ENVIRONMENTAL GEOSCIENCES

Prof. Prasoon Kumar Singh

Department of Environmental Science and Engineering

Indian Institute of Technology (Indian School of Mines), Dhanbad

Lecture-61

Geographic Information System

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are discussing the module twelve. In the module twelve, we have to discuss remote sensing and GIS applications, impact of climate change on water resources. We have already discussed the remote sensing part in the lecture one. Today, we will discuss the lecture two, that is geographic information system.

The important concepts in this lecture will be covered like introduction to geographic information system, definition of GIS, components of GIS, introduction to GIS data, type of GIS data, data representation or structure, data sources, data quality and errors in GIS, steps in a GIS project, limitations of GIS and GPS that is global positioning system. Now let us see first the introduction to geographic information system. The collection of data about the spatial distribution of significant properties of Earth's surface in the form of maps by navigators, geographers and surveyors has long been an important part of activities of organized society. Whereas the topographical maps can be regarded as general purpose maps, the thematic maps for assessment and understanding of natural resources are for specific purposes. The use of aerial photography and remote sensing has made it possible to map large areas with greater accuracy for producing thematic maps of large areas for resource exploitation and its management.

Handling of large volume of data for quantitative spatial variation of the data requires appropriate tool to process the spatial data using statistical methods and time series analysis. With the introduction of computer assisted cartography, many new tools were developed to perform spatial analysis of the data and to produce maps in desired formats. These operations required a powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world for a particular set of purposes. This set of tools actually constitutes a geographic information system. A geographic information system should be thought of as being much more than means of coding, storing and retrieving the data about the aspects of the Earth's surface because these data can be assessed, transformed and manipulated interactively for studying environmental process, analyzing the results for trends or anticipating the possible results of planning decisions.

Now let us see the definition of GIS. A geographic information system is a computer-based information system which is used to digitally represent and analyze the geographic features present on the Earth's surface and the events that take place on the Earth's surface. A GIS is an information system that is designed to work with reference data by spatial or geographical coordinates. In other words, a GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data. You can see in the figure also, this is the simplified diagram of the GIS.

Here, we are first collecting the data collection, then the data storage, then the manipulation analysis. And for this, then we are coming to the output products, then user take its action as per the user needs, and then planning are being done. So this GIS system helps us for assessing the resources which is lying on the Earth's surface or assessing the different phenomenon which is taking place on the Earth's surface in a very, very, accurate way. Now what are the components of GIS? Actually the components of GIS can be defined in various ways but very comprehensively it can have the following components.

First component is the computer system that is hardware and operating system. Second is the software. Third is the spatial data. Fourth is the data management and analysis procedures and fifth is the personnel to operate the GIS. Now see the computer system that is hardware and operating system.

The hardware components of GIS comprise of a central processing unit that is CPU, disk drive, tape drive, digitizer, plotter and visual display unit as you are seeing in the adjacent figure. CPU comprises of so many components for the GIS. The disk drive and tape drive are basically data storage devices. The tape can be used for communicating with other systems. A digitizer is an input device to convert graphics into digital data, whereas the plotter, an output device, converts the digital data into the graphical form.

The scanner is a graphic input device. The visual display unit, along with a keyboard or mouse, is required to interact with the computer. The printer is required to get hard copy of the reports, tables, charts, etc. And the CPU of the computer interacts with various hardware components and performs computations and analysis. Then the software.

The GIS software package has a set of models for performing digitization, editing, overlaying, networking, vectorizing, and data conversion, analysis, and for answering the queries, and lastly, generating the output. You can see here the open source and the commercial both. The open source are GRASS GIS, SAGA GIS, QUANTAM GIS, MAP Window GIS, ILWIS, uDig, gvSIG, and Commercial ERDAS Imagine, Esri-Arc Series, Intergraph-Geomedia, Mapinfo, ENVI, IGIS, Tntmips. In the next column, you can see Jump GIS, White Box GAT, Kalypso, Terra View, Capaware, and Supermap, Geomatica, IDRISI, Netcad. So these are the list of various GIS softwares.

Spatial data are characterized by information about position, connections with other features, and details of non-spatial characteristics. All GIS software are designed to handle spatial data. Spatial data require spatial referencing using a suitable geographic referencing system which should be flexible and lasting since a GIS may be intended to last many years. A traditional method of representing the geographic space occupied by spatial data in a GIS environment is in the form of a series of thematic layers. Alternatively, a space can be viewed as populated by discrete points or objects having empty spaces in between objects. The spatial data represented as either layers or objects are simplified by breaking down all geographic features with three basic entirety types, points, lines, and areas before they can be stored in the computer. Then the data management and analysis procedures.

Input data in the form of spatial data and non-spatial data and information about the linkages and updating of data are the most expensive and time-consuming part of any GIS project. Data input is the process of converting data from its existing form to one that can be used by the GIS. The management of data in GIS includes storage, organization, and retrieval using a database management system that is DBMS. The DBMS should provide support for multiple layers, for multiple users, and multiple databases, allowing efficient updating and minimizing the redundant information. It should also allow data independence, security, and integrity. GIS analysis procedures include, first, the storage and retrieval capabilities for presenting the required information. Second, the queries allowing the user to look at patterns in the data. Third, the prediction or modeling capabilities to have information about what data might be at different time and place. The data output in GIS depends on cost constraints, the type of users, and output device available.

Now, fifth is the personnel to operate the GIS. So, a GIS project requires a trained personnel who can plan, implement, and operate the system. They should also be capable of making decisions on the basis of the output. The success of any GIS project depends upon the skill and training of the personnel who are handling the project. Now input data for GIS. Input data for GIS cover all aspects of capturing spatial data and the attribute data.

The sources of spatial data are existing maps, aerial photographs, satellite imageries, field observations and other sources as you are seeing in the figures. That is maps, aerial photographs, satellite imageries, field observations, other sources and the digital input data are then we are getting and with the help of the techniques, The sources of spatial data are existing maps, aerial photographs, satellite imageries, field observations and other sources as shown in the adjacent figure. The spatial data not in digital form are converted into the standard digital form using digitizer or scanner for use in GIS. The digital spatial data in an acceptable format and the attribute data are stored in the computer memory and managed by the database management system, which is part of GIS for analysis and producing the results in users' desired formats.

Now types of the output products. GIS input data are collected from different sources in different formats and their organization in digital form in desired structure for use in GIS requires a thorough understanding. The output products can be of various kinds and since these products are computer generated, the user or analyst should be aware of the desired forms of the output options available in GIS software. A brief discussion on various kinds of output products of GIS is just discussing here. First is the most common graphic products produced by the GIS are maps.

A map is a two-dimensional model of a part of a surface and it can be of various kinds. The common types of thematic maps are first thematic maps concentrate on spatial variations of a single phenomenon that is population or the relationship between phenomenon that is different classes of land cover. Choropleth maps are typically used to communicate the relative magnitudes of continuous variables as they occur within the boundaries of unit areas. In these maps, different tones, colors, and shading patterns are used to convey the variation in different areas. Proximal or dasymetric maps focus on the location and magnitude of the areas exhibiting relative uniformity that is land cover classes. Different colors and shading patterns are used to describe differences in the thematic values and then the contour maps represent quantities by lines of equal value to emphasize gradients among the values.

Contour lines may be used to indicate variation in topography of a region, high and low pressure regions. Introduction to GIS data. Geographical data in digital form are numerical representation of the real world. It describes real world features and phenomena coded in specific ways in support of GIS and mapping applications using the computer. The digital geographic data must be organized as geographic database. Roughly two-thirds of the total cost of implementing a GIS involves building the GIS database which should be accurate and has a significant impact on the usefulness of the GIS.

Now type of GIS data. Geographic data consists of spatial data and non-special data. The spatial data give information about the geometrical orientation, shape and size of a feature, and its relative position with respect to the position of other features. Spatial data is described by its x and y coordinates. The spatial data is normally available in analog form as maps, but now the maps are also available directly in digital format. In GIS, both types of spatial data are handled differently. The non-spatial data, also known as attribute data, are information about various attributes like length, area, population, acreage, etc. The non-special data describe the attributes of a point, along a line, or in a polygon. In other words, they describe what is at a point, that is, for example, a hospital, along a line, for example, a canal, or in a polygon, for example, a forest.

The attributes of a soil category may be depth of soil, texture, type of erosion, or permeability. The non-special data, mostly available in tabular form, are also converted into digital format for use in GIS. Data Representation and Structure. The data representation is in different kinds of variables, also known as scales, that can be stored in a GIS. These variables are Nominal, Ordinal, Internal and Ratio. Nominal valuables are used when the data are principally classified into mutually exclusive sets or levels based on relevant characteristics.

The nominal variable is the commonly used measure for spatial data. Ordinal variables are lists of discrete classes but with an inherent order or sequence. This representation of data is more sophisticated and orderly as the classes are placed into some form of rank order based on a logical property of magnitude. Internal variables also have a natural sequence, but in addition, the differences between the values are quantified. Then the ratio variables have the same characteristics as internal variables but in addition they have natural zero or real origin that is the starting point.

The computer needs to be instructed exactly how spatial patterns should be handled and displayed. GIS data represents real-world objects as digital data. Real-world objects can be divided into two abstractions, discrete objects, a house, and a continuous field that is rainfall amount or elevation. There are two broad methods used to store data in a GIS for both abstractions, that is raster data structure and vector data structure. In the adjacent figure you can see the GIS data types in raster format as well as in vector format.

Raster data structure, it consists of rows and columns of cells wherein each cell stores a single value. Most often raster data are images, that is raster images, but besides the color, the value recorded for each cell may be a discrete value such as land use, a continuous value such as rainfall or a null value if no data is available. While a raster cell stores a single value, it can be extended by using raster bands to represent RGB, that is red, green, blue colours, colour maps or an extended attribute table with one row for each unique cell value. In raster structures, a point is represented by a single grid cell, a line by a number of neighboring cells strung out in a given direction, and an area by an agglomeration of neighboring cells. There are several complex methods for storing raster data, namely, chain code, run length code, quadtrees etc.

Vector Data Structure. It uses geometries such as points, lines, or polygons, also called areas to represent objects. In the vector model, information about points, lines, and polygons is encoded and stored as a collection of X-Y coordinates. The location of a point feature, such as borehole, can be described by a single X-Y coordinate. Linear features, such as roads and rivers can be stored as a collection of point coordinates. Polygonal features, such as sales territories and river catchments, can be stored as a closed loop of coordinates. Vector features can be made to represent spatial integrity through the application of topology rules such as polygons must not overlap. Vector data can also be used to represent continuously varying phenomena. Now data sources.

The data for GIS collected from different sources. First is the satellite imagery. Remote sensing data in the form of satellite imagery is an important element of the organization of any GIS database as it makes possible repetitive coverage of large areas. Satellite images can support numerous GIS applications, including environmental impact analysis, site evolution for large facilities, highway planning, development and monitoring of environmental useful baselines, emergency and disaster response, agriculture and forestry. Satellite images are also useful for urban planning and management.

In addition to image analysis, satellite images are used to generate thematic information, resulting into thematic maps. Second is the existing maps. Paper maps are the most important source of data for GIS. Maps of various scales, sizes, formats, and time periods showing different features are available for large portion of the Earth, and these are the major sources of data for the GIS database. The information available on a paper map is converted into digital form by the process of digitization for use in GIS.

Then next is the aerial photograph and digital orthophotographs. Another major source of data for GIS application is the aerial photographs. Aerial photographs rectified for relief displacement or radial distortions, these are known as orthophotos. An orthophoto is geometrically equivalent to a conventional line map, and represents planimetric features on the ground in their true orthographic positions. Then next is the attribute data.

Attribute data for GIS are mainly tabular data collected by sampling. The tabular data, which are tables consisting of rows representing samples and columns representing parameter values, can be incorporated into GIS as rational tables. Survey data and records. Some survey data and records about rock types, soil types, elevation, population, and other features are collected by the related national agencies of a country and maintained in the form of maps and tables. These data can be incorporated into a GIS. Other sources. Conventionally, terrain data can be obtained by field surveying using grid leveling, stadia tachometry, or other field surveying methods.

These methods have been replaced by the new generation surveying instrument such as electronic tachometer or total station and the global positioning system that is gps for collecting locational as well as attribute data. Then data verification and editing. It is important to check the acquired data for errors due to possible inaccuracies, omissions, and other factors. The errors in the spatial data are, generally checked by printing the data or by taking its computer plot, preferably on translucent or thin paper, at the same scale as the original. The printout or computer plot is placed over the original map. The two maps are compared visually and the discrepancy in the form of missing data, locational errors and other errors are clearly marked on the printout. If the map is a unique drawing, locational errors are only considered within the boundary of the map.

If the map is one of the series of maps covering large extent of area or the digitized data is to be linked up with the map data already in the computer, then the spatial data must also be examined for spatial continuity across the map boundaries. Certain operations such as polygon formation may also indicate errors in the spatial data. Now sources of error in GIS. Age of data, the data may be old or out of date. For example, old roads and buildings that may have been changed, land surface elevation may change due to human construction, etc. Shorelines may change through natural processes. Some older datasets may have used unusual or outdated classifications.

Second source of error is the partial or incomplete coverage. There may be incomplete coverage in a geological map or very little known about a part of a mapped area. Third is the map scale. One important aspect of a map includes at what scale were the data originally mapped. This affects the degree of generalization necessary to produce a map at a given scale. Every data set has limitations as to scale at which it may be used. Then density of observations. The density of observations determine the level of detail in a map. The average spacing of sampling locations would determine how large the unit should be to be sampled. Relevance, where the data that are really required are not readily available, it is necessary to collect a proxy of data. For example, vegetation type may be used to map soil types from satellite images.

Format. This involves physical storage media, that is disk, tape, FTP, data structure, that is raster or vector, data scale projection, and classification. Transfer from one format to another may result in errors or omissions. Accessibility. The best data may not be easily accessible, so a less detailed data set is used, and the cost of the most accurate data may be too high. Now the steps in a GIS project. To conduct a GIS analysis one must identify the objectives of the project create a project database containing the data one needs to solve the problem, use GIS functions to create an analytical model to solve the problem, and present the results. So first step is the identification of project objectives. The first Step of the process is to identify the objectives of the analysis. One should consider the following questions when he is identifying the objectives. What is the problem to solve? How is it solved now? Are there alternative ways to solve it using a GIS?

Second, what are the final products of the project - reports, working maps, presentation-quality maps? Who is the intended user of these projects - the public, the technologists, the planners or officials? And then, will the data be used for other purposes? What are the requirements for these other purposes? This step is important because the answer to these questions determine the scope of the project as well as how one goes about implementing the analysis. Step two is the creation of project database. The second step is to create a project database. The project database may include data in different formats, depending on the operations that one will use.

Creating a project database is a three-step process. The steps are designing the database, automating and gathering data for the database, and managing the database. Designing the database includes identifying the spatial data that one would need, determining the required feature attributes, setting the study area boundary, choosing the attributes each feature type needs. Automating the data involves digitizing or converting data from other systems and formats into a usable format as well as verifying the data, correcting the errors, and creating topology. Then managing the database involves putting spatial data into the same real-world coordinate system and joining adjacent coverage. And then creating the project database is a critical and time-consuming part of the project.

The completeness and accuracy of the data one would use in his analysis determines the accuracy of the final products. Then analysis of the data. The third step is to analyze the data. Analyzing data in a GIS is often referred to as spatial modeling. A model is a representation of reality used for simulation of a process, prediction of an outcome, or analysis of a problem. A spatial model involves applying one or more of three categories of GIS function to some spatial data.

These functions are geometric modeling functions, that is calculating distances, generating buffers, and calculating the areas and perimeters. Then coincidence modeling functions, that is overlay of data sets to find places where values coincide and then the adjacency modeling functions - allocating then path finding and redistricting. With a GIS, one can quickly perform analysis that would otherwise be impossible or extremely time consuming if done manually. One can create alternative scenarios by changing the methods or parameters and running the analysis again. And step four is the presentation of the results. The fourth step in a project-based analysis is to present the result of the analysis.

The final product should effectively communicate the findings usually to the potential beneficiaries who do not use GIS but have different levels of experience in dealing with maps. Often the results of a GIS analysis can best be shown on a map. Chart to communicate the data and reports to communicate the analysis and the findings are two other ways to communicate the answer to the question. Now benefits of using GIS. GIS helps a planner to make trade-off decisions in resource allocation, that is varying assumptions and criteria can be instantaneously simulated and manipulated to generate different final scenarios or to test varying hypothesis. Multi-source data can be put to analysis. Rapid access to huge volume of data ensuring the decisions or outcome have an added degree of objectivity which can be accomplished in some situations in real time.

Once digitized, any GIS data can be quickly and efficiently updated thereby allowing frequent revisions. Time series changes can be monitored rapidly and statistical calculations of these can be quantified allowing future projections to be predicted. The cost effectiveness is such that GIS allows a company to be competitive in various ways. GIS allows the production of special purpose maps at low cost. GIS technology enables a high quality of output.

Limitations of GIS. A GIS has many beneficial applications, however, like other technological systems, there are also some limitations for its use. The first is the GIS data are relatively expensive than traditional data. Additionally, privacy and security issues can sometimes limit distribution of data. Collecting the data can be very time consuming. Then GIS data may also be subject to misuse or misinterpretation.

GIS has its origin in the earth science and computer science. GIS often relies on the quality of available data, which may introduce serious errors. GIS shows only spatial relationships but does not necessarily explain them or provide absolute solutions which is the actual need of the user. Therefore, solutions derived from GIS may not be appropriate for humanities, science, research. Learning time on GIS software and systems can be long because it easily becomes the objective of the study rather than just a tool.

GIS integrates several individual subjects which demands proper knowledge on all of the integrated disciplines. And then the GIS needs specialized computer equipment and software. Now GPS. That is Global Positioning System. It is a satellite navigation system. It stands for Global Positioning System.

Global Positioning System provides continuous positioning and timing information anywhere in the world under any weather conditions. Because it serves an unlimited number of users as well as being used for security reasons, GPS is one-way-ranging system, that is, users can only receive the satellite signals. GPS consists, normally, of a constellation of twenty four operational satellites. Out of which four GPS satellite signals are used to compute positions in three dimensions and the time offset in the receiver clock. GPS consists of mainly three segments. First is the space segment, that is satellites. Second is the control segment, that is the ground stations.

And third is the user segment, that is user and their GPS receiver. You can see in the diagram also the different segments. That is space segment, control segment, and user segment. Space segment is the satellites. The space segment consists of the twenty four satellites.

Each GPS satellite transmits a signal, which has a number of components that is two sine waves also known as carrier frequency, two digital codes and a navigation message. The codes and the navigation message are added to the carriers as binary bi-phase modulations. The carriers and the codes are used mainly to determine the distance from the user's receiver to the GPS satellites. The navigation message contains, along with other information, the coordinates, that is the location of the satellites, as a function of time. The transmitted signals are controlled by a highly accurate atomic clock on board the satellites.

Next is the control segment that is the ground stations. The control segment of the GPS system consists of a worldwide network of tracking systems with a master control station that is MCS located in the United States at Colorado Springs, Colorado. The primary task of the operational control segment is tracking the GPS satellites in order to determine and predict satellite locations, system integrity and behavior of the satellite atomic clocks, atmospheric data, the satellite almanac and the other considerations. This information is then packed and uploaded into the GPS satellites through the S-band link. And third is the user segment, that is user and their GPS receiver.

GPS user equipment varies widely in cost and complexity depending on the receiver design and application. Most GPS receivers consist of three basic components, that is first an antenna which receives the signal and in some cases has anti-jamming capabilities. Second, a receiver processor unit which converts the radio signal to a usable navigation solution. And third, a control display unit which displays the positioning information and provides an interface for receiver control. The user segment includes all military and civilian users. With a GPS receiver connected to a GPS antenna, a user can receive the GPS signals which can be used to determine his or her position anywhere in the world.

Now what's the use of GPS? GPS are being used for several purposes. First is the navigation and mapping. GPS helps users to find directions and navigate accurately using devices like smartphones and car navigation systems. Then tracking and security, GPS is used to track vehicles, pets and people, improving security and fleet management.

Then disaster management, GPS aids in search and rescue operations during disasters by locating affected areas and people in need. Then agriculture and farming, farmers use GPS for precision farming, helping with soil mapping, irrigation and crop monitoring. In military and defense, GPS is essential for military operations, guiding missiles, aircraft and soldiers with precise positioning. The working principle of GPS. The GPS receiver gathers information on satellite locations through two types of data, that is almanac and ephemeris, which enable precise positioning.

Almanac data, this is a broad orbital model for all satellites, continuously transmitted and stored in the GPS receiver. It remains valid for several hours and helps the receiver to predict the satellite locations. Second is the ephemeris data. This highly precise data contains orbital and clock corrections for individual satellites ensuring accurate positioning. Each satellite broadcasts only its own ephemeris data which remains valid for a short duration. Ground stations track satellite orbits, altitude, and speed. They send corrections to the master control station, which updates the satellites with precise orbital adjustments and clock corrections. The stored almanac data allows the GPS receiver to quickly identify and track satellites, reducing the time required to determine the location. And by combining almanac and ephemeris data, the GPS receiver can accurately calculate its own position by determining the exact locations of the visible satellites and accounting for clock errors.

Now let us summarize the chapter. We have first discussed about the GIS, that is geographic information system. A geographic information system is a computer-based information system which is used to digitally represent and analyze the geographical features present on Earth's surface and the events that take place on it. Then we have discussed about the components of GIS. The component of GIS can be defined in various ways, but very comprehensively it can have the following components.

That is computer system, hardware and operating system, software, spatial data, data management analysis procedure and personnel to operate the GIS. Then we have discussed the common type of thematic maps. We have seen thematic maps, choropleth, proximal or dasymetric and the contour maps. Then we have discussed the types of data. GIS generally consists of spatial data and non-spatial data.

Then we have discussed the data sources in GIS. These sources are satellite imagery, existing maps, aerial photographs, attribute data, and survey data and records. Also, we have discussed about the sources of error in GIS because of the age of data, partial or incomplete coverage, map scale, density of observation, relevance, format, accessibility, and cost. Then we have discussed about the data representation or structure. The data representation is of different types, that is nominal, ordinal, internal, and ratio.

There are two broad methods, which is using two stored data in a GIS, that is, raster data structure and vector data structures. We have also seen the steps of GIS project. The steps are identification of the project objective first, then creation of project database, then analysis of data, and then lastly the presentation of results. And in last, we have discussed about the GPS, that is global processing system. It is a satellite navigation system.

It provides continuous positioning and timing information anywhere in the world under any weather conditions. Thank you very much to all.