Table 6.2 Some commercially available GIS software

S. No.	System name	Computing environment	First installed	Data structure
1.	ARC/INFO	DEC, PRIME, DG, IBM, PCs, etc.	1981	Vector
2.	CRIES-GIS	PCs/DOS	1978	Raster
3.	ERDAS	PCs/DOS, SUN/UNIX/VAX/VMS	1979	Raster
4.	GIMMS	Mainframe, Minis (under UNIX) PCs/DOS, Macintosh	1970	Vector/ Raster
5.	GRASS	SUN, MASS COMP/UNIX, etc.	1985	Vector/Raster
6.	IDRISI	PCs/DOS	1987	Raster
7.	IMAGE	PCs/DOS	1989	Vector
8.	ILWIS	PCs/Work stations	1984	Vector/Raster
9.	MAP II	Macintosh	1989	Raster
10.	MAPINFO	Windows/SUN/Work stations	1989	Raster
11.	Micro Station GIS	Intergraph/UNIX	1989	Vector/ Raster
12.	MIPS	PCs/DOS	1987	Vector/ Raster
13.	MOSS	DG, PRIME	1977	Vector/ Raster
14.	PMAP	PCs/DOS	1980	Raster
15.	SPANS	PCs/DOS	1985	Vector/ Raster
16.	STRINGS	PCs/DOS	1979	Vector
17.	TIGRIS	Intergraph/UNIX	1988	Vector/ Raster
18.	USE MAP	PCs/DOS	1973	Vector/ Raster
19.	Win GIS	Windows/NT	1990	Vector

6.7 EXPERT SYSTEMS AND GIS

Expert systems are computer-based systems designed to assimilate the knowledge of human experts, making that knowledge conveniently available to others in a useful way. Since early 1980s, expert systems have witnessed increased attention in various disciplines.

Figure 6.12 shows a simple overview of an expert system (*Gautam, et.al.*, 1994). The principle is that the expert (i.e., the person who has a deep and thorough understanding of a problem area), makes his/her knowledge available to a computer program. This phase is known as knowledge acquisition. The knowledge acquired is converted into sets of rules for recognizing or describing certain entries that may exist in the knowledge base that the system can access. Initially, knowledge is coded in the form of formal logical statements, but humans use much more sophisticated methods, such as analogy, when confronted by a problem.

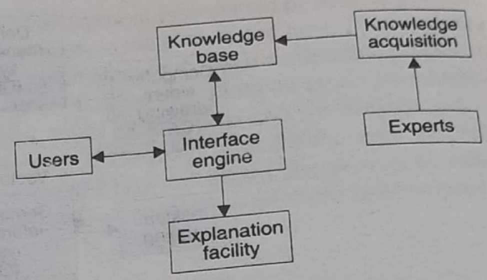

Fig. 6.12 Overview of an expert system

The user, who wants to get information out of the knowledge base, enters the queries through a program known as an inference engine. This module has the task of converting the user's requirements into a set of formulated queries that can be used by the acquired knowledge to process the knowledge base. The inference engine also has an explanation facility which can tell the user why it is searching for particular kinds of entities.

Expert systems have been developed and used in several fields, notably landuse classification, geological exploration and digital image processing.

An expert system could be used to pool information from the real experts on a world-wide or continent-wide basis, so that the users instead of following inappropriate methods, could benefit from the expert advice available.