GIS FOR BEGINNERS

THINKING SPATIALLY

"The most incomprehensible thing about the world is that it is comprehensible."

—Albert Einstein

Floods in Kathmandu

This year's monsoon has brought more rain than usual to the country—even in Kathmandu, where the increasing population and the scarcity of land means that too many homes are being built on farms and lowland, without regard for either sustainability or susceptibility to disaster.

Although the Bagmati and the Bishnumati are the two major rivers flowing through the Kathmandu valley, it is the Tukucha and Samakhusi rivers that give trouble more frequently—their banks have been heavily built up with large buildings and squatter settlements.

Seeing this story, a person who is familiar with Kathmandu can visualize the scenario. He knows these problem areas, how these localities look, and the types of houses that are prevalent in these areas. This is called a "mental map." It is generated from information stored consciously or unconsciously in a person's brain over the years. However, mental maps are not sufficient if we want to understand the problem in more detail or devise a remedy. Planners, engineers, and construction workers need maps and drawings to guide them. But sometimes maps alone are not enough. Super maps, capable of storing and displaying vast amounts of data, have become increasingly necessary.

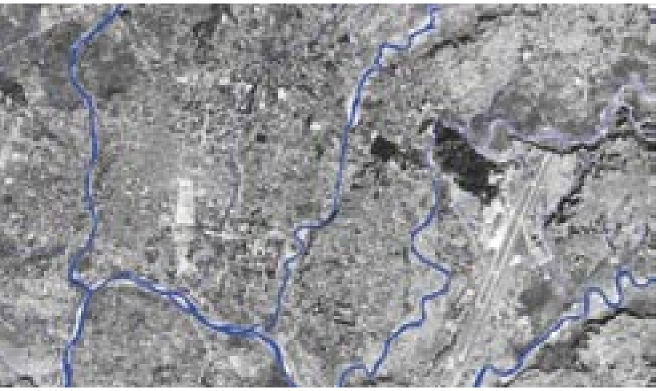


Figure 1: Kathmandu valley from space, with rivers overlay.

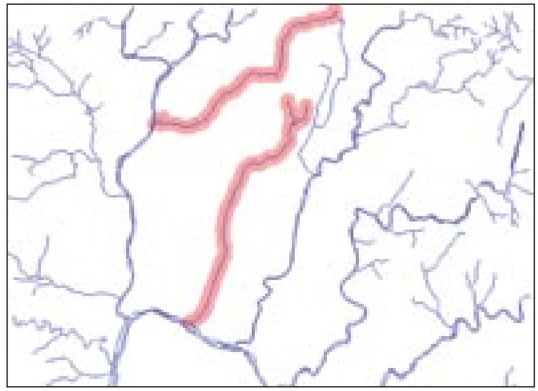


Figure 2: Area within 150 meters of Tukucha and Samakhusi Rivers.

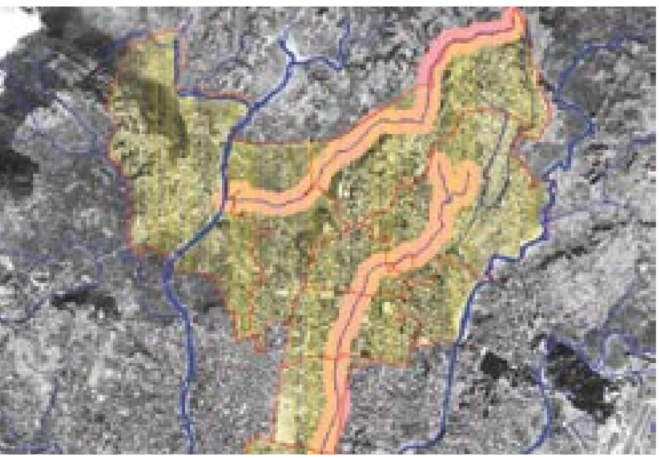


Figure 3: Wards that are intersected by the buffer zone.

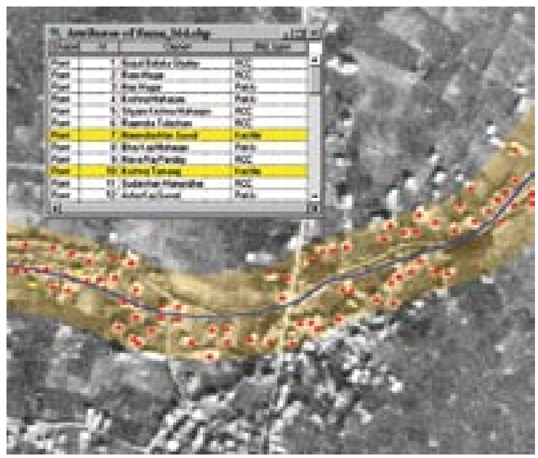


Figure 4: List of households within the buffer zone.

To find the areas that are most likely to be affected by floods, let's demarcate the area within 150 meters of these rivers (figures 1 and 2). This buffer area can be considered as the flood-prone zone. Now, if we want to make plans to improve the situation, we need to involve local bodies such as the ward offices. We should identify the stakeholders; these are the wards falling in these flood-prone areas and the households that are likely to be affected by flooding. For this, we need to identify the wards and then the households that lie within the buffer zone (figures 3 and 4).

When we do so, we are engaging in spatial reasoning, the essential human factor in any GIS.

Buying a new house

People from all over Nepal migrate to Kathmandu valley looking for jobs (figure 5). After some time, they think of buying a piece of land and building a house. However, there are many constraints to overcome before this dream can come true.

The first thing is to find suitable land. With the rapid urban expansion in the valley, it is becoming more difficult to find good places for living. People have their preferences, but there are common issues that need to be considered.

The land should be close enough to basic infrastructure such as roads, water, and electricity supplies. In Kathmandu, facilities such as water and electricity are dependent on accessibility to roads. Figure 6 shows the area within 500 meters of major roads.

We have already seen that there are places in the heart of the Kathmandu valley that are frequently affected by floods. Figure 7 shows the area at least 500 meters from major rivers.

Also, the land should be safe from natural hazards, such as landslides, that occur on steep slopes. The area that has a slope greater than ten degrees is shown in figure 8. This land would not be suitable for building purposes.

Excluding all land that is not suitable because of road, river, or slope criteria, we find the area that is suitable for residence building (figure 9).

We have used information based on geographic features—rivers, roads, and slope—and their relationships to solve our problem.

Figure 5: Kathmandu valley.

Figure 6: Area within 500 meters of major roads.

Figure 7: Area at least 500 meters from major rivers.

Figure 8: Areas with steep slopes.

Figure 9: Area suitable for building.

Let's have a broader outlook

So far, we have discussed our desire to build a house and the need for improvements in the urban environment of Kathmandu valley. However, what is the scenario if we look at the country as a whole? We know that there is a lot to be done in all sectors and all regions of the country to improve the livelihoods of the people. However, with our limited resources it is not possible to meet all the needs at once. How then do we identify the most pressing needs?

Let us plot these figures on a map and see how it looks (figure 10).

Similarly, we can look at the indices for poverty and deprivation, women's empowerment, socioeconomic and infrastructural development in Nepal on a map (figures 11, 12, and 13).

We can see that when we plot values on a map, things become clearer and it is easier to make decisions. In this example, we can see that the situation in the far western region is the poorest in all indices. Therefore, greater focus is needed on development in this region.

What we see here is that when we add a spatial or geographic component to our analysis, we have a better picture of the real-world scenario. This is often called "spatial thinking." It gives us better insight of our problems and allows us to make better decisions.

The use of computerized information systems is a growing part of our everyday life. GIS is one such system that uses the power of computers to answer questions related to location by arranging and displaying data about places in a variety of ways, such as maps, charts, and tables. In the following chapters, we will discuss more about maps, mapping, and GIS.

Figure 10: Gender imbalance ratio in literacy status.

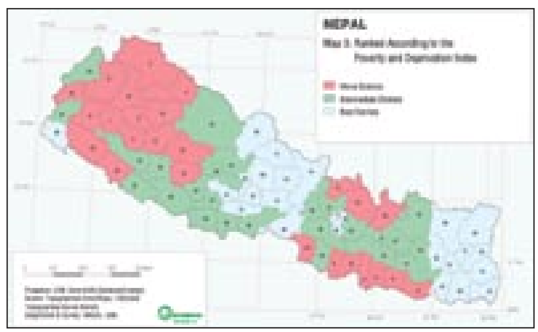


Figure 11: Poverty and deprivation index.

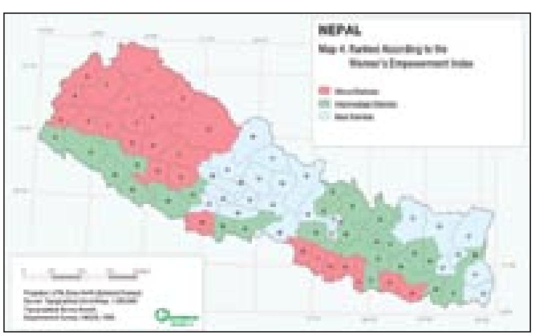


Figure 12: Women's empowerment index.

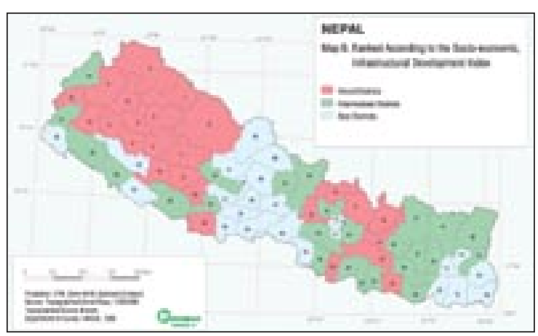


Figure 13: Socioeconomic and infrastructural development index.

YOU AND MAPS

"A journey of a thousand miles starts in front of your feet."

—Lao Tzu

After going through the examples in the previous section, you have probably noticed one thing—we used lots of maps to give a clear picture of the areas discussed. We have seen that maps are powerful means of conveying messages related to places or location. Now let us look at maps in more detail.

A map is a picture of a place. It gives you a better understanding of that place. It is a two-dimensional representation of a particular place. Maps are made for many reasons and, therefore, they vary in content and context. Different maps show different information. Different symbols are used to represent the features of the environment on a map. These features are explained in a map's legend.

Some examples

A PHOTOGRAPH

A photograph shows a place as our eyes see it. However, the area that is viewed on the ground is limited. It is often difficult to see a substantial landscape in one photograph.

AERIAL PHOTOGRAPH

A photograph taken from an aircraft is known as an aerial photo (figure 14). These photographs are normally taken to prepare maps of an area. Aerial photographs give a "birds-eye" view of the earth's surface. Features on Earth look different from above; consequently, field experience is needed to make correct interpretations of these photographs.

Figure 14: Aerial photograph.

SHADED RELIEF MAP

A shaded relief map shows how an area looks when sunlight is shining on it from a particular direction (figure 15). It gives an impression of the nature of the terrain. We can visualize whether an area is plain or rugged by looking at these maps.

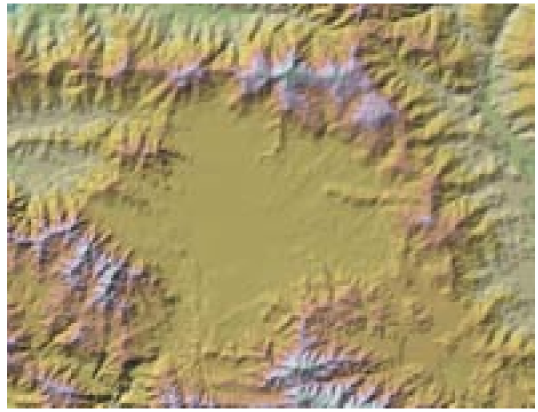


Figure 15: Shaded relief map.

TOPOGRAPHIC MAP

A topographic map (figure 16) shows the shape of the earth's surface by contour (elevation) lines. Contours are the imaginary lines that join points of equal elevation on the surface of land above or below a reference surface such as mean sea level. These maps include symbols that represent features such as streets, buildings, rivers, and forests. Topographic maps are used by most applications as the base map on which other features or phenomena are referenced.

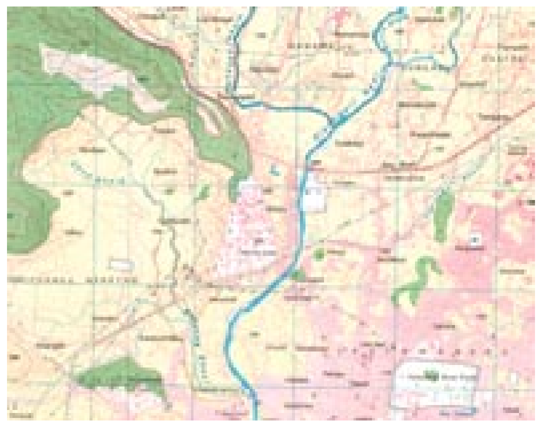


Figure 16: Topographic map.

ROAD/TOURIST MAP

Road maps show people the route for travelling from one place to another. They show some physical features such as rivers and forests, and political features such as cities and towns (figure 17). Normally, tourist maps emphasize the locations of monuments and tourist spots.

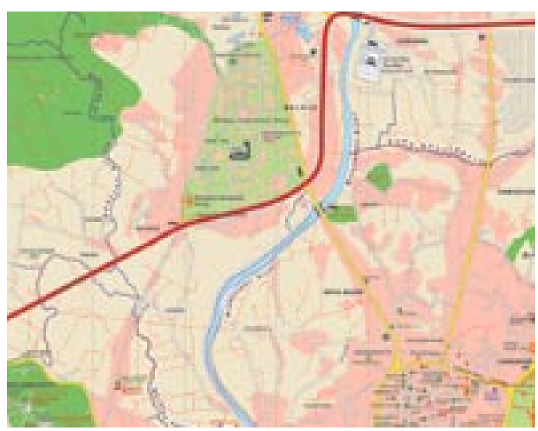


Figure 17: Road/tourist map.

3-D MAP

3-D maps show a landscape in three dimensions (figure 18). They help us visualize an area as a continuous surface that rises and falls, showing the high and low values of the elevation.

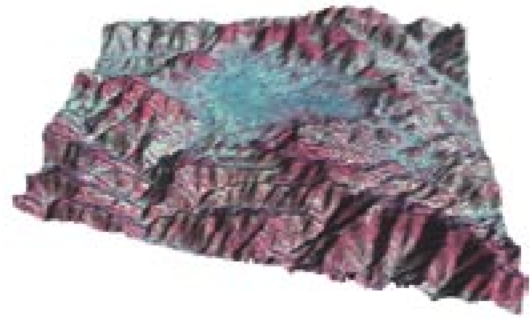


Figure 18: 3-D map.

Use of maps

Maps give us a better understanding of a place. The information they contain depends on the type of map. However, maps are used to obtain answers to the following fundamental questions.

LOCATION: WHERE ARE WE?

We sense our surroundings visually and attempt to locate ourselves with relation to visible features in our surroundings. We use rivers, mountains, buildings, trees, and other landmarks as references to where we stand. Similarly, we also think of places in terms of other places. For example, you know where you live relative to your friends' houses, your school, and the supermarket you visit.

Since these features are depicted on a map, with their positions relative to each other, we can locate ourselves by relating these features on the map and these features in our surroundings. To know exactly where we stand in a more scientific way, maps also provide information on latitude and longitude, the coordinate system to measure all places on the earth.

NAVIGATION: WHERE ARE WE GOING?

Traveling is part of our daily life, whether it is going from our house to school or going from one city to another. Travel depends on skills of navigation; this is the ability to find a route from one place to another and back. Maps have been used as an aid for navigation since ancient times. From a tourist in a new town to the pilot of a fighter jet, everybody uses maps and navigation charts as a guide to reach to their destinations.

INFORMATION: WHAT ELSE IS HERE?

Apart from road maps and topographic maps that help us locate ourselves and navigate, there are many other types of maps, which are made for conveying information on a specific topic. These are known as thematic maps. These maps are made for a purpose. Maps of rainfall, temperature, earthquake zones, household incomes, or spread of typhoid are thematic maps that give us information on a theme in the area concerned.

EXPLORING: WHERE DO WE GO FROM HERE?

With developments in science and space technology, the making of maps and expansion of their uses has made great progress in the last few decades. Developments in data acquisition techniques—such as remote sensing, digital photogrammetry, and global positioning—and the graphic capabilities of computers have greatly changed mapping techniques and practices.

Mapping technologies are being used in many new applications. Biological researchers are exploring the molecular structure of DNA, or mapping the genome; geophysicists are mapping the structure of the earth's core; oceanographers are mapping the ocean floor; and so on. Mapping techniques are even being used to explore the relationships between ideas in what is known as concept mapping.

MAP READING

Reading a map means interpreting colors, lines, and other symbols. Features are shown as points, lines, or areas, depending upon their size and extent (figure 19). Besides recognizing features, knowing their locations and relative distances is also important. Map symbols and map scale provide this information.

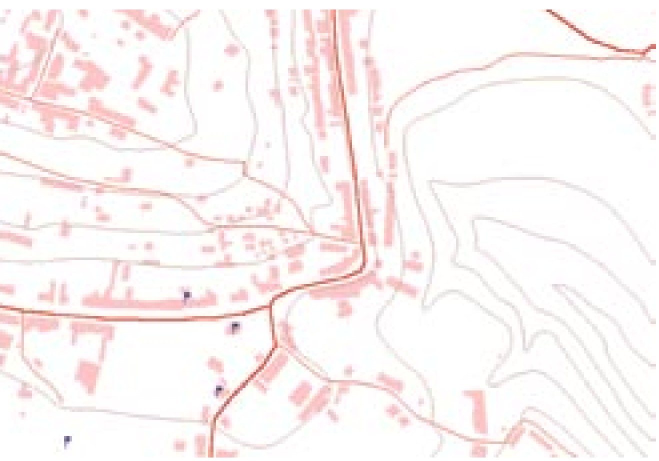


Figure 19: Types of map features.

POINT FEATURES

Point features, or geographically defined occurrences, are features whose location can be represented by a single x,y or x,y,z location. Points have no linear or area dimensions but simply define the location of a physical feature—control point monument, sign, utility pole—or an occurrence such as an accident.

LINE FEATURES

Lines represent features that have a linear extent but no area dimensions. Centerlines of roads, water mains, and sewer mains are examples of line features.

AREA FEATURES

Area features, also called polygons, have a defined two-dimensional extent and are delimited by boundary lines that encompass an area. Typical area features are maintenance districts and soil types.

THREE-DIMENSIONAL SURFACES

Some geographic phenomena are best suited to representation in three dimensions. The most common example is surface terrain, often represented by contour lines that have an elevation value. This concept can be applied to other spatially continuous data as well. For instance, population density or income levels could be mapped as a third dimension to support demographic analysis or water consumption statistics.

SCALE

Map scale describes the relationship between mapped size and actual size. It is expressed as a relationship between linear distances on the map and corresponding ground distance. Two methods of notating scale are commonly used.

Inch–foot equivalent: The scale relationship is expressed as 1 inch = × feet, in which the map distance of 1 inch equates to its corresponding ground distance.

Representative fraction (RF): This is a pure fraction that represents the ratio of map distance to ground distance without specifying any measurement unit. The inch–foot equivalent of 1 inch = 100 feet is represented in RF form as 1:1200 or 1/1200.

Large-scale maps cover small areas and usually include a greater level of detail than small-scale maps that depict larger areas in lesser detail. There are no precise definitions for large or small scale but, for most map users, the following general scale categories apply.

Large scale: 1" = 50' to 1" = 200'
(1:240 to 1:1200)

Medium scale: 1" = 100' to 1" = 1000'
(1:1200 to 1:12,000)

Small scale: 1" = 1000' to 1" = 5000'
(1:6000 to 1:60,000)

Very small scale: 1" = 5000' and smaller
(1:60,000 and smaller)

SYMBOLS

The meaning of each symbol used in a map is described in the map's legend. However, many symbols in topographic maps have become conventional and can be interpreted without looking at the legend. For example, an area feature shown in green is vegetation, blue is water, and a built-up area is grey or red. Similarly, many line symbols such as curved, dashed, dotted, or a combination are used to show various features. Usually the contours are brown, streams and canals are blue, roads are red and black, and borders are black dash-dots. Various point symbols are used to show schools, hospitals, temples, and so on. Figure 20 presents some of the standard symbology used in mapmaking.

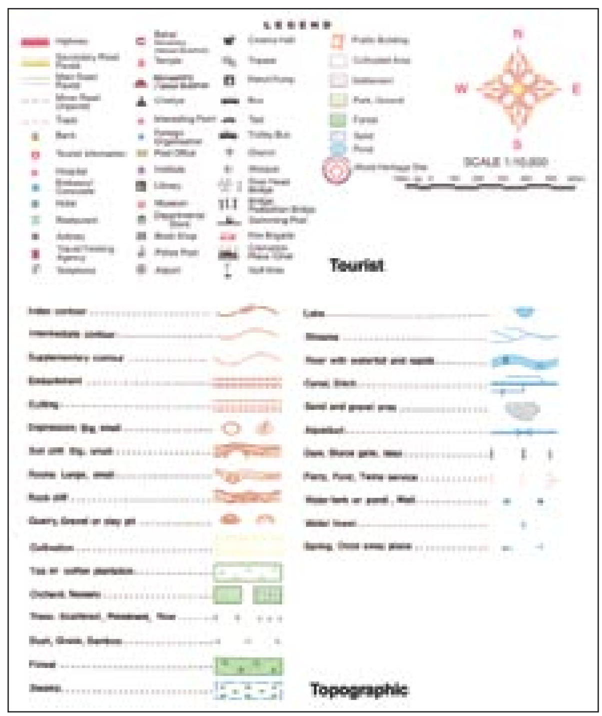


Figure 20: Map symbols.

Figure 21: A globe.

MAP PROJECTION

A globe is the best way to show the relative positions of places, but it is neither portable nor practical for large scales (figure 21). The three-dimensional shape of the earth means that it is not possible to depict locations and features directly onto a two-dimensional map space without some distortions. (Try to flatten the skin of an orange onto a piece of paper.) Map projection is a procedure that transforms locations and features from the three-dimensional surface of the earth onto two-dimensional paper in a defined and consistent way.

The transformation of map information from a sphere to a flat sheet can be accomplished in many ways. Mapmakers have invented projections that show distances, directions, shapes, or areas as they are on a globe to at least some extent. Each projection has advantages and disadvantages. Orthographic projections, for example, show shapes as they appear when the globe is viewed from space. Equal-area projections do not distort the size of areas but do distort their shape. Conformal projections are those on which the scale is the same in any direction at any point on the map. Many projections retain one geometric quality and a few retain more than one, but no single projection can accurately portray area, shape, scale, and direction (figures 22, 23, and 24).

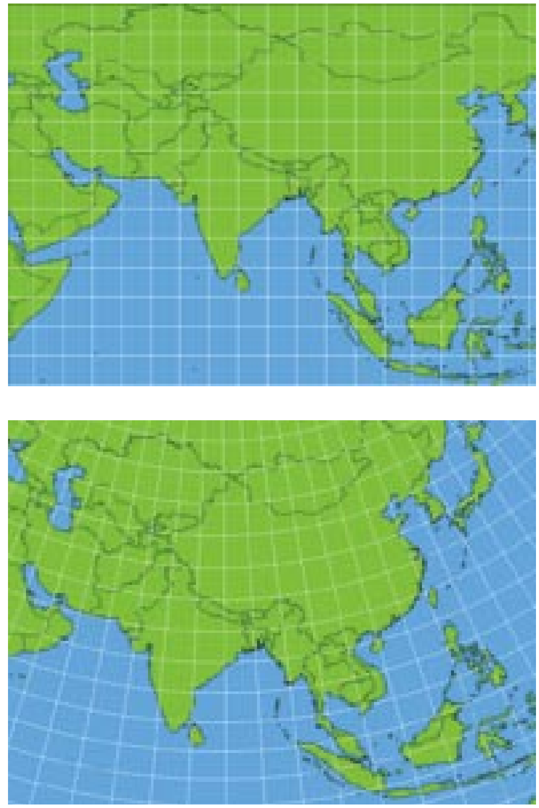


Figure 22: Plate carree projection and albers equal area projection.

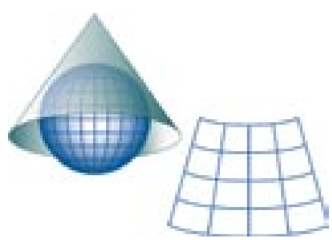


Figure 23: Conical projections.

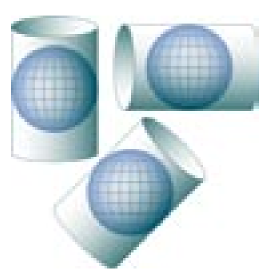


Figure 24: Cylindrical projections.

GIS

"The new source of power is not money in the hands of a few but information in the hands of many."

—John Naisbitt

Every day you wake at six o'clock in the morning. At eight o'clock you go to school, which is four kilometers south of your house. You return home at four o'clock in the afternoon, traveling along the same route. Then at five o'clock, you call your friends and go play a game of football at the nearby playground that is a ten-minute walk from your house. Many of our activities are related to place and time in one way or the other. Planning and decision making—whether it is planning a new road or finding a suitable location for a health center—are influenced or dictated by location or a geographic component. The major challenges we face in the world today—over-population, deforestation, natural disasters—have a critical geographic dimension.

Our geography can be considered as a number of related data layers, as illustrated in figure 25. GIS combines layers of information about a place to give an understanding of that place. Which layers of information are combined depends on a purpose: for example, finding the best location for a new supermarket, assessing environmental damage, tracking delivery vehicles, or modeling the global environment. A GIS stores information about the world as a collection of thematic layers that can be linked together by geography. This simple, but extremely powerful and versatile concept has proven invaluable for solving many real-world problems.

In the strictest sense, a GIS is a computer system for collecting, storing, manipulating, and displaying geographic information. There are many definitions for GIS. However, its major characteristic is a geographic (spatial) analysis function that provides a means for deriving new information based on location.

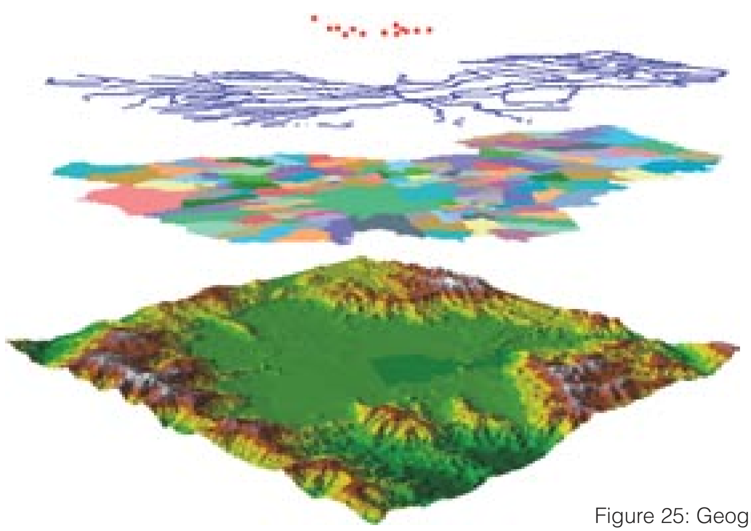


Figure 25: Geography in layers.

GIS functions

There are four basic functions of a GIS: data capture, data management, spatial analysis, and presenting results.

DATA CAPTURE

Data used in a GIS comes from many sources, is of many types, and is stored in different ways. A GIS provides tools and methods for the integration of data in formats that allow it to be compared and analyzed. Data sources are mainly manual digitization/scanning of aerial photographs, paper maps, and existing digital data. Remote-sensing satellite imagery and GPS are also data input sources.

DATA MANAGEMENT

After data is collected and integrated, a GIS provides facilities that can contain and maintain data. Effective data management includes the following aspects: data security, data integrity, data storage and retrieval, and data maintenance.

SPATIAL ANALYSIS

Spatial analysis is the most distinctive function of a GIS when compared to other systems such as computer-aided design(CAD). Spatial analysis includes such functions as spatial interpolation, buffering, and overlay operations.

PRESENTING RESULTS

One of the most exciting aspects of a GIS is the variety of ways in which information can be presented once it has been processed. Traditional methods of tabulating and graphing data can be supplemented by maps and three-dimensional images. These capabilities have given rise to new fields such as exploratory cartography and scientific visualization. Visual presentation is one of the most remarkable capabilities of a GIS, which allows for effective communication of results.

Questions GIS can answer

A GIS can be distinguished by listing the types of questions it can answer.

LOCATION: WHAT IS AT . . .?

This question seeks to find what exists at a particular location. A location can be described in many ways using, for example, a place name, postal code, or geographic reference such as longitude/latitude or x and y.

CONDITION: WHERE IS IT . . .?

This question is the converse of the first and requires spatial data to answer. Instead of identifying what exists at a given location, one may wish to find locations where certain conditions are satisfied (e.g., a nonforested area of at least 2,000 square meters, within 100 meters of a road, and with soils suitable for supporting buildings).

TRENDS: WHAT HAS CHANGED SINCE . . .?

This question might involve both of the first two and seeks to find the differences within an area over time (e.g., changes in forest cover or the extent of urbanization over the last ten years).

PATTERNS: WHAT SPATIAL PATTERN EXISTS . . .?

This question is more sophisticated. It might be asked to determine whether landslides are occurring mostly near streams, or to find out at which traffic points accidents are occurring most frequently. It might be just as important to know how many anomalies there are and where they are located.

MODELING: WHAT IF . . .?

This question is posed to determine what happens if, for example, a new road is added to a network or a toxic substance seeps into the local ground water supply. Answering this type of question requires both geographic and other information (as well as specific models).

Geographic data

There are two important components of geographic data: geographic position and attributes or properties—in other words, spatial data (where is it?) and attribute data (what is it?). Geographic position specifies the location of a feature or phenomenon by using a coordinate system. The attributes refer to the properties of spatial entities such as identity (e.g., maize, granite, lake), ordinal (e.g., ranking such as class 1, class 2, class 3), and scale (e.g., value such as water depth, elevation, erosion rate). They are often referred to as nonspatial data since they do not in themselves represent location information.

Figure 26: Vector format.

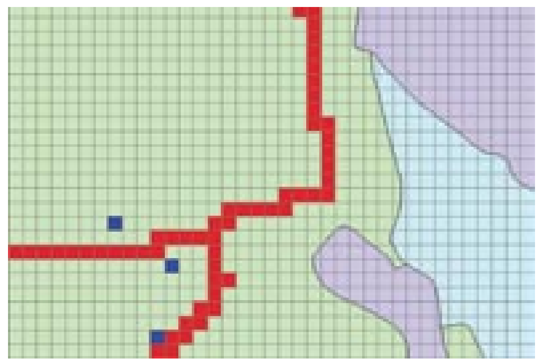


Figure 27: Raster format.

RASTER AND VECTOR DATA

Spatial features in a GIS database are stored in either vector or raster form. GIS data structures adhering to a vector format store the position of map features as pairs of x,y (and sometimes z) coordinates. A point is described by a single x,y coordinate pair and by its name or label. A line is described by a set of coordinate pairs and by its name or label. In theory, a line is described by an infinite number of points. In practice, this is of course not feasible. Therefore, a line is built up of straight line segments. An area, also called a polygon, is described by a set of coordinate pairs and by its name or label, with the difference that the coordinate pairs at the beginning and end are the same (figure 26).

A vector format represents the location and shape of features and boundaries precisely. Only the accuracy and scale of the map compilation process, the resolution of input devices, and the skill of the data-inputter limit precision.

In contrast, the raster or grid-based format generalizes map features as cells or pixels in a grid matrix (figure 27). The space is defined by a matrix of points or cells organized into rows and columns. If the rows and columns are numbered, the position of each element can be specified by using column number and row number. These can be linked to coordinate positions through the introduction of a coordinate system. Each cell has an attribute value (a number) that represents a geographic phenomenon or nominal data such as land-use class, rainfall, or elevation. The fineness of the grid (in other words, the size of the cells in the grid matrix) will determine the level of detail in which map features can be represented. There are advantages to the raster format for storing and processing some types of data in a GIS. The vector–raster relationship is shown in figure 28.

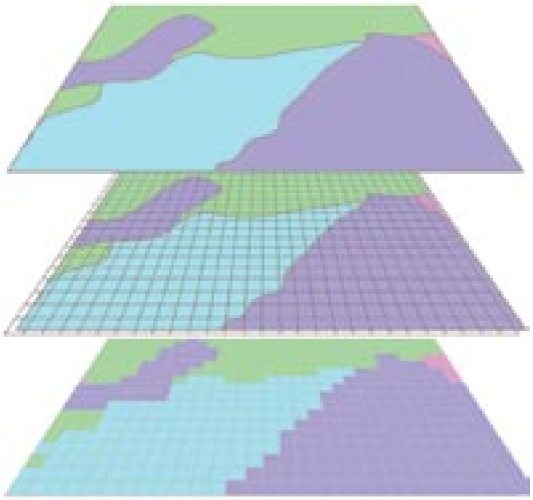


Figure 28: Vector–raster relationship.

Figure 29: Linking attribute data.

Organizing attribute data

A GIS uses raster and vector representations to model Earth features or phenomena. Apart from locations, a GIS must also record information about them. For example, the center line that represents a road on a map does not tell you much about the road except its location. To determine the road's width or pavement type or condition, such information should be stored so that it can be accessed by the system as needed. This means that the GIS must provide a linkage between spatial and nonspatial data. These linkages make the GIS "intelligent," as the user can store and examine information about where things are and what they are like. The linkage between a map feature and its attributes is established by giving each feature at least one unique means of identification—a name or number, usually called its ID. Nonspatial attributes of the feature are then stored, usually in one or more separate files, under this ID number (figure 29).

This nonspatial data can be filed in several forms, depending on how it needs to be used and accessed. GIS software often uses a relational database management system (RDBMS) to handle attribute data.

A relational database organizes data as a series of tables that are logically associated with each other by shared attributes. Any data element in a relationship can be found by knowing the table name, the attribute (column) name, and the value of the primary key. The advantage of this system is that it is flexible and can answer any question formulated with logical and mathematical operators.

Metadata

Metadata is simply defined as data about data. It gives the information about the content, source, quality, condition, and other relevant characteristics of the data (figure 30). For instance, it may describe the content as road or land-use data, the source as where the data has come from, the quality as the level of accuracy, the condition as whether the data is outdated or partial, and so on.

Figure 30: Metadata.

DATA CAPTURE

"A decision is as good as the information that goes into it."

—John F. Bookout, Jr.

Data: the fuel

Geographic data is information about the earth's surface and the objects found on it. Data is fuel to a GIS. How can we feed data such as a map into a GIS? Data capture is the process of putting information into the system. A wide variety of sources can be used for creating geographic data.

Types and sources of geographic data

Geographic data is generally available in two forms: analog data and digital data. Analog data is a physical product displaying information visually on paper, such as a map. Digital data is information that a computer can read, such as satellite transmissions.

There are various sources of digital data: maps, aerial photographs, satellite images, existing analog tables, and GPS receivers. Creating a database from such disparate sources (i.e., capturing the data) is the first and most time-consuming stage of a GIS project.

Data capturing methods

Methods of capturing data from various sources commonly used in a GIS are briefly discussed below.

PHOTOGRAMMETRIC COMPILATION

The primary source used in the process of photogrammetric compilation is aerial photography. Generally, the process involves using specialized equipment (a stereoplotter) to project overlapping aerial photos so that a viewer can see a three-dimensional picture of the terrain. This is known as a photogrammetric model. The current technological trend in photogrammetry is toward a greater use of digital procedures for map compilation.

DIGITIZING

A digitizing workstation with a digitizing tablet and cursor is typically used to trace digitize. Both the tablet and cursor are connected to a computer that controls their functions. Most digitizing tablets come in standard sizes that relate to engineering drawing sizes (A through E and larger). Digitizing involves tracing with a precise crosshair in the digitizing cursor features on a source map that is taped to the digitizing tablet, and instructing the computer to accept the location and type of the feature. The person performing the digitizing may input separate features into map layers or attach an attribute to identify the feature.

MAP SCANNING

Optical scanning systems automatically capture map features, text, and symbols as individual cells or pixels and produce an automated product in raster format. Scanning outputs files in raster form, usually in one of several compressed formats to save storage space (e.g., TIFF 4, JPEG). Most scanning systems provide software to convert raster data to vector format that differentiates point, line, and area features. Scanning systems and software are becoming more sophisticated, with some ability to interpret symbols and text, and store this information in databases. Creating an intelligent GIS database from a scanned map will require vectorizing the raster data and manual entry of attribute data from a scanned annotation.

SATELLITE DATA

Earth resources satellites have become a source of huge amounts of data for GIS applications. The data obtained from satellites is in digital form and can be imported directly into a GIS. There are numerous satellite data sources such as LANDSAT or SPOT. A new generation of high-resolution satellite data, that will increase opportunities and options for GIS database development, is becoming available from private sources and national governments. These satellite systems will provide panchromatic (black and white) or multi-spectral data in the one- to three-meter range as compared to the ten- to thirty-meter range available from traditional remote-sensing satellites.

FIELD DATA COLLECTION

Advances in hardware and software have greatly increased opportunities for capture of GIS data in the field (e.g., utility sign inventory, property surveys, landuse inventories). In particular, electronic survey systems and the global positioning systems (GPS) have revolutionized surveying and field data collection. Electronic distance measurement services allow for survey data to be gathered quickly in an automated form for uploading to a GIS. Sophisticated GPS collection units provide a quick means of capturing the coordinates and attributes of features in the field.

TABULAR DATA ENTRY

Some of the tabular attribute data that is normally in a GIS database exists on maps as annotation, or can be found in paper files. Information from these sources has to be converted to a digital form through keyboard entry. This kind of data entry is commonplace and relatively easy to accomplish.

DOCUMENT SCANNING

Smaller format scanners can also be used to create raster files of documents such as permit forms, service cards, site photographs, and so on. These documents can be indexed in a relational database by number, type, date, engineering drawings, and so forth, and queried and displayed by users. GIS applications can be built that allow users to point to and retrieve for display a scanned document (e.g., tax parcel) interactively.

TRANSLATION OF EXISTING DIGITAL DATA

Existing automated data may be available from existing tabular files maintained by outside sources. Many programs are available that perform this translation. In fact, there are many GIS packages with programs that translate data to and from several standard formats that are accepted widely by the mapping industry. They have been used as intermediate "exchange" formats for moving data between platforms (e.g., Intergraph® SIF, TIGER®, Shapefile, and AutoCAD® DXF™).

REMOTE SENSING

"To envision information—and what bright and splendid visions can result—is to work at the intersection of image, word, number, art."

—Edward R. Tufte

What is remote sensing?

We perceive the surrounding world through our five senses. Some senses (touch and taste) require contact of our sensing organs with the objects. However, we acquire much information about our surroundings through the senses of sight and hearing, which do not require close contact between the sensing organs and the external objects. In other words, we are performing remote sensing all the time.

Generally, remote sensing refers to the activities of recording/observing/perceiving (sensing) objects or events in distant (remote) places.

Remote sensing is defined as the science and technology by which the characteristics of objects of interest can be identified, measured, or analyzed without direct contact. Remote sensing deals with gathering information about the Earth from a distance. This can be done a few meters from the Earth's surface, from an aircraft flying hundreds or thousands of meters above the surface, or by a satellite orbiting hundreds of kilometers above the Earth.

Remote-sensing satellites

Remote-sensing satellites are equipped with sensors that look down at the Earth. They are "eyes in the sky," constantly observing the Earth (figure 32).

Figure 31: Earth from space.

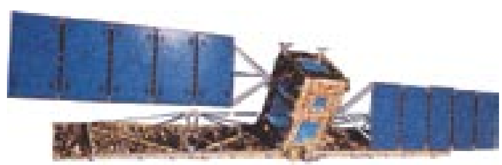


Figure 32: Remote-sensing satellite.

Why remote sensing?

Remote-sensing satellite images give a synoptic (bird's eye) view of any place on the Earth's surface. This allows us to study, map, and monitor the Earth's surface at local, regional, and/or global scales. It is cost effective and gives better spatial coverage compared to ground sampling.

How does remote sensing work?

Electromagnetic radiation reflected or emitted from an object is the usual source of remote-sensing data. A device to detect the electromagnetic radiation reflected or emitted is called a remote sensor. Cameras or scanners are examples of remote sensors. A vehicle to carry the sensor is called a platform. Aircraft or satellites are used as platforms.

The characteristics of an object can be determined using its reflected or emitted electromagnetic radiation. That is, each object has a unique characteristic of reflection or emission if the object type or environmental conditions are different. Remote sensing is a technology to identify and understand the object or the environmental conditions through the uniqueness of its electromagnetic reflection or emission.

Types of remote-sensing images

Presently there are several remote-sensing satellite arrays in operation. Different satellite systems have different characteristics—such as resolution or number of bands on which they transmit—and have their own importance for different applications.

Remote-sensing images

Remote-sensing images are normally digital images (figure 33). In order to extract useful information, image processing techniques are applied to enhance the image to help visual interpretation, and to correct or restore the image if it has been subjected to geometric distortion, blurring, or degradation by other factors. There are many image analysis techniques available and the method used depends upon the requirements of the specific problem concerned.

Figure 33: Satellite images of Kathmandu.

USE OF REMOTE-SENSING DATA IN A GIS

Remote-sensing data can be integrated with other geographic data. There has been an increasing trend in the integration of remote-sensing data into a GIS for analytical purposes. There are many ways to use remote-sensing data; some examples are illustrated in figures 34 and 35.

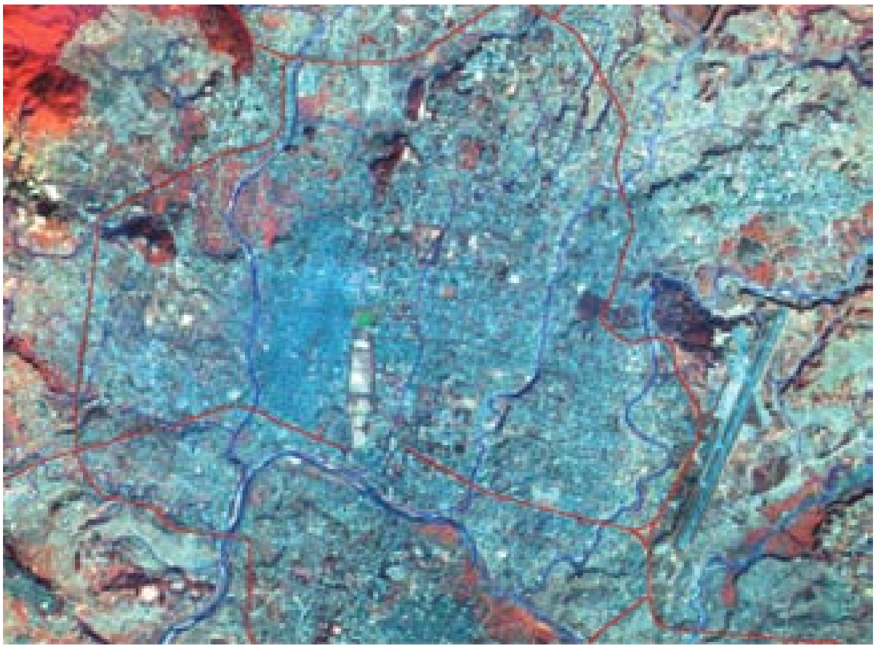


Figure 34: Kathmandu urban area observed from an ADEOS-AVNIR M Japanese satellite image, 1997, and overlaid with road and river features.

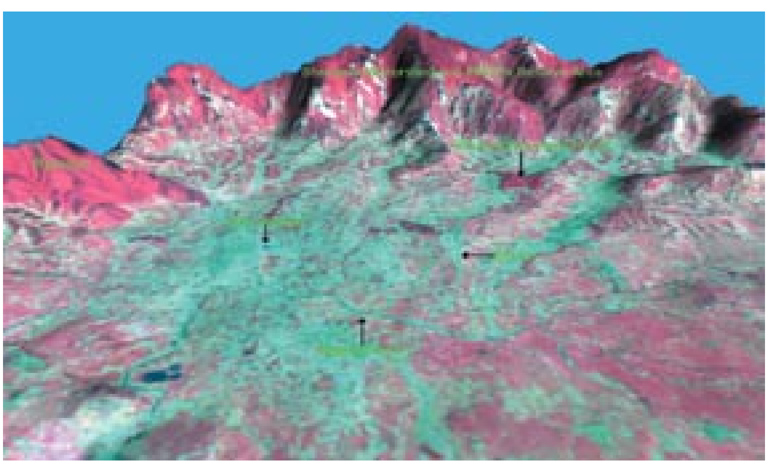


Figure 35: 3-D perspective of the Kathmandu valley generated by draping a LANDSAT-TM, 1998, satellite photo over a DEM.

GLOBAL POSITIONING SYSTEM

"No matter where you go, there you are."

—Anonymous

Knowing where you were and where you were going was the most crucial and challenging task faced by explorers in ancient times. Positioning and navigation are extremely important to many activities, and many tools and techniques have been adopted for this purpose. People have used a magnetic compass, sextant, or theodolite and measured the positions of the sun, moon, and stars to find their own position. More recently, a Global Positioning System (GPS) has been developed by the U.S. Department of Defense (DoD) for worldwide positioning at a cost of 12 billion U.S. dollars.

GPS is a worldwide radio-navigation system formed from a constellation of twenty-four satellites and five ground stations. It uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. GPS receivers are remarkably economical and have made the technology accessible to virtually everyone. The GPS provides continuous three-dimensional positioning twenty-four hours a day to military and civilian users throughout the world. These days, GPS is finding its way into cars, boats, planes, construction equipment, farm machinery, and even laptop computers. It has tremendous potential for use in GIS data collection, surveying, and mapping. GPS is increasingly used for precise positioning of geospatial data and collection of data in the field.

Components of the GPS

The Global Positioning System is divided into three major components: the control segment, the space segment, and the user segment.

CONTROL SEGMENT

The control segment consists of five monitoring stations—Colorado Springs, Ascension Island, Diego Garcia, Hawaii, and Kwajalein Island. Colorado Springs serves as the master control station. The control segment is the sole responsibility of the DoD, who undertakes the construction, launching, maintenance, and constant monitoring of all GPS satellites. The monitoring stations track all GPS signals and send correctional data back to the satellites.

SPACE SEGMENT

The space segment consists of the constellation of Earth-orbiting satellites. The satellites are arrayed in six orbital planes inclined 55 degrees to the equator (figure 36). They orbit at an altitude of about 12,000 miles. Each satellite contains four precise atomic clocks (Rubidium and Cesium standards) and has a microprocessor on board for limited self-monitoring and data processing. The satellites are equipped with thrusters that can be used to maintain or modify their orbits, based on correctional data received from the tracking stations.

Figure 36: The satellites are deployed in a pattern that has each one passing over a monitoring station every twelve hours, with at least four visible in the sky at all times.

USER SEGMENT

The user segment consists of all Earth-based GPS receivers. Receivers vary greatly in size and complexity, although the basic design is rather simple. The typical receiver is composed of an antenna and preamplifier, radio-signal microprocessor, control and display device, data recording unit, and power supply. The GPS receiver decodes the timing signals from the visible satellites (four or more) and, having calculated their distances, computes its own latitude, longitude, elevation, and time. This is a continuous process and generally the position is updated on a second-by-second basis. It is output to the receiver display device and, if the receiver provides data capture capabilities, stored by the receiver logging unit.

How GPS works

The GPS uses satellites and computers to calculate positions anywhere on Earth based on satellite ranging. This means that a position on Earth is determined by measuring its distance from a group of satellites in space. The GPS measures the time it takes for a radio message to travel from each satellite to the position on Earth. For this, it needs an extremely accurate clock. It then converts this time into a distance and, using triangulation, calculates each satellite's distance from Earth. It then needs to know where each satellite is in space. To compute a satellite's position in three dimensions, the GPS needs to have four satellite measurements. It uses a trigonometric approach to calculate these positions (figure 37). The satellites are so high that their orbits are very dependable.

GPS errors

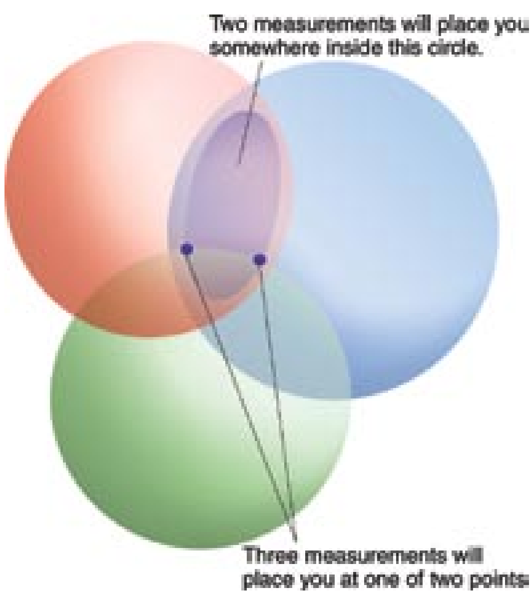
Although the GPS looks like a perfect system, there are a number of sources of errors that are difficult to eliminate.

SATELLITE ERRORS

Slight inaccuracies in time-keeping by satellites can cause errors in calculating positions on Earth. Also, the satellite's position in space is important because it is used for the starting point of the calculations. Although GPS satellites are at extremely high orbits and are relatively free from the perturbing effects of atmosphere, they still drift slightly from their predicted orbits. Though they are regularly corrected, this drifting contributes to errors.

THE ATMOSPHERE

The GPS signals have to travel through charged particles and water vapor in the atmosphere. This slows their transmission. Since the atmosphere varies in different places and times, it is not possible to compensate accurately for the delays that occur.



MULTIPATH ERROR

As the GPS signal arrives on the Earth's surface, it may be reflected by local obstructions before it reaches the receiver's antenna. This is called multipath error because the signal reaches the antenna along multiple paths.

RECEIVER ERROR

Receivers are also not perfect. They introduce errors that usually occur from their clocks or internal noise.

SELECTIVE AVAILABILITY

Selective availability (S/A) was the intentional error introduced by the DoD to make sure that hostile forces could not use the accuracy of the GPS against the United States or its allies. Some noise was introduced into the GPS satellite clocks that reduced their accuracy. The satellites were also given erroneous orbital data that were transmitted as part of each satellite's status message. These two factors significantly reduced the accuracy of GPS for civilian uses. On May 1, 2000, the U.S. government announced a decision to discontinue the intentional degradation of public GPS signals. Civilian users of GPS are now able to pinpoint locations up to ten times more accurately. The decision to discontinue S/A is the latest measure in an ongoing effort to make GPS more responsive to civil and commercial uses worldwide.

Figure 37: The first reading puts you somewhere on the globe. The second narrows the possibilities to the circle where the two globes intersect. The third places you at one of the two points (one of which can usually be disregarded).

Differential positioning

To eliminate most of the errors discussed above, the technique of differential positioning is applied. Differential GPS carries the triangulation principle one step further, with a second receiver at a known reference point. The reference station is placed on the control point—a triangulated position or the control point coordinate. This allows for a correction factor to be calculated and applied to other roving GPS units used in the same area and in the same time series. This error correction allows for a considerable amount of error to be negated—potentially as much as 90 percent. The error correction can be made either by postprocessing or in real time (figure 38).

Integration of GPS and GIS

It is possible to integrate GPS positioning in GIS for field-data collection. GPS is also used in remote-sensing methods such as photogrammetry, aerial scanning, and video technology. GPS is an effective tool for GIS data capture. The GIS user community benefits from the use of GPS for locational data capture in various GIS applications. The GPS can easily be linked to a laptop computer in the field and, with appropriate software, users can place all their data on a common base with little distortion. Thus, GPS can help in several aspects of the construction of accurate and timely GIS databases.

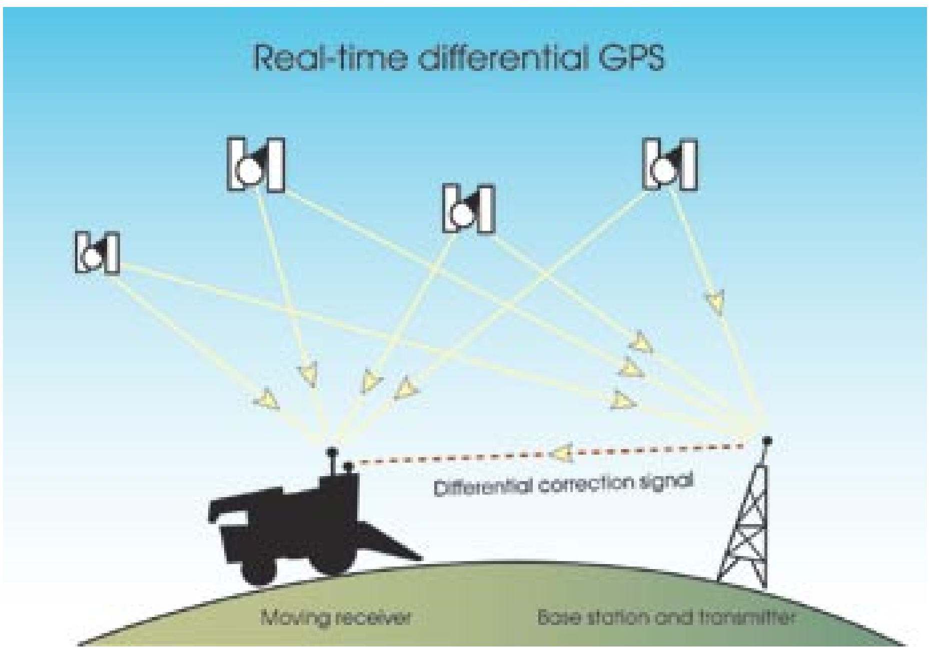


Figure 38: Differential positioning.

SPATIAL ANALYSIS

"Knowing where things are and why is essential to rational decision making."

—Jack Dangermond

When you think of a name and address database, you probably visualize a table of data in rows and columns. What you might miss is that each of these records represents a person or family that lives in a particular place (location). Furthermore, that particular location can tell us something about a person's standard of living, neighborhood, access to schools, access to a hospital, distance to the main market, vulnerability to local crime, exposure to pollution levels, and much more. GIS analysis allows us to visualize the "bigger picture" by allowing us to see patterns and relationships within the geographic data. The results of analysis may offer insight into a place, help focus actions, or select an appropriate option.

What is spatial analysis?

Spatial analysis is a process for looking at geographic patterns in data and relationships between features. The actual methods used can be simple—just a map of the theme being analyzed—or more complex, involving models that mimic the world by combining many data layers.

Figure 39: Boolean operations.

Spatial analysis allows us to study real-world processes. It gives information about the real world that may be the present situation of specific areas and features, or changes and trends in a situation. For instance, it may be able to answer *where and by how much are forest areas decreasing or increasing?* or *where are urban areas growing in the Kathmandu valley?* and so on.

Spatial analysis functions

Spatial analysis functions range from simple database query, to arithmetic and logical operation, to complicated model analysis. Each of these functions is briefly described below.

DATABASE QUERY

Database query is used to retrieve attribute data without altering the existing data. The function can be performed by simply clicking on the feature or by means of a conditional statement for complex queries. The conditional statement can involve Boolean (logical) operators—and, or, not, xor (exclusive of or)—or relational (conditional) operators—=, >, <, ≠ (not equal to). An example of Boolean operators that combine more than two conditions is shown in figure 39.

For example, in figure 40, the Boolean operator used is ([LandUse] = 'Agriculture') OR ([LandUse] = 'Shrub').

RECLASSIFICATION

(Re)classification operations involve the reassignment of thematic values to categories of an existing map. The following are examples.

- Classify an elevation map into classes with intervals of 500 meters (figure 41).
- Reclassify a VDC (village development committee) map based on population density (figure 42).

OVERLAY

Overlay is at the core of GIS analysis operations. It combines several spatial features to generate new spatial elements. Overlay can be defined as a spatial operation that combines various geographic layers to generate new information. Overlay is done using arithmetic, Boolean, and relational operators, and is performed in both vector and raster domains.

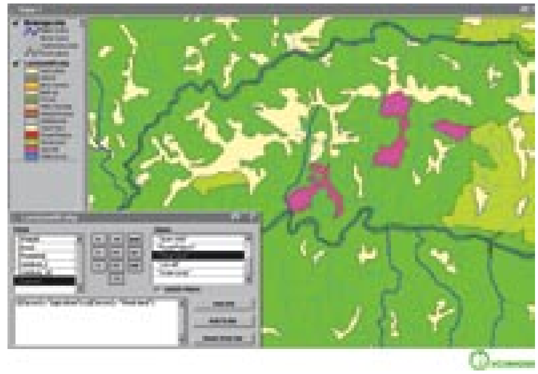


Figure 40: Selection using Boolean operators.

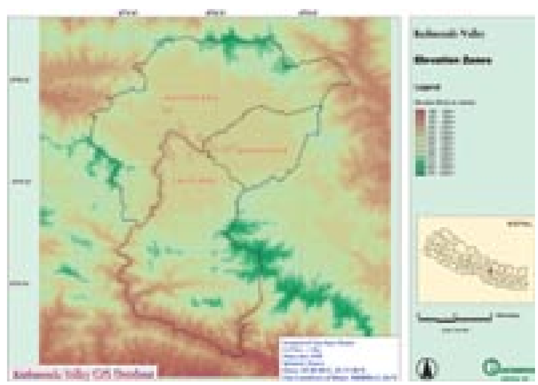


Figure 41: Classification of an elevation map of Kathmandu valley into different intervals.

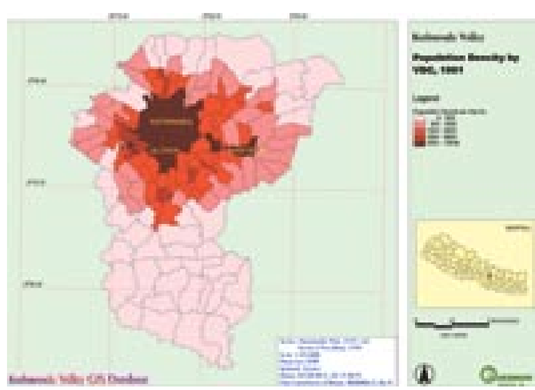


Figure 42: Classification of a VDC map of Kathmandu valley based on population density, 1991.

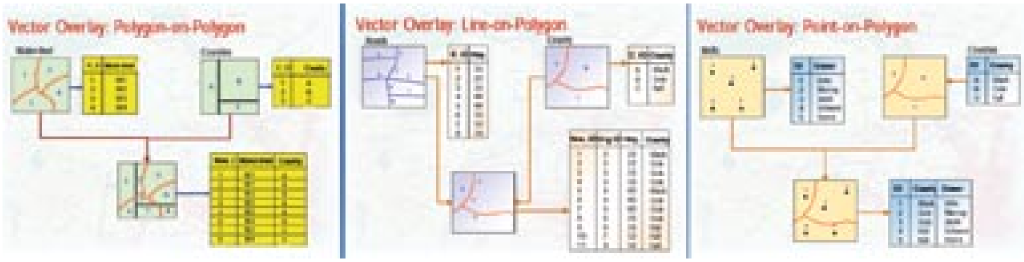


Figure 43: Vector overlay.

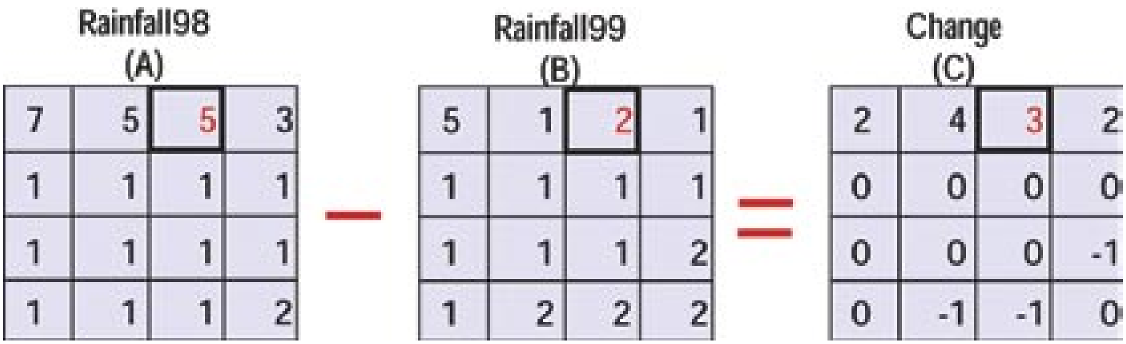


Figure 44: Map algebra.

Vector overlay

During vector overlay, map features and their associated attributes are integrated to produce a new composite map. Logical rules can be applied to determine how the maps are combined. Vector overlay can be performed on various types of map features: polygon-on-polygon, line-on-polygon, point-on-polygon (figure 43). During the process of overlay, the attribute data associated with each feature type are merged. The resulting table will contain all the attribute data.

Raster overlay

In raster overlay, the pixel or grid cell values in each map are combined using arithmetic and Boolean operators to produce a new value in the composite map. The maps can be treated as arithmetic variables and perform complex algebraic functions. The method is often described as map algebra (figure 44). The map algebraic function uses mathematical expressions to create new raster layers by comparing them.

There are three groups of mathematical operators in the map calculator: arithmetic, Boolean, and relational.

- Arithmetic operators (+, −, ×, ÷) allow for the addition, subtraction, multiplication, and division of two raster maps or numbers or a combination of the two.
- Boolean operators (and, not, or, xor) use Boolean logic (true or false) on the input values. Output values of true are written as 1 and false as 0.
- Relational operators (<=, =, >, >=) evaluate specific relational conditions. If the condition is true, the output is assigned 1; if the condition is false, the output is assigned 0.

Figure 45 shows examples of simple raster overlay using different logical operators.

The following GIS application illustrates landuse and landcover changes over time in the Kathmandu valley (figure 46). The analysis is done by overlaying landuse/landcover data from different dates. The figure shows the landuse/landcover data for 1978 and 1995, and the changes between 1978 and 1995 derived from this data.

This is the analysis of connectivity between points, lines, and polygons in terms of distance, area, travel time, optimum paths, and so on. Connectivity analysis consists of the following analyses.

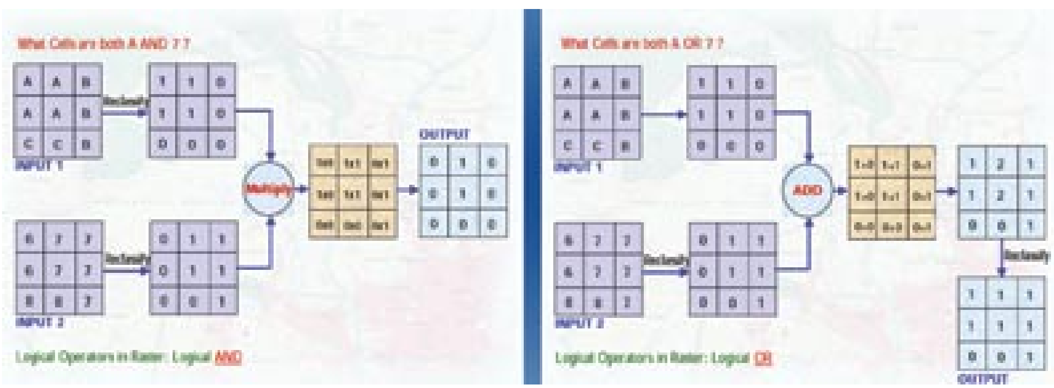


Figure 45: Raster overlay using “and” and “or” logical operators.

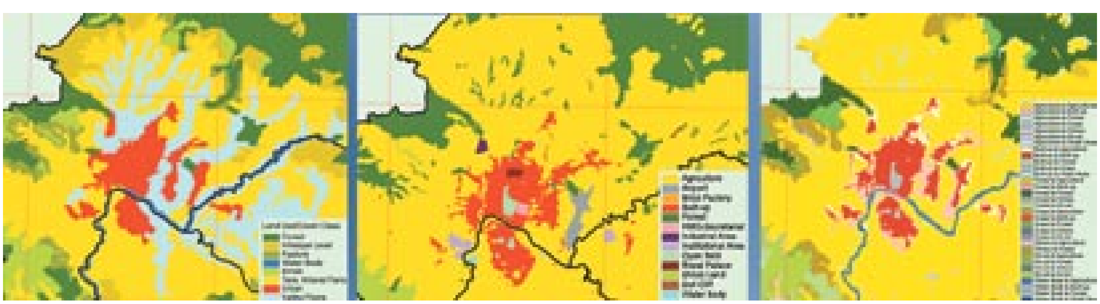


Figure 46: Landcover change in the Kathmandu valley between 1978 and 1995. The left panel shows landuse/landcover of Kathmandu valley in 1978; the center panel shows the same in 1995. The right panel shows landuse/landcover of the Kathmandu valley from 1978–1995.

Proximity analysis

Proximity analysis is the measurement of distances from points, lines, and boundaries of polygons. One of the most popular types of proximity analysis is “buffering,” by which a buffer zone with a given distance is generated around a point, line, or area, as shown in figure 47. Buffering is easier to generate for raster data than for vector data.

Figure 48 shows walking distances from the ICIMOD building.

Network analysis

Network analysis is commonly used for analyzing the movement of resources from one location to another through a set of interconnected features. It includes determination of optimum paths using specified decision rules. The decision rules are likely to be based on minimum time or distance, and so on.

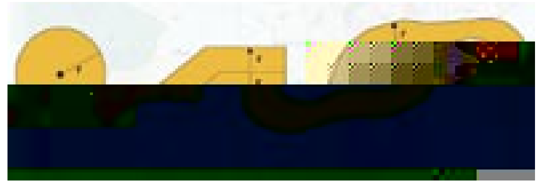


Figure 47: Buffer operations.

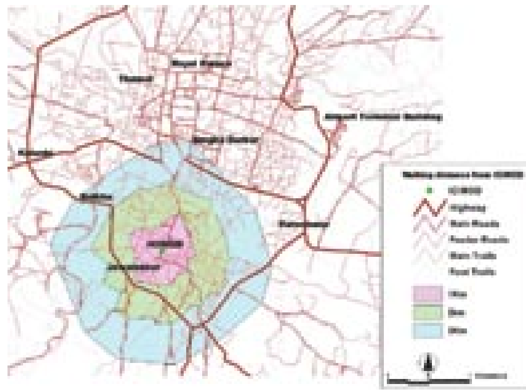


Figure 48: Walking distances from ICIMOD.

PRESENTING YOUR RESULTS

"A picture is worth a thousand words."

—Chinese proverb

Visualization

Visualization is defined as the translation or conversion of spatial data from a database into graphics. These graphics are in the form of maps that enable the user to perceive the structure of the phenomenon or the area represented. The visualization process is guided by the question *How do I say what to whom, and is it effective? How* refers to the cartographic methods that are used for making the graphics or map. *I* refers to the cartographer or GIS user who is preparing the map. *Say* refers to the semantics that represent the spatial data. *What* refers to the spatial data and its characteristics, and the purpose of the map. *Whom* refers to the map's audience. The usefulness of a map depends upon the following factors.

WHO IS GOING TO USE IT?

The map's audience or users will influence how a map should look. A map made for school children will be different from one made for scientists. Similarly, tourist maps and topographic maps of the same area are different in content and look as if they are made for different users.

WHAT IS ITS PURPOSE?

The purpose of a map determines what features are included and how they are represented. Different purposes such as orientation and navigation, physical planning, management, and education lead to different categories of maps.

WHAT IS ITS CONTENT?

A map's usefulness also depends upon its contents. Contents can be seen as primary content (main theme), secondary content (base-map information) and supporting content (legends, scale, and such).

WHAT IS THE SCALE OF THE MAP?

The map scale is the ratio between a distance on a map and the corresponding distance in the terrain. Scale controls the amount of detail and extent of area that can be shown. Scale of the output map is based upon considerations such as the purpose of the map, needs of the map user, map content, size of the area mapped, accuracy required, and so on.

WHAT IS THE PROJECTION OF THE MAP?

Every flat map of a curved surface is distorted. The choice of map projection determines how, where, and how much the map is distorted. Normally, the selected map projection is that which is also used for topographic maps in a certain country.

HOW ACCURATE IS THE MAP?

GIS has simplified the process of information extraction and communication. Combining or integrating datasets has become possible. However, this has created the possibility of integrating irrelevant or inconsistent data. The user should be aware of aspects of data quality and accuracy. *What is the source of the data? Are the places at correct locations? Are the attribute values correct? Are the themes correctly labelled? Is the data complete?*

Map design

Mapmaking is both a science and an art. A beautiful map may be more popular than a plain map, even if it is less accurate. Maps influence people's perception of space. This influence is partly a result of convention and partly a result of the graphics used. People understand the world differently; they express this understanding differently in maps and also gain different understandings from maps.

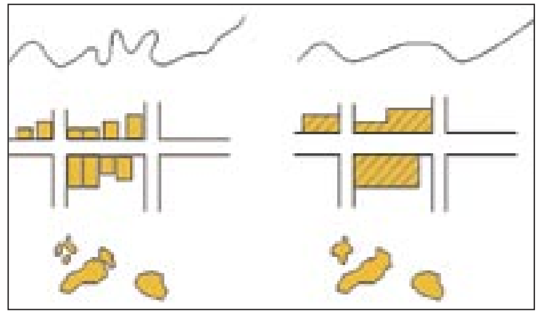


Figure 49: Generalization.

GENERALIZATION

A map contains a certain level of detail depending on its scale and purpose. Large-scale maps usually contain more detail than small-scale maps. Cartographers often generalize the data by simplifying the information so that the map is easier to read (figure 49). The process of reducing the amount of detail on a map in a meaningful way is called generalization. Generalization is normally done when the map scale has to be reduced. However, the essence of the contents of the original map should be maintained. This implies maintaining geometric and attribute accuracy as well as the aesthetic quality of the map. There are two types of generalization—graphic and conceptual. Graphic generalization involves simplification, enlargement, displacement, or merging of geometric symbols. Conceptual generalization mainly deals with the attributes and requires knowledge of the map contents and the principles of the themes mapped.

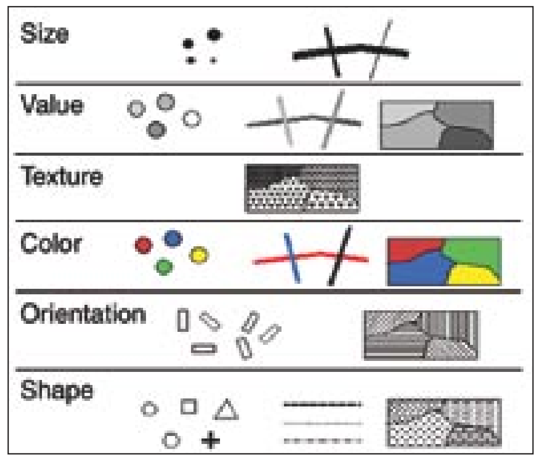


Figure 50: Graphic variables.

GRAPHIC VARIABLES

Differences in the graphic character of symbols convey different perceptions to the map reader. These graphic characteristics are termed graphic variables and can be summarized as size, lightness or grey value, grain or texture, color, orientation, and shape or form (figure 50). Knowledge of graphic variables and their perceptual characteristics helps map designers to select those variables that provide a visualization that matches the data or the objective of the map.

USE OF COLOR

Colors have psychological, physiological, and conventional aspects. It has been noted that it is difficult to perceive color in small areas, and greater contrast is perceived between some colors than others. In addition to distinguishing nominal categories, color differences are also used to show deviations or gradation.

DATA ANALYSIS, ADJUSTMENT, AND CLASSIFICATION

Data needs to be analyzed before it is mapped. Data is either qualitative—roads, rivers, districts—or quantitative—elevation, temperature, population density. Representation also depends on the measurement scale used—nominal, ordinal, interval, or ratio scale.

For nominal scale, the differences in data are only of a qualitative nature (e.g., differences in gender, language, landuse, or geology).

For ordinal scale, only the order of the attribute values is known and a hierarchy can be established such as *more than or less than; small, medium, large;* or *cool, tepid, hot*.

For interval scale, both the hierarchy and the exact difference are known but it is not possible to make a ratio between the measurements (e.g., temperature or altitude values). A temperature of 8 degrees C is not twice as warm as 4 degrees C; it is only the difference between two temperatures.

For ratio scale, data can be measured on a ratio measurement scale (e.g., the number of children in a family or an income).

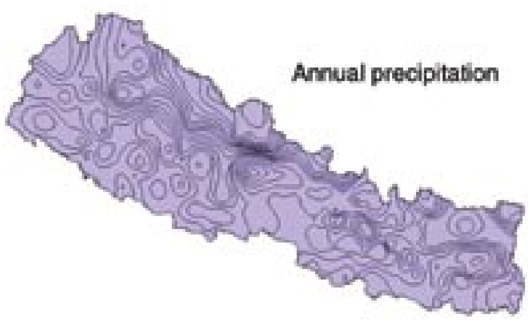
Grouping of data can also be done in different ways. Ranges of values may be grouped according to natural breaks, at round numbers, at statistical means, or standard deviations. Different grouping or classification schemes give different perception of the phenomena.

Mapping methods

Mapping methods are standardized ways of applying graphic variables based on measurement scale and the nature of the distribution of objects. Various map types are given below.

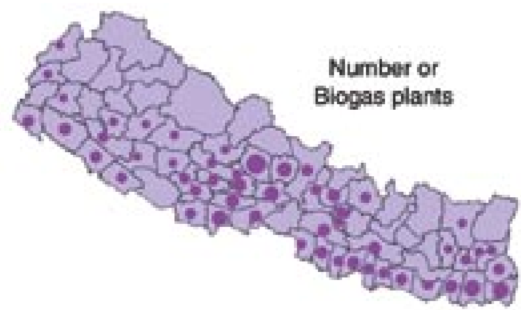
Chorochromatic maps This method renders nominal values for areas with different colors (in Greek, choros = area, chroma = color). The term is also used when patterns are used to render nominal area values. Only the nominal qualities are rendered and there is no suggestion of hierarchy or order conveyed.

Choropleth maps In this method, the values are rendered for areas (in Greek, choros = area, plethos = value). Values are calculated for area and expressed as stepped surfaces showing a series of discrete values. The differences in grey value or in intensity of a color denote the differences in the phenomenon. A hierarchy or order between the classes can be perceived.



Isoline maps Isoline maps are based on the assumption that the phenomenon to be represented has a continuous distribution and smoothly changes in value in all directions of the plane. Isolines connect the points with an equal value (e.g., equal height above sea level or equal amounts of precipitation). Isoline maps show the trends of the phenomenon, such as in which direction it is increasing or decreasing.

Nominal point data maps Nominal data for point locations is represented by symbols that are different in shape, orientation, or color. Geometric or figurative symbols are more common in maps for tourists and schools.



Absolute proportional maps Discrete absolute values for points or areas are represented by proportional symbols. Different values are represented by symbols differing in size. The primary considerations for these symbols are legibility and comparability.

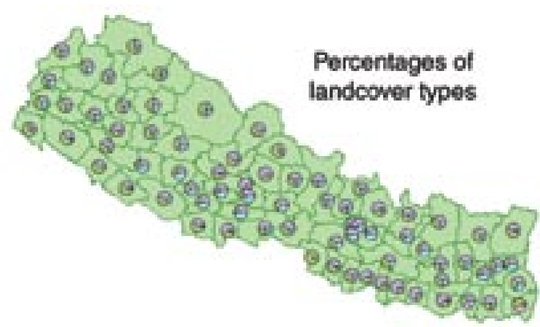
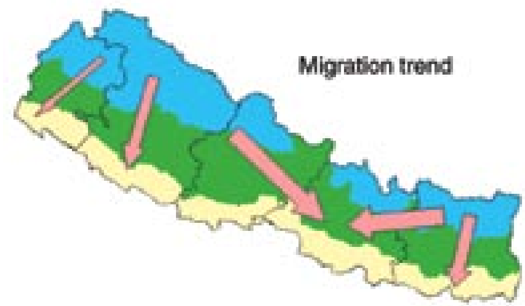
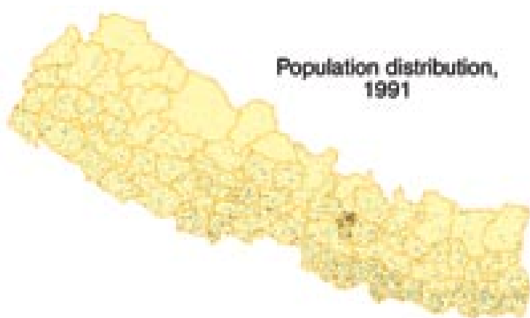


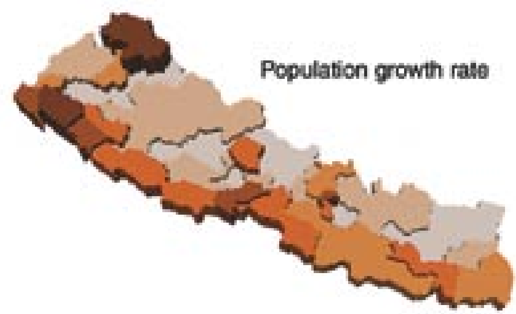
Diagram maps Diagrams are used in maps to allow comparisons between figures or to visualize temporal trends. Line diagrams, bar graphs, histograms, or pie graphs are normally used on maps. However, care has to be taken that there are not so many distracting features that the image becomes too complicated.



Flowline maps Flowline maps simulate movement using arrow symbols. Arrows indicate both route and direction of flows. The volume transported along the route is shown by the relative thickness of the arrow shaft.



Dot maps Dot maps are a special case of proportional symbol maps, as they represent point data through symbols that each denote the same quantity, and that are located as closely as possible to the locations where the phenomenon occurs.



Statistical surfaces Statistical surfaces are three-dimensional representations of qualitative data such as used in choropleth and isoline maps.

New map output types

New ways of visualization and using spatial information are being developed. New products such as electronic atlases, cartographic animations, and multimedia systems are appearing in the field of spatial information.

Multimedia allows for interactive integration of sound, animation, text, and video. In a GIS environment, this new technology offers a link to other kinds of information of geographic nature. These could be text documents describing a parcel, photographs of objects that exist in a GIS database, or a video clip of the landscape of the study area.

Maps on the Internet

With new interactive tools and facilities offered by the Internet, maps are being used extensively online for various purposes. Apart from their traditional role of representing spatial data, maps can now function as an index of spatial data, a preview of data, and a search engine to locate spatial data. The Internet is becoming a major form of map distribution. With the new functions offered by map servers for interactive mapping, the user can define the content and design of maps. This is changing the way visualization applications are developed, delivered, and used.

Figure 51: Maps on the Internet (source: *www.mapquest.com*).

IMPLEMENTING GIS

"Few things are harder to put up with than the annoyance of a good example."

—Mark Twain

GIS is an information management tool that helps us to store, organize, and use spatial information in a form that allows everyday tasks to be completed more efficiently. In the last two decades, GIS software, and the hardware required to operate it, has become much more affordable and easy to use. This means it's possible to develop a GIS without making large investments in software, hardware, and the support staff that were once needed to implement it. With the widespread implementation of GIS, we see dramatic improvements in the way we access information, execute responsibilities, and respond to requests from citizens, potential developers, and other clients.

A working GIS

A working GIS integrates five key components: hardware, software, data, people, and policy and procedures.

HARDWARE AND SOFTWARE

Hardware is the computer on which a GIS operates. Today, GIS software runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations.

GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are as follows:

- Tools for the input and manipulation of geographic information
- A database management system (DBMS)
- Tools that support geographic query, analysis, and visualization
- A graphical user interface (GUI) for easy access to tools

The affordability of desktop computers with rapidly increasing power, and the decreasing cost of software has resulted in widespread use of desktop GIS.

DATA

Data is one of the most important and costly components in implementing a GIS. The database is the longest existing part of any GIS implementation. Building the database takes the most time, costs the most money, and requires the most effort in terms of planning and management. Implementing a GIS requires adequate emphasis on database planning and choosing the right information base for the particular applications of an organization.

Most GIS applications in a particular area require a common set of spatial data. However, this data is often possessed by different organizations. A lack of adequate data-sharing mechanisms means that different organizations are involved in collecting the same data, wasting resources and time. This duplication of effort is also a result of insufficient or inappropriate standards in data collection. The major obstacle in the reuse of data is the lack of awareness or willingness among organizations to share data. GIS as a technology will only be viable and cost effective if data is readily available at an affordable cost.

PEOPLE

GIS technology is of limited value without people to manage the system and develop plans for applying it to real-world problems. GIS users range from technical specialists, who design and maintain the system, to those who use it to help them perform their everyday work. GIS is a truly interdisciplinary field; it requires varied backgrounds of expertise, depending upon the applications. The skill all these people have in common is the ability to *think spatially*.

POLICIES AND PROCEDURES

A successful GIS operates according to a well-designed plan and the business rules that are the models and operating practices unique to each organization. GIS exists in the context of application within an organization. The functional requirements of a municipal GIS are quite different from those of an agriculctural GIS, for example.

Besides technical components such as hardware, software, and databases, institutional frameworks and policies are also important for a functional GIS. The interest and willingness of decision makers to exploit GIS technology, and the organizational setup for collecting spatial data, analyzing it, and using the results for planning and implementation form an important component of a GIS.

Choosing the right GIS for a particular implementation involves matching the GIS needs to the functionality demanded by the type of application required by an organization.