UNIVERSITY OF BENIN

Benin City, Nigeria

Training Course 2

REMOTE SENSING AND GIS

Module 1: Overview of GIS and Remote Sensing
Module 2: Fundamentals of Remote Sensing
Module 3: Application of GIS and RS in Water Resource Planning and Management

TRAINING COURSE 2: **REMOTE SENSING AND GIS**

Module I: overview of GIS and Remote Sensing.

Introduction to GIS and Remote sensing,

Geographical Information is information about geography, that is, information tied to some specific set of locations on the Earth's surface including the zones of atmosphere. 'Spatial' is often used synonymously with or even in preference to, 'geographical' in this context, although in principle it might be taken to include information that is tied to frames other than the earth's surface, such as, human body (as in medical imaging) or a building.

Today, the term GIS tends to be applied whenever geographical information in digital form is manipulated, whatever be the purpose of that manipulation. Thus using a computer to make a map is referred to as 'GIS'. This entails using the same computer to analyze geographical information and to make future forecasts using complex models of geographical processes. The earth images collected by remote sensing satellites are geographical data, but the systems that process the images are not to be called GIS as long as they remain confined to this particular form of data in such cases. 'GIS' tends to be reserved for systems that integrate remotely sensed data with other types, or process data that have already been cleaned and transformed. Similarly, an atmospheric scientist or oceanographer will tend to associate 'GIS' with the system used more for multidisciplinary work and policy studies, and other software environments for modelling and analysis within the confines of one's own discipline.

Digital representation,

Management of GIS data consists of storing a variety of data categorized under two types, entity (spatial data) and attribute (aspatial) data in a way that permits us to retrieve or display any combinations of these data after analysis and manipulation. In order to perform these operations, the computer is able to store, locate, retrieve, analyze and manipulate the raw data derived from a number of sources by using representational file structures. In other words, each graphical identity must be stored explicitly, along with its attributes, so that, we can retrieve and select the correct combinations of entities and attributes in a reasonable time.

GIS database comprise: spatial or entity or graphical database, non-spatial or attribute database, and a linkage mechanism for their topology, to show the relationship between the spatial data and attribute data for further analysis.

An entity (either a point, or a line, or an area) has both spatial and attribute data to describe it.

Spatial data can be known as "where things are" data and attribute data the 'what things are' (Ian Heywood et. aI., 1998).

Nature of geographic data (raster and vector data),

An entity is the element in reality. It is a phenomenon of interest in reality that is not further subdivided into phenomena of the same kind. For example, a city can be considered an entity. A similar phenomena stored in a database are identified as entity types. All geographical phenomena can be represented in two dimensions by three main entity types: **points**, **lines**, and **areas**.

There are two additional spatial entities: **networks** and **surfaces**. These are an extension of the area and line concepts.

A point has zero dimension and has only the property of location. A point feature is made up of a point or a set of points. Wells, benchmarks, and gravel pits are examples of point features.

A line is one-dimensional and has the property of length in addition to location. A line has two end points and points in between to mark the shape of the line. The shape of the line may be a smooth curve or a connection of straight line segments. A polyline feature is made up of lines. Roads, streams and contour lines are examples of polyline features.

A polygon is two dimensional and has the property of area (size) and perimeter in addition to location. Made up of connected, closed, nonintersecting line segments, a polygon may stand alone or share boundaries with other polygons. A polygon feature is made up of a set of polygons, example of polygon features includes timber stands, land parcels and water bodies.

A surface entity is used to represent continuous features or phenomena. For these features there is a measurement or value at every location, as in the case of elevation, temperature and population density. This makes representation by a surface entity appropriately. The continuous nature of surface entities distinguishes them from other entity types (points, lines, areas, and networks) which are discrete, that is, either present or absent at a particular location.

A network is a series of interconnecting lines along which there is a flow of data, objects or materials, for example, the road network, along which there is a flow of traffic to and from the areas. Another example is that of a river, along which there is a flow of water. Others not visible on the land surfaces, include the sewerage and telephone systems considered network type of entities.

Features with 'fuzzy' boundaries, such as the woodland, can create problems for the GIS designer and the definition of entities, and may have an impact on later analysis. Deciding which entity type should be used to model a real-world feature is not always straightforward. The way in which individuals represent a spatial feature in two dimensions will have a lot to do with how they conceptualize the feature. In turn this will be related to their own experience and how they wish to use the entity they produce. An appreciation of this issue is central to the design and development of all GIS applications.

There are two fundamental methods of representing geographical entities. They are

(i) Raster data model, and
(ii) Vector data model.

A vector data model also called a discrete object model prepares data in two basic steps so that the computer can process the data. First it uses points and their x-y coordinates to represent discrete spatial features as points, lines and polygons (areas) over an empty space. Secondly, it organizes geometric objects and their spatial relationships into digital data files the computer can access, interpret and process.

A rater data model uses a regular grid to cover the space. The value in each grid cell corresponds to the characteristics of a spatial phenomenon at the cell location and the changes in the cell value reflect the spatial variation of the phenomenon. It is better at representing continuous phenomena and is field-based model.

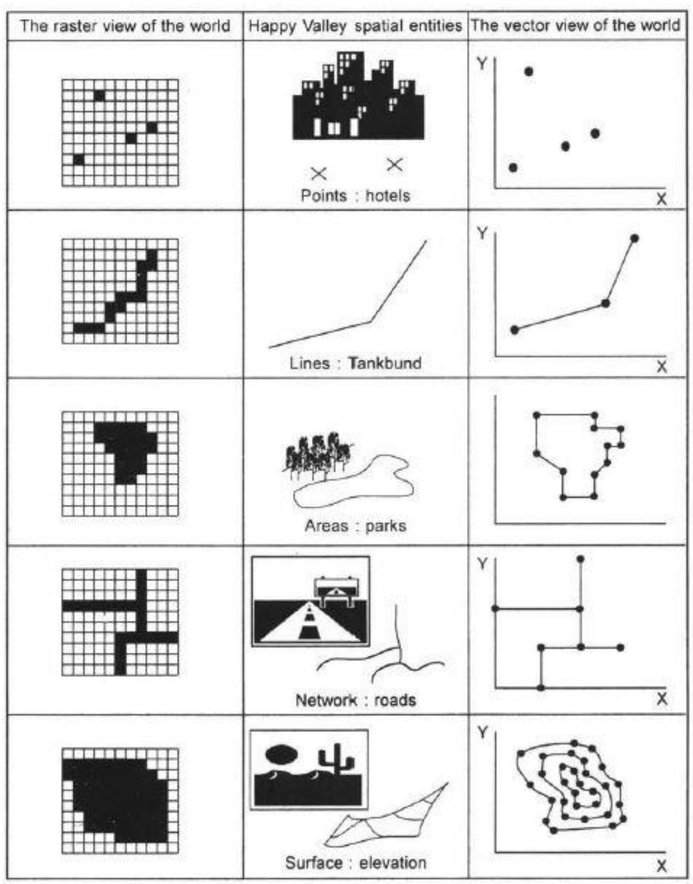

Figure: 1 Data Representation for different elements

Coordinate systems and Map projections,

The first important spatial concept in mapping technology is to locate objects with respect to some reference system. The system must have a structured mechanism to communicate the location of each object under study. The characteristics that a referencing system should possess include stability, the ability to show points, lines and areas and the ability to measure length, size and shape (Dale and McLaughlin,1988). There are several methods of spatial referencing systems and they can be grouped into three categories, namely, **geographic coordinate systems**, **rectangular coordinate systems** and **non-coordinate systems**.
In geographic coordinate systems, the coordinates of any location on the earth surface can be defined by latitude and longitude. Lines of longitude, called meridians are, drawn from pole to pole. The starting point for these lines called the prime meridian runs through Greenwich.

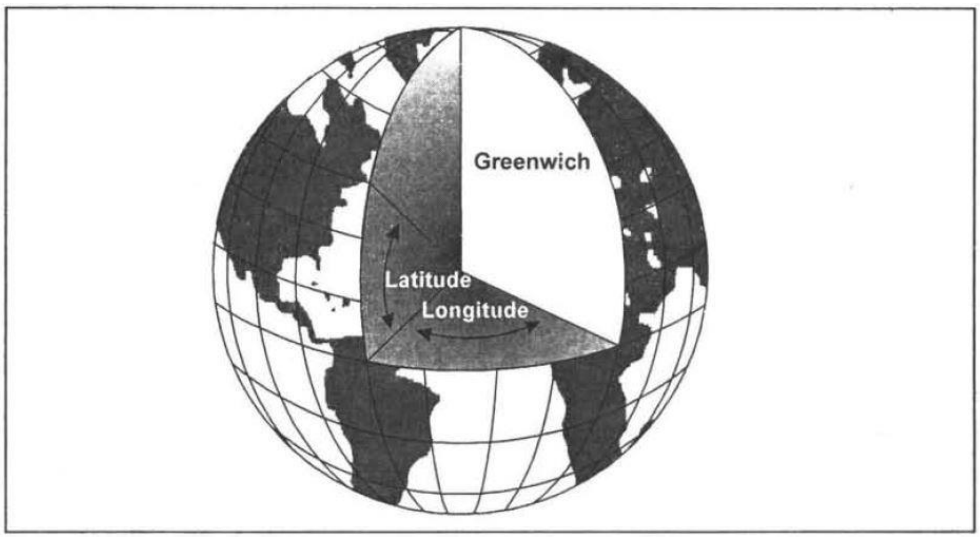

Figure 2 The geographic grid.

The **prime meridian** is the starting or zero point for angular measurements, east and west. The lines of latitude lie at right angles to lines of longitude, and run parallel to one another. That is, each line of latitude represents the circle rounding the globe. Each circle will have a definite circumference and area depending on where it lies relative to the two poles. The circle of greatest circumference is called the **equator** and will be at equidistant from the poles. This type of location is called absolute location and it gives a definitive, measurable, and fixed point in space. This system is also called spherical grid system. This spherical grid system is produced by slicing the entire globe and placing two sets of imaginary lines around the earth. The first set of lines starts at the middle of the earth or equator called **parallels**, and circle the globe from east to west. These parallels are called **latitudes**. The second set of lines, called **meridians**, are drawn from pole to pole. These are called **longitudes**. Simply, it can be stated that the system of angular measurements allows us to state the absolute position of any location on the surface of the earth while calculating the degrees of latitude north or south of the equator, and the degrees of longitude east and west of the prime meridian.

Most of the spatial data available by means of remote sensing systems or any other sources of data for use in GIS are in two-dimensional form. This coordinate referencing system to locate any object point is called **rectangular coordinate system**. The location of any point on the earth's surface with reference to rectangular coordinate system is generally termed as **relative position**.
A **datum** is a mathematical model of the earth which serves as the reference or base for calculating the geographic coordinates of a location (Burkard 1984; Mosffitt and Bossler 1998). The definition of a datum consists of an origin, an ellipsoid and the separation of the ellipsoid and the earth at the origin. Because of this definition, datum and ellipsoid are often interchangeable to GIS users.
The third coordinate system, namely, **non-coordinate system**, provides spatial references using a descriptive code rather than a coordinate, such as, postal codes, which are numeric in nature. Some countries use the non-coordinate system which is alpha numeric as in the case of UK and Canadian postal codes. This type of reference system is of particular importance for GIS users. **Public land survey systems** of Western United states are a classic example of this non-coordinate-referencing system (Heywood et. al 2000). For instance, in relation to prominent features a point may be referred to as being so many kilometers in a given direction from a city, mountain, lake, river mouth, or any other easily located feature on the map.

COORDINATES SYSTEMS AND MAP PROJECTION

The location of a point on the earth surface and subsequent on a map is defined in terms of either rectangular (X, Y) or (N, E) coordinates system or in terms of their Geographic coordinates (Latitude (Ø) and Longitude (ʎ)).

From coordinates, we can compute distances, L, Areas (A) and Volume (V) from a map.

The earth is a three-dimensional surface and in order to project it in a two-dimensional map, map projections are used. The third dimension of a 3D surface earth is elevation H which is measured with reference to Datum. The most commonly used Datum for elevation is mean sea level.

For Nigeria, the Lagos Datum is used. In GIS mapping transformation from one coordinate system to another are desirable.

PLANE COORDINATES SYSTEM

There are generally two types of 2-D coordinates system. These are:

- Rectangular coordinates XY and
- Polar coordinates (ƒ, Ø)

However, in mapping, it is 3D coordinates system that are mainly in use.

The 3-D coordinates system include.

- Rectangular coordinates system and
- Spherical coordinates system

In the rectangular coordinate system, a point is located in term of (XYZ) or (N, E, H)

In the spherical coordinates system, a point is represented in term of Latitude, Ø, Longitude ʎ and Elevation H.

DATUMS AND GEODETIC COORDINATES SYSTEM

A datum is a reference surface used for survey measurements and consist of a set of constants that specify the coordinate system used.

Datums are usually characterized as horizontal and vertical Datum.

For Nigeria, the Minna Datum is used for characterizing the horizontal component of coordinates while the Lagos Datum (mean sea level) at Lagos is used for characterizing the vertical Datum.

In designing a horizontal Datums, Eight parameters are generally required and these include.

- Three parameters to represent origin of coordinates
- Three parameters to specify orientation of the coordinates system
- Two parameters to present the reference ellipsoid.

An ellipsoid is defined by two qualities which are flattering (f) and eccentricity (e) which are both functions of Semi major axis “a” and Semi Minor Axis “b”

For Nigeria, the Datum parameters consist of the followings.

Datum-Minna Nigeria

Spheroid: Clark 1880 (modified)

Semi major Axis: a = 6378249.145m

Semi minor Axis: b = 63256514.870m

First eccentricity squared: $e^2 = 0.006803511283$

Inverse of plattering: $^1/_f$ = 293.465000.000

Projection scale factor: = 0.99975

WORLD GEODETIC SYSTEM WGS 84

WGS 84 is a global Geodetic system that was established by the Global Geodetic society led by the united states NASA and US coast and Geodetic Surveys.

The WGS 84 is based on conventional terrestrial reference system (CTRS) which is a 3 – D geocentric coordinates system with origin coinciding with the center of the earth.

The parameters of WGS 84 generally used for computation are as follows.

Datum: word Geodetic System 1984 (WGS 84)

Spheroid: Word Geodetic System 1984

Semi major Axis: a= 6378137.00m

Semi minor Axis: b= 6356752.314m

First eccentricity squared e^2 = 0.006694.379

Inverse of flattering $^1/_f$ = 298.2572236

Scale factor (sf) = 0.99975

MAP PROJECTIVES

A map projection may be viewed as simply the transformation of features from the curved earth surface to a flat 2 – dimensional surface

The basic aims of map projection are to try to represent geographic coordinates latitude and longitude on a flat surface without distortion.

A number of projection systems have been mathematically derived that approximate curved surface to the earth flat surface (the map) and each of these strive to maintain the following properties.

- Preservation of areas
- Preservation of shapes
- Preservation of scale
- Preservation of direction (Azimuth)

To minimize distortion, map projection systems are designed to satisfy some specific properties which helps in minimizing various forms of distortion.

The three most commonly used include.

- Azimuthal projection in which the azimuth from the center of the map to all other points are correctly located.
- Conformal or Orthomorphic Projections which are special forms of cylindrical or conical projection systems where the scale although variable throughout the map is the same in all directions at any point so that very small areas are correctly represented to the correct shape and finally.
- Equal area projection in which equal areas on the ground are represented as equal areas on the map.

  In Nigeria, modified cylindrical orthomorphic projection also known as Mercator projections are used.

These are:

- Transverse Mercator projection in which we convert the latitudes Ø and longitude (ʎ) into the projection parameters and then construct grid rectangles from the computed coordinates.
- The universal Transverse Mercator (UTM) projection in which the earth is divided into zone of 6^0 longitudes and the maps are all orthomorphic having transverse Mercator projection in each zone.

GIS software

Geographic information systems, better known as GIS software, capture, analyze, and display geospatial data to make 2D or 3D maps. These tools act as asset management platforms for the geographic data they capture, meaning GIS technology has the ability to understand patterns and improve operations in land-based operations. Desktop GIS mapping software typically integrates with a number of drafting and design tools, such as BIM or CAD solutions, to take its analytics capabilities to the next level. These tools also allow users to analyze valuable data such as land use and location of geographic features, including rivers or mountains, right from their desktop.

GIS software usually focuses on gathering, analyzing, and displaying geographical data to manage business operations. GIS can be deployed on-premises or in the cloud. Typical implementations can result in a savings in operational expenses. GIS often integrates with CAD, BIM, and other drafting and design software, to enhance its analytics capabilities.

To qualify for inclusion in the Geographic Information Software (GIS) category, a product must:

- Store, organize, edit, and analyze geographical data
- Include visualization capabilities to display geographical information
- Either have GIS capability or utilize a GIS platform in its solution
- Align and/or manipulate data from maps and sources.

A few examples of GIS software used by GIS professionals include but not limited to:

(i) GRASS GIS – Originally developed by the U.S. Army Corps of Engineers, open source: a complete GIS
(ii) SAGA GIS – System for Automated Geoscientific Analysis- a hybrid GIS software. SAGA has a unique Application Programming Interface (API) and a fast growing set of geoscientific methods, bundled in exchangeable Module Libraries.
(iii) Quantum GIS – QGIS is an Open Source GIS that runs on Linux, Unix, Mac OS X, and Windows.

(iv) Map Window GIS – Free, open source GIS desktop application and programming component.

(v) ILWIS – ILWIS (Integrated Land and Water Information System) integrates image, vector and thematic data.

(vi) Google earth engine: A cloud- based analysis software which uses the Google servers to process satellite based data with GIS programming capabilities. User data can also be uploaded.

There are a number of GIS software packages in operation; some of the most commonly used packages include ARCGIS, IDRISI, ILWIS, GEO MEDIA, GRAM, AUTODESK QUANTUM GIS etc.

i) ARCGIS was developed by Environmental Systems Research Inc. (ESRI) USA and is one of the most widely used GIS software worldwide. The software consists of several components and extensions which include ARC GIS SERVER advanced, ARCGIS desktop Advanced, ESRI City Engine Advanced, etc.

ii) AUTODESK; Autodesk has several software applications that are designed to meet GIS Requirements for various applications, for instance Autodesk map is designed for the creation, maintenance and production of maps and geographic data. They can run on UNIX, PC, Macintosh and palm devices.

iii) IDRIS 32; IDIRSI 32 is a raster GIS and image processing software package and runs on windows platform, it was developed by Clark Laboratory Graduate School, department of Geography in Worcester USA

iv) ILWIS; Is a GIS and Remote sensing software designed for rectification, Geo-Statistical analysis and Overlay functions, it also run on Windows platform

v) GeoMedia; This Intergraph product offers GeoMedia family of solutions and modular GIS Environment (MGT) suite of mapping. The system consists of GeoMedia, GeoMedia Professional, GeoMedia Web Enterprise.

This Modular GIS Environment product set provide readymade capabilities for automation, managing analysis, and presenting GIS data, and is completely inter-operable table with Geo-Media. It can also run on Windows platform like the earlier listed software

vi) MapInfo Professional; MapInfo professional is a GIS Software that contains analytical tools, it also runs on Windows platform

vii) GRASS (Geographic Resources Analytical Support System); This was one of the original GIS software for series of applications, it is a raster-based GIS, Vector GIS, image processing capabilities, Graphic production, Data management, and spatial modelling are all embedded in the software systems.

It runs on LINUX and Windows platform and is a free online software package

viii) Quantum GIS; QGIS is a free open source cross platform Desktop Gis software system that supports viewing, editing and analysis of Geospatial Data. It operates on Microsoft windows, MacOS, Android(beta) with the programming language Python, QT, C++

Web-based mapping

Web mapping is the process of using the maps delivered by geographic information systems (GIS) in World Wide Web. A web map on the World Wide Web is both served and consumed, thus web mapping is more than just web cartography, it is a service by which consumers may choose what the map will show. The terms web GIS and web mapping remain somewhat synonymous. Web GIS uses web maps, and end users who are web mapping are gaining analytical capabilities. The term location-based services refer to web mapping consumer goods and services. Web mapping usually involves a web browser or other user agent capable of client-server interactions.[4]Questions of quality, usability, social benefits, and legal constraints are driving its evolution.

Web GIS is a type of distributed information system, comprising at least a server and a client, where the server is a GIS server and the client is a web browser, desktop application, or mobile application. In its simplest form, web GIS can be defined as any GIS that uses web technology to communicate between a server and a client.

Here are a few key elements essential to web GIS:

- The server has a URL so that clients can find it on the web.
- The client relies on HTTP specifications to send requests to the server.
- The server performs the requested GIS operations and sends responses to the client via HTTP.
- The format of the response sent to the client can be in many formats, such as HTML (Hypertext Markup Language), binary image, XML (Extensible Markup Language), or JSON (JavaScript Object Notation).

The web GIS advantage

By utilizing the Internet to access information over the web without regard to how far apart the server and client might be from each other, web GIS introduces distinct advantages over traditional desktop GIS, including the following:

- A global reach: As an ArcGIS user, you can present web GIS applications to the world, and the world can access them from their computers or mobile devices. The global nature of web GIS is inherited from HTTP, which is broadly supported. Almost all organizations open their firewalls at certain network ports to allow HTTP requests and responses to go through their local network, thus increasing accessibility.
- A large number of users: In general, a traditional desktop GIS is used by only one user at a time, while a web GIS can be used by dozens or hundreds of users simultaneously. Thus, web GIS requires much higher performance and scalability than desktop GIS.
- Better cross-platform capability: The majority of web GIS clients are web browsers: Internet Explorer, Mozilla Firefox, Apple Safari, Google Chrome, and so on. Because these web browsers largely comply with HTML and JavaScript standards, web GIS that relies on HTML clients will typically support different operating systems such as Microsoft Windows, Linux, and Apple Mac OS.
- Low cost as averaged by the number of users: The vast majority of Internet content is free of charge to end users, and this is true of web GIS. Generally, you do not need to buy software or pay to use web GIS. Organizations that need to provide GIS capabilities to many users can also minimize their costs through web GIS. Instead of buying and setting up desktop GIS for every user, an organization can set up just one web GIS, and this single system can be shared by many users: from home, at work, or in the field.
- Easy to use: Desktop GIS is intended for professional users with months of training and experience in GIS. Web GIS is intended for a broad audience, including public users who may know nothing about GIS. They expect web GIS to be as easy as using a regular website. Web GIS is commonly designed for simplicity, intuition, and convenience, making it typically much easier to use than desktop GIS.
- Unified updates: For desktop GIS to be updated to a new version, the update needs to be installed on every computer. For web GIS, one update works for all clients. This ease of maintenance makes web GIS a good fit for delivering real-time information.
- Diverse applications: Unlike desktop GIS, which is limited to a certain number of GIS professionals, web GIS can be used by everyone in an enterprise as well as the public at large. This broad audience has diverse demands. Applications such as mapping celebrity homes, tagging personal photos, locating friends, and displaying Wi-Fi hot spots are a few of the many current examples of web GIS.

These characteristics reveal both the advantages and challenges facing web GIS. For example, the easy-to-use nature of web GIS stimulates public participation, but it also reminds you to take into account Internet users who have no GIS background. Conversely, supporting a large number of users requires web GIS to be scalable.

Web GIS is a new pattern for delivering GIS capabilities. Maps on the web provide a new paradigm for how people everywhere access and use geographic information. They use GIS maps on their desktops, the web, tablets, and smartphones for a sophisticated range of activities to apply advanced geographic information.

Web GIS is a transformation of GIS that brings analytics to spatial data in a way that wasn't possible before. Previously, spatial data had to be processed, modified, and extracted to answer a predetermined set of questions. Now, the data is transformed into web maps or services that are mashed up with different layers into a web GIS, which provides the flexibility to answer any possible question. The data is ready and waiting to dynamically answer questions. It no longer needs to be processed for each individual question. Web GIS is a much more flexible and agile workflow.

Web GIS brings GIS into the hands of the people. It reduces the need to create custom applications, provides a platform for integrating GIS with other business systems, and enables cross-organizational collaboration. Web GIS allows organizations to properly manage all their geographic knowledge. At the heart of web GIS is a map-centric content management system.

How does one go about implementing web GIS? One of the strengths of the ArcGIS platform is its flexibility to support the web GIS implementation method that best fits an organization. It can run completely in the cloud, completely within an organization's own infrastructure, or in a hybrid pattern.

DATA MODELS

Spatial data structures provide the information that the computer requires to reconstruct the spatial data model in digital form. Although some lines act alone and contain specific attribute information that describes their character, other more complex collections of lines called networks add a dimension of attribute characters. Thus, not only does a road network contain information about the type of road or similar variables, but it will also indicate, that travel is possible only in a particular direction. This information must be extended to each connecting line segment to advise the user that movement can continue along each segment until the attributes change perhaps until a one-way street becomes a two-way street. For example, one node might indicate the existence of a stop sign, a traffic signal, or a sign prohibiting U-turns. All these attributes must be connected throughout the network so that the computer knows the inherent real-world relationships that are being modelled within the network. Such explicit information about connectivity and relative spatial relationships is called topology. like line entities area entities can be produced in the vector data structure. By connecting pairs of coordinates into lines and organizing the lines into a looping form, where the first coordinate pair on the first line segment is the same as the last coordinate pair on the last line segment, we create an area or polygon. As with point and line entities, the polygon will also have associated with it a separate file that contains data about the attributes or characteristics of the polygon. Again, this convention improves the simple graphic illustration of area entities, making it possible for them to represent in a better way the abstraction of area patterns we observe on the earth's surface. To store such a huge quantity of GIS data in vector and/or raster, a number of models are developed. Raster models are based on grid cells and vector models are based on the vectors in the form of coordinate pairs of points, lines and areas. Each one of these models has its advantages and disadvantages and hence the selection of model depends upon number of parameters.

1. RASTER GIS MODELS

The simplest approach of structuring spatial data is to use grid cells to represent quantized portions of the earth which is called GRID based GIS or raster GIS. In the raster GIS, a range of different methods are used to encode a spatial entity for storage and representation in the computer. Fig. 8.6 shows the most straight forward method of coding raster data.

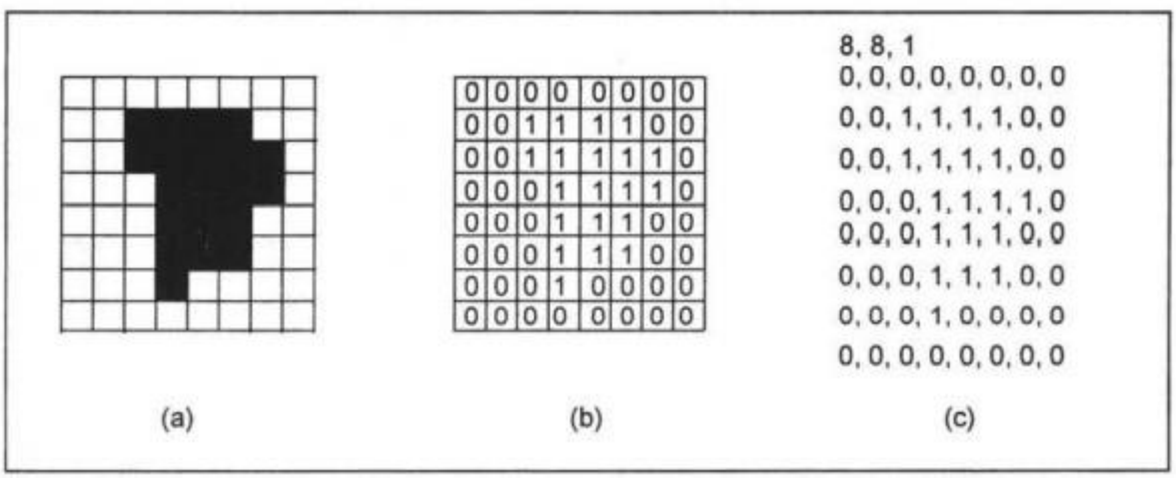

Figure 8: A Simple Raster Data Structure (a) Entity Model, (b) Cell Values and (c) File Structure

The cells in each line of the image are mirrored by an equivalent row of numbers in the structure. The line of the file structure indicates the number of rows, the number of columns and the maximum cell value in the image. In the example shown in the Figure 8, it can be seen that there are 8 rows, 8 columns and the maximum cell value is 1. The remaining cells are filled with 0. It indicates that the entity is not present. If the cell fills with '1 ' indicate that the entity is present. However, if the entities do not occupy the same geographic location (or cells in the raster model), then it is possible to store them all in a single layer, with an entity code given to each cell. This code informs the user which entity is present in which cell.

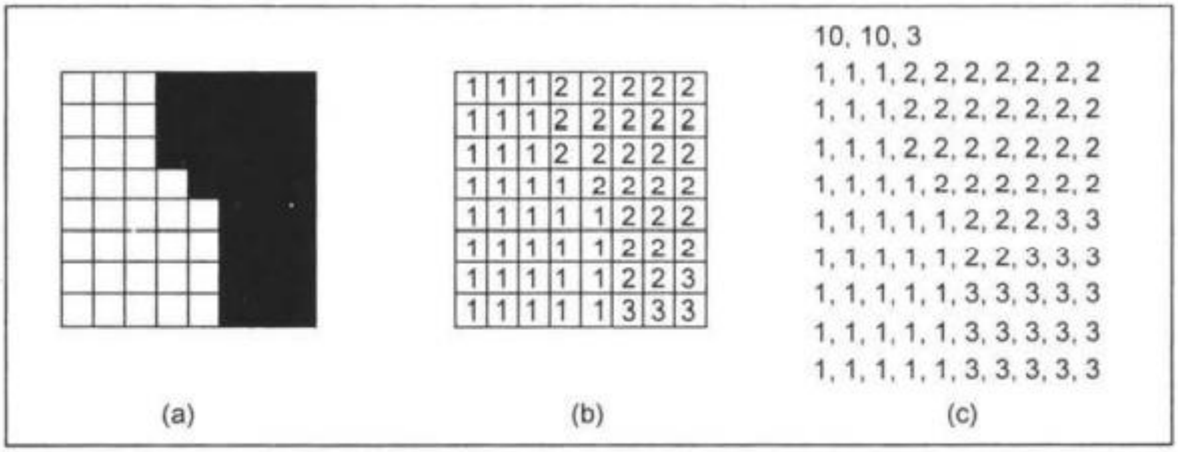

Figure 9: Coding of Features in Raster GIS

Figure 9 shows how different land uses can be coded in a single raster layer. The values 1, 2 and 3 have been used to classify the raster cells according to the land use present at a given location. The value 1 represents residential area; 2, forest; and 3, farmland.

One of the major problems with raster data sets is their size, in that a value must be recorded and stored for each cell in an image. Thus, a complex image made up of a mosaic of different feature such as a soil map with 20 distinct classes requires the same amount of storage space as a similar raster map showing the location of a single forest. To address this problem a range of data compaction methods have been developed. These include run length encoding, block coding, chain coding and quad tree data structures. One of the simplest data structures is a raster or cellular organization of spatial data. In a raster structure, a value for the parameter of interest, elevation in meters above datum, and land use class form a specified list. Plant biomass in grams per square meter, is developed for every cell in any array over space. A set of cells are located by coordinates, and each cell is independently addressed with the value of an attribute. The simplest raster data structure consists of an array of grid cells. Each grid cell is referenced by a row and column number and it contains a number representing the type of value of the attribute being mapped. Raster representation assumes that the geographical space can be treated as though it were a flat Cartesian surface. Each pixel or grid cell is then associated with a square parcel land. The resolution or scale of raster data is the relation between the cell size in the database and the size of the cell on the ground. The use of this type of model mainly related to the volume of data size of memory required. Data storage requirements can be considerably reduced by chain codes, run-length codes, quad trees, and block codes.

2. VECTOR GIS MODELS

Vector data structures allow the representation of geographic space in an intuitive way reminiscent of the familiar analogue map. The geographic space can be represented by the spatial location of items or attributes which are stored in another file for later access. Fig. 8.5 shows how the different entity, namely, points, lines, and areas can be defined by coordinate geometry. Like the raster spatial data model, there are many potential vector data models that can be used to store the geometric representation of entities in the computer.

A point is the simplest spatial entity that can be represented in the vector world with topology. A point requires to be topologically correct with respect to a geographical reference system which locates it with respect to other spatial entities. To have topology a line entity must consist of an ordered set of points a locus of number points, (known as an arc, segment, or chain) with a defined start and end points (nodes). Knowledge of the start and end points gives a line direction. For the creation of topologically correct area entities, the data about the points and lines used in its construction, and a knowledge of how these are connected to define the boundary, are required. The combination of points gives the line entity, and the combination of points and line segments forms an area entity.

The simplest vector data structure that can be used to reproduce a geographical image in the computer is a file containing (x, y) coordinate pairs that represent the location of individual point features. The limitations of simple vector data structures start emerging when more complex spatial entities are considered. There are several ways in which vector data structures can be put together into a vector data model by which the relationships between variables in a single coverage or among variables in different coverages can be defined. The two basic types of vector data models are (i) spaghetti model, and (ii) topological model.

TOPOLOGICAL MODELS

In order to use the data manipulation and analysis subsystem more efficiently and obtain the desired results, to allow advanced analytical techniques on GIS data and its systematic study in any project area, much explicit spatial information is to be created. The topological data model incorporates solutions to some of the frequently used operations in advanced GIS analytical techniques. This is done by explicitly recording adjacency information into the basic logical entity in topological data structures, beginning and ending when it contacts or intersects another line, or when there is a change in the direction of the line. Each line then has two sets of numbers: a pair of coordinates and an associated node number. The node is the intersection of two or more lines, and its number is used to refer to any line to which it is connected. In addition, each line segment, called a link, has its own identification number that is used as a pointer to indicate the set of nodes that represent its beginning and ending polygon. These links also have identification codes that relate polygon numbers to see which two polygons are adjacent to each other along its length. In fact, the left and right polygon are also stored explicitly, so that even this tedious step is eliminated. This design feature allows the computer to know the actual relationships among all its graphical parts to identify the spatial relationships contained in an analogue map document. Fundamentally, the topological models available in GIS ensure,

(a) that no node or line segment is duplicated,

(b) that line segments and nodes can be referenced to more than one polygon, and

(c) that all polygons can be adequately represented.

SHAPE FILE

Advancement of computer technology in terms of database management techniques, speed of the processor, and massive storage capacity of the devices, leads to the development of a newer and no topological structure called the shape file. The shape file structure is the file structure that stores the geometry, topographic information, and attribute information of the geographical features in a dataset file. The geometry and shape of the feature comprise a set of vector coordinates and topology corresponding to their attributes.

The shape file generally has lower processing overhead than its topological counterpart. This results in faster drawing speed and editing, allows for the handling of overlap and noncontiguous features, reduces disk space requirements and makes the files themselves easier to read and write.

Shape files are usually three separate and distinct types of files: main files, index files, and database tables. The main file is a direct access, variable record length file that contains the shape as a list of vertices. The index file contains character length and offset information for locating the values, and a database table which contains the attributes that describe the shapes.

GIS DATA AND DATABASES

Data and databases provide the foundation for water resources GIS development and management. Without an adequate database having accurate and complete entries, there can be no reporting and modelling to support the various decisions required. Sources of spatial data are myriad and include conversion of existing data from archived records and plans (maps) and creation of new data from field measurements. Technologies for field measurements continue to advance for on-ground, aerial, and satellite surveys. Consideration must be given to the inherent accuracy of the data per the intended uses. Given the existence of data in digital formats, it is then required to archive and manage those data for the purposes intended. This requires careful planning and design of spatial databases, which are the foundation of a successful GIS. This section shall deal with (a) principles and methods for GIS data development and maintenance, (b) sources for GIS data relevant to the water resources field, and (c) various attribute and spatial database models and their utility for management of geographic data.

GIS DATA DEVELOPMENT AND MAINTENANCE

GIS functions for spatial data capture include the numerous technologies for data capture as well as the many ways for conversion of source data into GIS-compatible formats. These functions include:

Tablet digitizing

Scanning

Format conversion

Surveying and COGO (coordinate geometry)

GPS (global positioning system)

Photogrammetric data development

Image processing

Geometric transformations

Projection conversions

Attribute entry and editing

Metadata

A large amount of current and historic maps is archived as paper, Mylar, and other flat media. Tablet digitizing has been a primary data-conversion function due to its simplicity and relatively low capital cost. Most GISs include interfaces for tablet digitizing; some packages emphasize this functionality as a primary product attribute. Quality control requirements applied to digitized data include those for topological integrity (nodes and links), projection registration, and feature attribution. Source data copies are "scrubbed" to identify feature classes to be digitized. Digitizing options range from in-house digitizing for small projects to professional contracting for large jobs.

Scanning technologies have advanced such that existing map stock can be captured and processed using image-processing procedures. Although OCR (optical character recognition) and advanced processing can identify map features, it is usually required that manual review and identification of feature attributes be conducted. "Heads-up" digitizing for vector conversion is replacing tablet digitizing for many GIS practitioners where scanned maps or other image data are displayed in the

GIS in the correct projection and coordinate system. Relevant features can then be digitized "on-screen" using a mouse or a pen, with the digitized features automatically assigned to the required image projection and coordinate system. The quality and precision of currently available display monitors greatly facilitate the use of "heads-up" digitizing, allowing operators to easily enter annotation and attribute information during the digitizing process.

Format conversions from other digital data sources can constitute a major portion of a GIS database development. One major source is conversion from CAD (computer-aided design) files. Most engineering organizations conduct their mapping and plan documentation using digital measurement and computerized technologies. For conversion to GIS, it is important that the CAD drawings be logically structured so that the features can be separated. In addition to digital map data, there are other data sources, including database files, raster maps and imagery, text reports, forms or service cards, and mechanical drawings.

COGO (coordinate geometry) is a technique for entering boundary information to a GIS by keyboard entry of distances, bearings, and curve calculations from field surveys and property titles. When distances and bearing are entered based on coordinate grids such as those found in state plane coordinate systems (SPCS), GIS uses this information to create a graphic representation of the lines.

Surveying has traditionally been the primary mapping tool for engineering projects. It is not uncommon for land surveys to be conducted entirely in digital formats. Electronic distance measurements can be taken directly to the computer, plots made, and uploaded to a GIS. The availability of automated measurement equipment has increased the survey data resolution, but knowledge of the principles of surveying is required to guide the survey.

GPS (global positioning system) has revolutionized field-data collection. GPS is based on a constellation of satellites, each of which broadcasts a unique signal. By reading the radio signals broadcast from as few as three of these satellites simultaneously, a receiver on Earth can pinpoint its location on the ground through a process called trilateration. The satellites and ground-based receivers transmit similarly coded radio signals so that the time delay between emission and receipt gives the distance between the satellite and the receiver. If signals from three or more satellites are available, then trigonometry is used to calculate the location and elevation of the receiver. GPS data can be ported directly to the GIS software to provide location information and travel paths of field-data collections. Typical handheld GPS accuracy is about 10 to 15 m. Through correction procedures known collectively as “differential GPS,” the accuracy level can be improved to a few centimeters for the more sophisticated instruments.

Photogrammetric data development is a primary means for developing high-resolution spatial databases for urban areas. Aerial overflights with high-resolution cameras provide the base data for photogrammetric processing. Using stereographic techniques, the analyst defines a photogrammetric model and develops point elevations, contours, and theme-feature identifications and tabulations. In the photogrammetric model, the locations of survey control points can be identified, and the mathematical relationship between control points and other features visible in the photos can be established.

Satellite remote sensing and image processing have become increasingly important, as platforms such as NASA’s Landsat 7, Digital Globe’s Quick bird and WorldView-1, GeoEye’s IKONOS and OrbView, and the French SPOT satellite systems are providing enormous amounts of high-resolution data. These orbital platforms collect and transmit data from various regions of the electromagnetic spectrum that, when analyzed using modern imaging-processing software, provide valuable information for a wide range of applications in water resources engineering, particularly when combined with airborne and ground-truth measurements. Satellite photogrammetry has greatly facilitated the mapping of selected areas with spatial resolutions of less than 1 m, and at a significantly lower cost than aerial photogrammetry. Further advantages of satellite imaging include the ability to obtain repetitive images in various seasons and under any weather conditions.

Object identification and editing are required to establish and maintain the features of a GIS database. All GISs require the capability to transform source data into the data structure of the system and to edit those files once they have been created.

Geometric transformations are applied to establish ground coordinates for a map. This requires that a registration correction be assigned to all data so that the overlay will correspond to the coordinate control and other map layers. The registration correction may be computed to a required acceptance level through least-squares analysis. Data sets having different origins, various units of measurement, or diverse orientations may be resolved to each other using appropriate linear mathematical transformations (called affine transformations) such as translations and scaling to create a common origin and rotation. Often a map layer is registered using a nonlinear rubber-sheeting procedure. Edge matching is required when the features crossing two or more maps do not match at the edge. Resolving mismatches between features located on two or more data layers requires a conflation procedure to reconcile the differences.

Projections involve the multiple ways that the oblate-spheroidal shape of the Earth is mapped to a planar surface as shown in Figure 1.

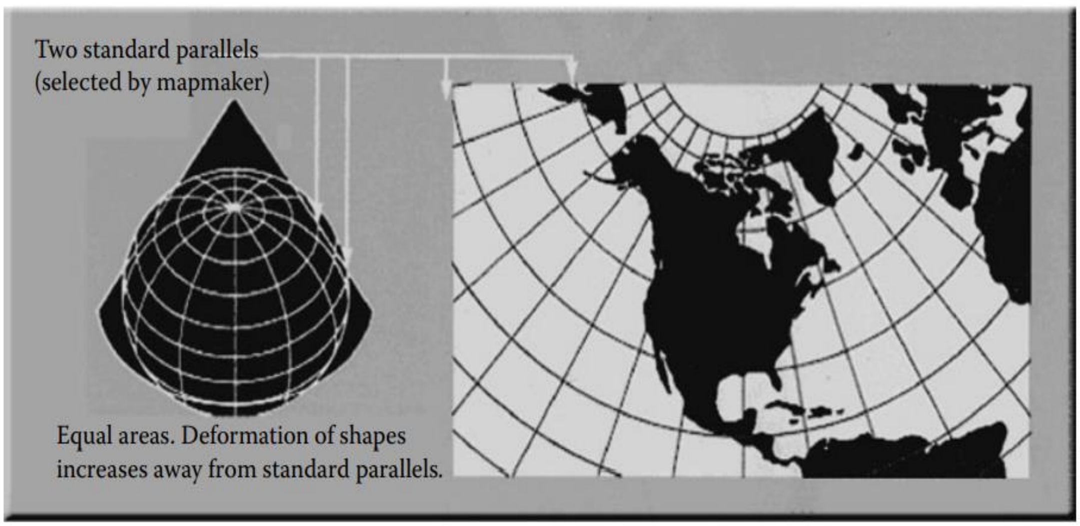

Figure 1: Coordinate Reference Systems arise from Geometric Mapping of the Earth using Projections onto three Shapes that can be Unrolled onto the Map.

Locations on Earth are mapped by a system of latitude and longitude, which is then projected to a map sheet. There are many projections used to portray the Earth as a planar surface, and it is a requirement of a GIS to convert between projections so that data layers can be overlay compared. Coordinate referencing systems continue to improve as base monuments having known coordinates are established within high-accuracy reference networks (HARN).

A map projection requires the specification of an Earth datum, a projection method, and a set of projection parameters. Although the Earth is commonly thought of as a sphere, it is an oblate spheroid or ellipsoid. All latitude and longitude (geographic) coordinates are defined on an Earth datum, which includes a reference ellipse rotated around a defined axis of rotation. For the United States, two horizontal Earth Datums are in common use: The North American Datum of 1927 (NAD 27) and the North American Datum of 1983 (NAD 83). The conversion from NAD 27 to

NAD 83 moves a particular point in latitude and longitude coordinates between 10 and 100 m, depending on location.

There are three main methods of map projection: cylindrical, conical, and azimuthal. The best-known cylindrical projection is the Transverse Mercator projection, which forms the basis of the Universal Transverse Mercator (UTM) coordinate system. The UTM is widely used in the United States for projections of states that have primarily a north-south orientation. The best-known conical projection is the Lambert Conformal Conic projection, used in the United States for projections of land masses with primarily east-west extents. Another conical projection is the Albers Equal Area projection, which preserves true Earth surface area on the flat map projection. An azimuthal map projection is one in which a flat-map surface touches the Earth's surface at one point; this approach is used for meteorological mapping and for views of Earth from space.

Several standardized projection systems exist for legal purposes. More modern standardized projection systems use the NAD 83 datum, and coordinates are in the units of meters. Regardless of the projection, all maps should contain certain elements per cartographic practice. The main elements of a map are the frame, title, key (legend), scale, labels, and north arrow. These are often called annotations. In addition to these, graphic image, grids, Graticule, and outline and filled boxes are also used as annotations. Annotations are text and graphic elements that help viewers interpret the information appearing on a map.

Attribute entry and editing involves the capture and management of the nonspatial data associated with objects such as point, line, and polygon features. Attributes are the characteristics of the objects. GIS functions for attribute data capture include forms for data entry that limit and check keyboard entries for appropriate format and range (e.g., no text for number fields). Import of attribute data from other digital files can be accomplished given standard formats. Scanning of attribute data and OCR (optical character recognition) processing can be used to convert paper records to digital formats. Number, type, date, engineering drawing, or picture can index these documents in a relational database. Regardless of the source, the GIS must provide functions to tag the attribute data to the graphic object; this usually occurs using an index or common key code for both the graphic and the attribute data. Geocoding is the process of tagging parcel identifiers to address and other tabular data on a property as seen in Figure 2.

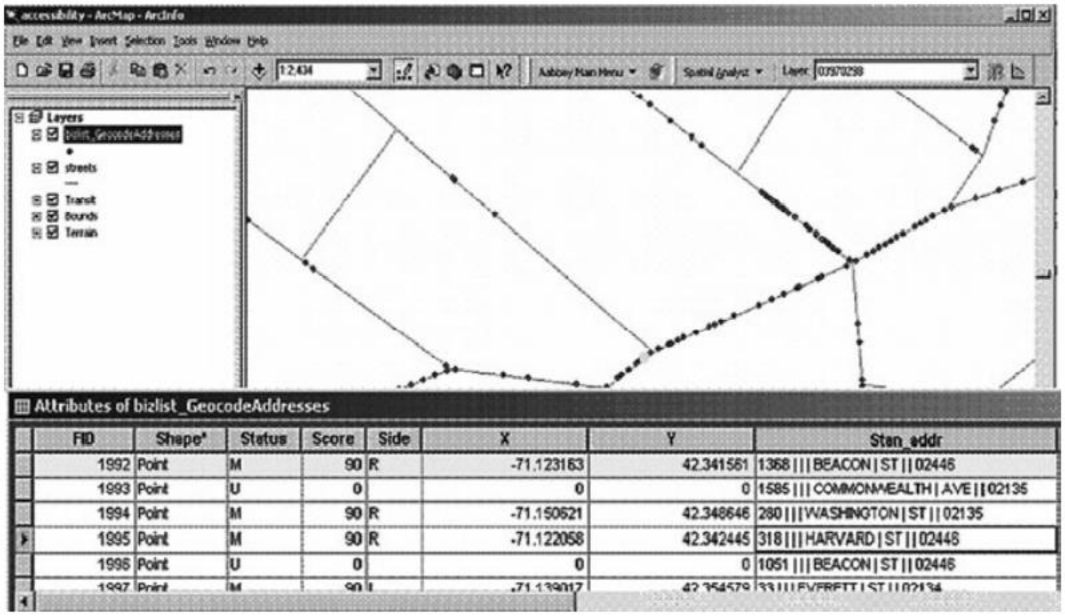

Figure 2: Geocoding of Addresses in a Table Allowing their Location of the Map.

GIS applications can be built that allow users to interactively point to a graphic object (e.g., parcel) and retrieve a database record for display (e.g., water-use records).

Metadata include information about the content, format, quality, accuracy, availability, and other characteristics of a GIS database. They are data about data. Metadata can help answer questions about GIS databases so users can decide which data sources may be useful for their needs.

WATERSHED/ BASIN ANALYSIS/ WATER DISTRIBUTION (NETWORK ANALYSIS, SPATIAL ANALYSIS IN HYDROLOGY)

2.1) WATERSHED

Watersheds are biophysical systems that define the land surface that drains water and waterborne sediments, nutrients, and chemical constituents to a point in a stream channel or a river defined by topographic boundaries. Watersheds are the surface landscape systems that transform precipitation into water flows to streams and rivers, most of which reach the oceans. Watersheds are the systems used to study the hydrologic cycle, and they help us understand how human activities influence components of the hydrologic cycle.

2.1.1) WATERSHEDS AND STREAM ORDERS

Watersheds and stream channels can be described according to their position in the landscape. It is useful to refer to an established nomenclature of stream orders in discussing watersheds and the water in streams that emanates from them. The commonly used method of stream orders classifies all unbranching stream channels as first-order streams (Fig. 1). A second-order stream is one with two or more first-order stream channels; a third-order stream is one with two or more second-order stream channels, and so forth. Any single lower stream juncture above a larger order stream does not change the order of the larger order stream. Thus, a third-order stream that has a juncture with a second-order stream remains a third-order stream below the juncture. The watershed that feeds the stream system takes on the same order as the stream. That is, the watershed of a second-order stream is a second-order watershed and so on. While there is little evidence that streamflow and watershed characteristics are related to stream order, the use of this terminology helps one place a stream channel or a watershed in the context of the overall drainage network of a river basin. The physical and biological characteristics of watersheds and the climate in which they exist determine the magnitude and pathways of water flow. Furthermore, the hierarchy of watersheds within a river basin generally influences the magnitude of water flow.

A river basin is commonly defined as the area of land drained by a river and its tributaries. It plays a vital part in the hydrologic cycle whereby water vapor in the atmosphere condenses, is precipitated on the earth in the form of rain, hail, or snow, and is returned to the atmosphere as vapor. Zone of the basic properties of water is that it flows and that (except under pressure) it always seeks its lowest level, hence its tendency to sink through porous surfaces or to run off impervious surfaces, and its ability to transport fragments of loose material which, given sufficient steepness of slope, enable the water to carve stream channels.

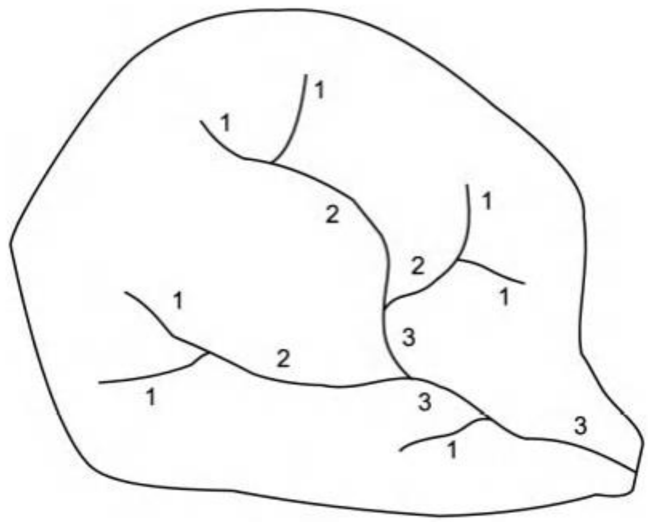

Figure 1: Stream Order in a Watershed

2.2) A GEOMORPHOLOGIC PERSPECTIVE

As the upper-most watersheds in a river basin, first-order watersheds, also called headwater watersheds, are the most upstream watersheds that transform rainfall and snowmelt runoff into streamflow. Headwater streams comprise 70–80% of total watershed areas and contribute most of the water reaching the downstream areas in river basins (MacDonald and Coe, 2007). Headwater watersheds are often forested or once were prior to the expansion of agriculture, urban areas, and other human development activities. These headwaters are particularly important in water resource management. First-order streams in mountainous regions occur in steep terrain and flow swiftly through V-shaped valleys. High rainfall intensities can erode surface soils and generate large magnitude streamflow events with high velocities that can transport large volumes of sediment downstream. Over geologic time, mountains erode and sediment becomes deposited downstream (Fig. 2). As water and sediment from headwater streams merge with higher order streams, sediment is deposited over vast floodplains as rivers reach sea level or discharge points.

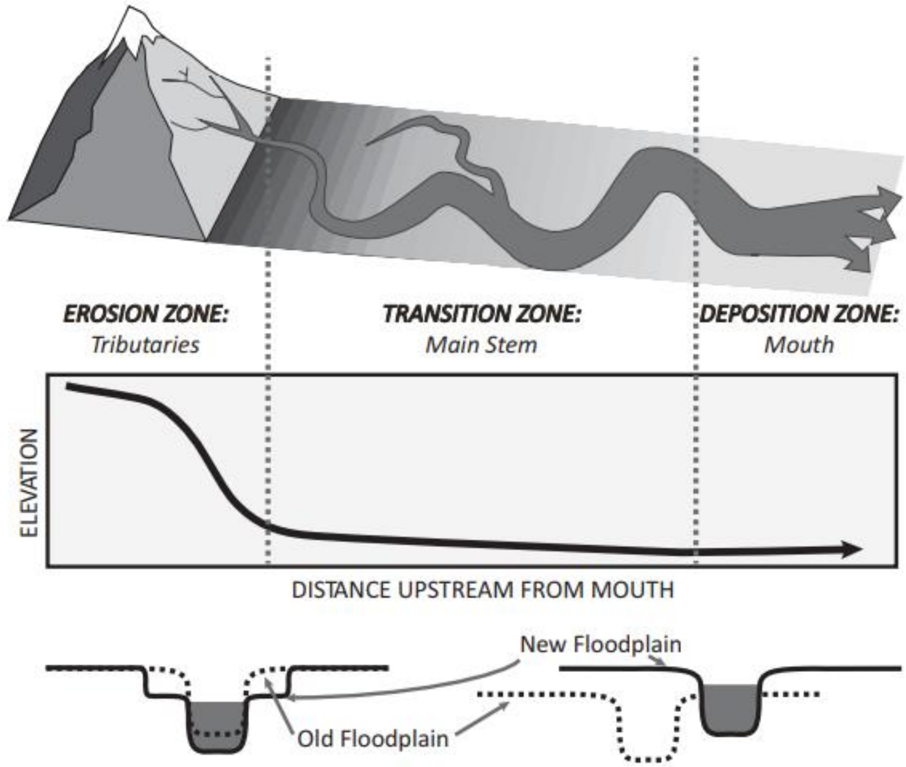

Figure 2: A Geomorphologic Perspective of a Watershed

A transitional zone exists between the steep headwater steams and the lower zone of deposition at the mouth of major rivers and is typically characterized by broad valleys, gentle slopes, and meandering streams. The "work" of water on soils, hillslopes, and within rivers forms landscapes with topography and soils that are better suited for some types of land use than others. Agricultural centres have developed in the transitional and depositional areas of a river basin while the steeper uplands are likely to prohibit intensive agricultural cultivation, resulting in landscapes with forests, woodlands, and rangelands suitable for forestry and livestock-grazing enterprises.

2.1.3) WATERSHED HYDROLOGY AND MANAGEMENT

Hydrology deals with the earth's water in all its phases and is therefore a subject of great importance to society for the creation of livable environment. Human activities such as cultivation on terraced lands, clearing of forests for different purposes, construction of roads, mining, over exploitation of groundwater, dumping wastes into rivers and reservoirs, and application of high fertilizer doses for achieving higher yields, etc., changes the pattern of distribution and circulation of the earth's water. As every inhabitant living on the earth belongs to a particular watershed, they are continuously influencing quantity/availability and quality of water by their actions, and the use of water. The protection, conservation, and management of water resources and water quality depend upon our understanding of the basic concepts of hydrology at a watershed scale and watershed health. It is pertinent to study the hydrological processes as it occurs in a watershed.

2.1.3.1) HYDROLOGIC CYCLES

Hydrologic cycle can be defined as the natural water cycle that describes the continuous movement of water on, above, and below the surface of the earth. There is an endless circulation of water on the earth, linking oceans, land surface and subsurface and atmosphere. The hydrologic cycle as shown in Fig.3, present a pictorial representation of the processes by which water moves around the globe. It begins with the evaporation of water from the ocean which then forms moist air masses. As moist air is lifted, it cools and water vapors condense to form clouds. Moisture is transported in the atmosphere by air currents towards land surfaces around the globe until it returns as precipitation over the earth surface. While falling over the earth a part of precipitation is intercepted by the vegetation and man-made structures. The water that eventually reaches the ground, a part of it may evaporate back into the atmosphere or it may infiltrate into the soil and percolate to become groundwater. Groundwater either seeps its way into the rivers, streams, and oceans, or is released back into the atmosphere through evaporation and transpiration. The balance amount of water that remains on the earth's surface is runoff, which flows and empties into lakes, rivers and streams and is carried back to the oceans, where the cycle starts again. Hence, the major components of the hydrologic cycle are: Precipitation— rain, snow, hail, sleet, dew, drizzle, fog, etc.; Evaporation and transpiration; Interception, depression storage, infiltration, percolation and seepage; Surface runoff, sub-surface runoff or interflow and groundwater or base flow; and water storage over and below the land surface including water stored in the soil profile. From a global perspective, the hydrologic cycle can be considered to comprise of four major systems as can be seen in Fig. 3, the Hydrosphere is the source of water, the Atmosphere is the deliverer of water, and the Lithosphere and the Biosphere are the users of water. The hydrologic cycle is indeed a natural machine run by solar energy and the gravitational forces with water as the material process. There is no gain or loss of water in the cycle. That means the total amount of water on the planet and its atmosphere remains same but is continuously changing from one state to another and is moving at different speeds through different paths. The water falling on earth surface follows different routes on its way back to the ocean. The shortest leg of this journey is the water falling directly into the ocean. The longest leg of journey is probably the water infiltrating into the land surface and percolating down to join the groundwater, which eventually flows to the streams as spring flow and finds its way back to the ocean.

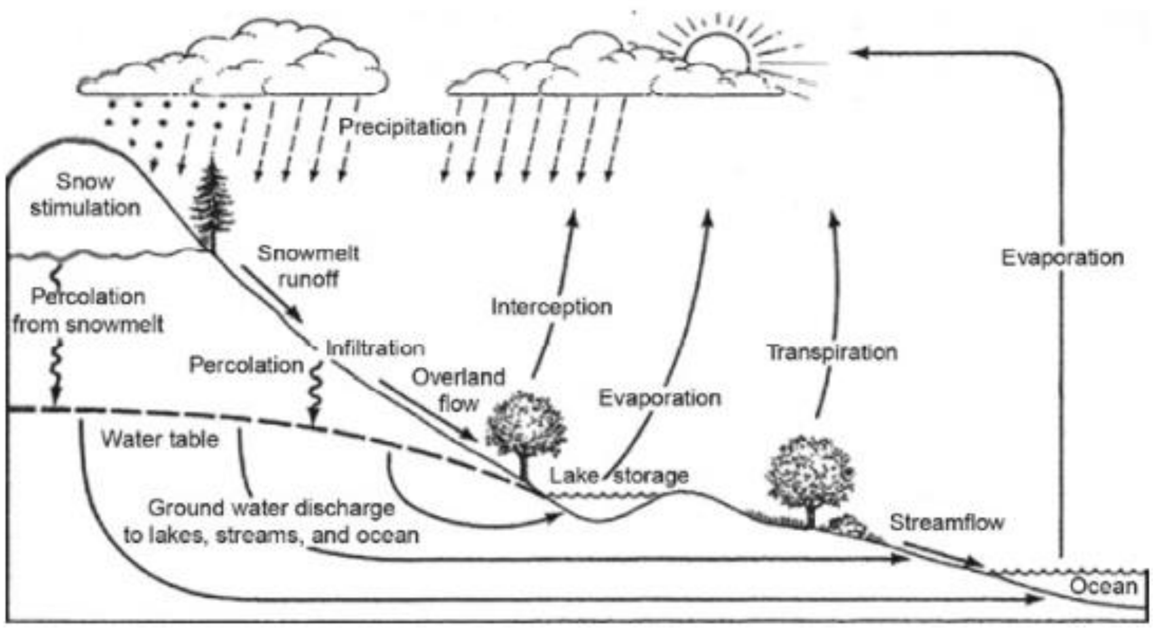

Figure 3: Hydrologic Cycle

2.1.3.2) HYDROLOGY AND WATERSHED

The science which deals with water and its movement in the hydrologic cycle is known as hydrology. That means it deals with the occurrence, circulation and distribution of water from the earth surface to the earth's atmosphere and back to the earth's surface. It is concerned with the water falling as precipitation on land surface, surface water accumulation which turns into surface runoff, water flow in the streams, lakes and reservoirs, soil and rocks below the earth's surface. From an application point of view hydrology deals with occurrence, movement, distribution, circulation, storage, use, development and management of water. Traditionally, hydrology is divided into two main branches: surface water hydrology, and groundwater hydrology. Surface water hydrology deals mainly with water on the earth's surface, whereas groundwater hydrology deals with the water below the earth's surface. Hydrologic knowledge helps us to solve water-related problems: the problems of quantity, quality and availability within a hydrologic unit known as a watershed.

A watershed is defined as the area above a certain point which drains water through that particular point, i.e., outlet. In other words, it is an area of land which drains or sheds all of the incoming excess precipitation at the same place, toward the same body of water or the same low elevation area resulting from its topography. This means that a watershed's boundary is defined by its topographic high points which can also be refer to as surface water divide. The precipitation that falls within the boundary of a watershed would flow, after topsoil have been saturated, as excess precipitation towards its outlet, i.e., point of lowest elevation. Depending on the location of the outlet, the watershed area, shape and characteristics would be different. A watershed is fairly simple to identify in hilly areas because its boundaries are well defined by ridges. However, in flatlands such as the alluvial plains and deltaic regions, identifying topographic high points may be quite challenging because the highest and lowest elevations may have a difference of only a few centimeters. At all points on the earth's surface, even where there is no evidence of surface runoff flow, a watershed does exist. This is because a difference in elevations exists everywhere, and when rainfall occurs, even if it is infrequent, the topographical features of the watershed will determine where runoff water will accumulate and flow. Also, all the drainage lines are located on low points on the land where surface runoff accumulates and flow. The size of a watershed depends on the location of the outlet and it is largest when the streams or river of that watershed discharges directly into an ocean. In that case the watershed might be referred to as a river basin and the rivers involved in such cases generally used to be perennial rivers. A river basin or a large watershed or catchment includes several small watersheds within its boundary, each draining runoff into the same river. Watershed or river basin boundaries do not respect district or state boundaries determined by political considerations.

2.1.3.3) HYDROLOGICAL SCALES

Hydrological scales deal the geographical and temporal extent of analyzing or studying hydrological related problems. Depending on a given hydrologic problem and the situation, the hydrologic cycle or its component processes can be assumed to vary at different scales of space and time.

SPATIAL OR GEOGRAPHICAL SCALE

Spatial scales can be categorized into three, these are the global scale, the river basin scale and the watershed scale. The global scale is the largest scale and the watershed is the smallest spatial scale. Hydrologic study at the global scale is necessary to understand the global fluxes and global circulation patterns of the various component of the hydrologic cycles such as precipitation, temperature, humidity etc. The global hydrologic study can be considered to be comprised of three major systems namely the oceans, the atmosphere, and the land surfaces. The principal processes that transmit water from one system to another are required to be considered. These are precipitation, runoff, groundwater and evaporation. The results of these hydrologic studies are important in water resource planning and assessment at national or regional level, weather forecasting, and climate change studies. In the river basin scale, the spatial coverage can range from a few square km to thousands of square km. In the water movements of the earth system, three systems can be recognized and considered. These are the surface system, the subsurface system, and the aquifer or groundwater system. When the focus is on the hydrologic cycle of the land surface system, the dominant processes to be considered are precipitation, evaporation and transpiration, infiltration, and surface runoff. The surface system comprises of three subsystems: vegetation or land use pattern, topography and soil. The exchange of water among these subsystems takes place through the processes of infiltration, base flow or exfiltration, percolation, and capillary rise. These subsystems abstract and store water from precipitation through interception, depression and detention storage, which is either lost to the atmospheric system or enters subsurface system. The watershed scale or micro scale is the smallest scale for conducting a hydrologic study for studying the different components of hydrologic cycle. It is more or less similar to river basin scale except the spatial coverage on the earth system. The spatial coverage of the watershed scale can range from less than a hectare to a few thousand hectares. As in the case of basin scale, three systems can be recognized to study the water movement of the watershed: the surface system, the subsurface system, and the aquifer or groundwater system. The surface system of a watershed comprises of three subsystems: vegetation or land use type, topography and soil. These three subsystem characteristics are generally manipulated within a watershed to modify the response/output of the watershed in the form of runoff to different values of rainfall input. This makes watershed the most important and basic spatial scale to modify hydrologic response as per the needs of the inhabitants and the environment.

TEMPORAL SCALES

The time scale used in hydrologic studies could be anything from a storm lasting for a few hours to a study spanning many years. It depends on the nature of the hydrologic problem and its objectives. Hourly, daily, monthly, seasonal or annual time scales are common. Sometimes the time interval for the collection of data determines the time scale. The time interval of the available data also affects the time scale of the hydrologic study.

A hydrologic variable like rainfall varies in both the time and space within a watershed. However, depending on the objective or purpose of the study, type of hydrologic analysis and above all the spatial scale, rainfall can be assumed to be either constant in both time and space; constant in space but varying in time; or varying in both time and space. The spatial scale or size of the watershed determines which one of these assumptions is reasonable from a practical point of view. For small watersheds, rainfall can be assumed constant in both time and space in modelling rainfall—runoff relationships. As the size of the watershed increases to medium size, rainfall is considered variable in time but constant in space. But rainfall over a large watershed or a river basin is assumed to vary both in time and space. The areal extent of these watersheds may be different in hilly areas and in plain areas. Rainfall may be considered as constant over larger areas when watershed land topography is plain, as compared to hilly watersheds.

2.1.3.4) WATERSHED AS HYDROLOGIC UNIT

The watershed is a fundamental concept in hydrology and is the basis for understanding the hydrologic processes and for the planning and management of water resources. Storage and movement of water at a watershed scale is complicated due to the coupled processes which act over multiple spatial and temporal scales. Hydrologic processes within a watershed are extremely complex and are difficult to understand completely. However, in an absence of perfect knowledge, these processes may be studied by means of the systems concept. Considering the watershed as a hydrologic system that can be defined as a structure or volume in space, surrounded by a boundary, that accepts water and other inputs, operates on them internally, and produces them as output. Here precipitation is the input, distributed in space over the watershed area; stream flow in the form of runoff concentrated at the outlet of the watershed is the output. Evaporation, transpiration and sub-surface flow could also be considered as outputs, but these are small compared to runoff or the stream flow during a storm. The structure of the system consists of the drainage lines over the watershed land surface or flow paths through the soil below the land surface and includes the tributary streams which merge to form stream flow at the watershed outlet. That means the watershed receives precipitation as input, operates upon it through the processes of interception, infiltration, percolation, overland flow, and channel flow, etc., and depending upon the soil, slope, and land-use/land-cover, antecedent moisture and other watershed characteristics generate output in the form of runoff as stream flow going out of the watershed through its outlet.

2.1.3.5) WATERSHED HYDROLOGIC PROCESSES

An understanding of the various hydrologic processes within a watershed is essential to keep the watershed in good health through the effective management of rainwater/runoff, soil water and soil erosion. When we consider and study the occurrence, movement, circulation and distribution of water, i.e., hydrologic cycle and its component processes within the boundaries of a watershed, it is called watershed hydrology. The term describes how water moves and is stored within a watershed, what are the various water inputs into the watershed and water outputs from the watershed. Understanding how water is used and cycled through a watershed provides the foundation for understanding and describing how land and water interact within that watershed. The major component processes to be studied under watershed hydrology are precipitation, evapotranspiration, infiltration, and runoff and stream flow.

PRECIPITATION

Precipitation provides the primary input of water into the watershed. Precipitation is the moisture or water that falls from the atmosphere in the form of rain, snow, sleet, fog or hail. It varies in its amount, intensity, and form by season and the geographic location of the watershed. However, rainfall and snowfall contribute water significantly to the watershed hydrologic system. In most parts of the world, snow and rainfall are observed and records are maintained. The watersheds located in Himalayas that are at the mean sea level of around 2000 m generally receive precipitation more as snowfall and less as rainfall, and those located in foot-hills or lower hills and plain areas including coastal regions receive that as rainfall. Precipitation is influenced by the elevation of the watershed. However, rainfall being the predominant form of precipitation causing flood flow, the term precipitation is synonymous with rainfall. The coastal watersheds tend to have higher amounts of precipitation than the plain lowlands. It may be due to the orographic effect, in which rising air mass currents cool, condense and release moisture as precipitation. The leeward side of the mountains or barriers receive less precipitation than the windward sides because most of the available moisture in the air mass is lost to precipitation before it reaches the leeward side. The snow packed watersheds contribute stream flow significantly as a main source of water round the year for the major perennial river systems of the world. In fact, the factors such as rainstorm characteristics that is; amount, duration, intensity and average return period determines whether the rainwater will flow into streams or infiltrate into the ground. And this information is crucial for crop planning and management as well as for engineering design of water harvesting and flood control structures in the watershed. The capacity of vegetated surfaces to intercept and store the precipitation water is of great practical importance to the hydrologists. A part of the precipitation while falling from the atmosphere is trapped or intercepted by the vegetation and other structures above the ground surface and is evaporated back to the atmosphere. This portion of the precipitation is known as interception losses and is not available either for infiltration or for runoff generation. As such, interception and its subsequent evaporation constitute a net loss to the watershed hydrologic system which may assume considerable values under certain conditions. It may be responsible for losses reaching 10%–20% of the total precipitation, annually. Interception is a function of precipitation characteristics and the type, age and density of vegetation. The amount of interception, although negligible during the extreme events, is an important term of water balance. Interception water losses from tall forests exceed those associated with lower vegetation, such as grass land and agricultural crops. Coniferous trees tend to intercept more water than deciduous trees on an annual basis as the deciduous trees drop their leaves for a period of time. The presence or absence of vegetation not only affects the amount of precipitation reaching the watershed surface, but also its kinetic energy, and thus its capacity to detach and transport soil material.

DEPRESSION STORAGE

Depression storage is the amount of rainwater stored in the micro or macro depressions on the watershed surface before starting of runoff. The roughness of the soil surface, including roughness brought about by tillage, affects runoff and erosion, and determines the volume of water that can be held on the surface as depression storage. Four grades of surface roughness are categorized (0–

1.2 cm; 1.2–2.0 cm; 2.0–3.0 cm; and > 3 cm micro-relief) in relation to tillage. Only a proportion of the depression depth constitutes effective depression storage. It produces a rainwater loss that depends on the local characteristics of slope, land use and soil type. The amount of water that is stored in the surface depressions is ponded to evaporate or be infiltrated later. Hence, the rainwater loss then depends on the evaporation from the water surface and the infiltration. It has been found that no appreciable surface storage exists on slopes above 20%.

EVAPOTRANSPIRATION

Evapotranspiration is a loss of water from the watershed hydrologic system unlike precipitation, which is an input to the system. Evapotranspiration is the combined net effect of the processes of evaporation and transpiration. Evaporation is a loss of water from the land surface and water bodies, and transpiration is the evaporation of water from leaf stomata following movement of soil water and ground water from the roots upward through the plants and trees. Transpiration accounts for approximately 10% of all evaporating water. The evaporation and transpiration depend on the same physical processes to transform water from a liquid to a gas and both the processes result in a loss of water from the watershed. Hence these processes are often considered together and termed as evapotranspiration. This process moves large quantities of water from the soil and land surface back to the atmosphere. More than 50% of the total amount of precipitation is returned to the atmosphere through this process. Evaporation and transpiration rates vary widely depending upon many factors, including precipitation, temperature, aspect, humidity, and wind speed. Higher temperatures usually result in increased evaporation and transpiration unless soil moisture is limited. Aspect, i.e., the position of watershed slopes or land surface relative to the sun, affects the amounts of solar radiation and heat received with the result that both evaporation and transpiration increase from north to east to west to south-facing aspects. Lower relative humidity also increases evapotranspiration because dry air has a greater capacity to accept moisture than more humid air at same temperature. That is why evaporation and transpiration during precipitation events used to be very low as the air is saturated with moisture. Evaporation increases in response to wind because it energizes the change from liquid water to water vapor at the molecular level, also because moist air is moved away from the water source and replaced with relatively dry air. Similarly, when plants transpire, a thin layer of air around the leaves becomes saturated. Wind stirs and moves that saturated air away from the leaves and replaces it with drier air that enhances evaporation from stomata. The amount of evapotranspiration from an area under field crops, in addition to these factors depends on how much water is available in the root zone, which depends on the field capacity of soil. In forests, transpiration accounts for much greater loss of water than any other mechanism or process in the watershed. A mature tree can transpire tens to hundreds of liters of water per day, depending upon soil moisture availability.

INFILTRATION

Infiltration is the entry of precipitation water into the soil surface within the watershed. It ensures that moisture will be available to sustain the growth of vegetation and helps to sustain the ground water supply to wells, springs and streams. The rate of infiltration may be influenced by the watershed characteristics such as soil type, antecedent moisture content of soil, slope, land use and land cover, and the precipitation characteristics like amount, intensity and duration. On reaching the ground surface, water infiltrates into the soil, saturates the soil in the crop root zone and percolates down to the groundwater reservoir or it may flow over the land surface as runoff. Percolation is the infiltration process below the root zone. Light textured soils having large well-connected pores tend to have higher infiltration rates than heavy textured soils. Land use and land cover also affects infiltration. Infiltration would be higher for soils under forest vegetation and trees than bare land. Tree roots loosen the soil and provide flow paths for infiltrating water. Crop foliage and residues and also surface litter reduce the impact of falling rain drops and prevent choking of the soil pores and passages, thereby maintaining infiltration rates.

SURFACE RUNOFF OR OVERLAND FLOW

Surface runoff is the rainwater that travels over the land surface in the watershed towards the stream channel after satisfying all the precipitation losses. It is generated either when rainfall intensity exceeds the infiltration capacity of the soils or where the soil is already saturated from below. Runoff generated in first case is called infiltration excess runoff or Hortonian overland flow, and that in second case it is called saturation excess runoff or saturation overland flow. Hortonian overland flow is an important runoff mechanism in arid and semiarid regions, where rainfalls tend to be intensive and infiltration rates low or in urban areas having impervious surfaces. Saturation excess runoff mechanism of surface runoff generation occurs primarily on the lower slopes of the watershed and along valleys adjacent to stream channels. Subsurface runoff, also called interflow represents that portion of infiltrated rainfall that moves laterally through the upper soil layers until it reaches the stream channel. Interflow moves below the ground surface but above the water table. The movement of interflow or subsurface runoff is much slower than surface runoff. The proportion of total runoff that moves as subsurface runoff depends on the spatial and temporal characteristics of rainfall and physical characteristics of the watershed. Generally, mechanized agricultural lands and forest lands or lands having thin soil layer overlying more impermeable soil layers tend to promote more interflow. In sloping situations, particularly if there is a reduction in permeability with depth, lateral flow develops in both the litter layer and the upper soil zone. Water then flows laterally down the slope as interflow, meeting and becoming part of stream flow. Base flow is different from interflow in the sense that it responds much more slowly to rainfall and does not fluctuate rapidly. It represents the drainage of water to the stream from deep groundwater. Infiltration water percolates below the root zone and recharges the groundwater that provides water for stream flow through contributions known as base flow. Base flow is the portion of stream flow that is not attributed to the current precipitation; it may be rainfall or snowmelt inputs and is the only portion of stream flow that is present during precipitation-free periods. Base flow occurs at the existing intersection between the water table and the bed of stream channels. On the other hand, storm flow is the component of stream flow that results directly from current precipitation events. Surface runoff and interflow constitute storm flow in a watershed. In forest watersheds, in the beginning of a precipitation event only small portions of the watershed area actively contribute to storm flow. But contributing areas continuously expand non-uniformly throughout the event. Most of the areas that contribute directly to storm flow tend to be adjoining to the stream channels where soils already have higher antecedent soil moisture contents, and areas with shallow soils that become saturated rapidly and therefore can release water for stream flow quickly. In agricultural watersheds, stream flow generation occurs quite differently. Due to tillage operations in agricultural systems a till layer that is more compacted than the overlying soil often forms just below the depth of the tilling implement (15–20 cm) below the land surface. This till layer retards the downward movement of infiltrating water and diverts it laterally at this shallow depth. Consequently, precipitation water moves laterally as subsurface flow at a relatively rapid rate and becomes a part of stream flow quickly. In urban watersheds, there is much less opportunity for precipitation to infiltrate into the soil because of large impervious concrete surfaces. As urban runoff flows through drains directly to streams and rivers, stream flow increases spontaneously.

2.1.3.6) WATERSHED DELINEATION

This stage gives a practical approach to watershed delineation using the ArcGIS software. This generates hydrological boundaries for a specified outlet point(s) on a stream network. At this stage we shall be using the Spatial Analyst Tools. To assess the Spatial Analyst Tool, click on the Arc Toolbox window to expand it, select the spatial analyst tools and expand the hydrology toolbar as shown in Figure 4.

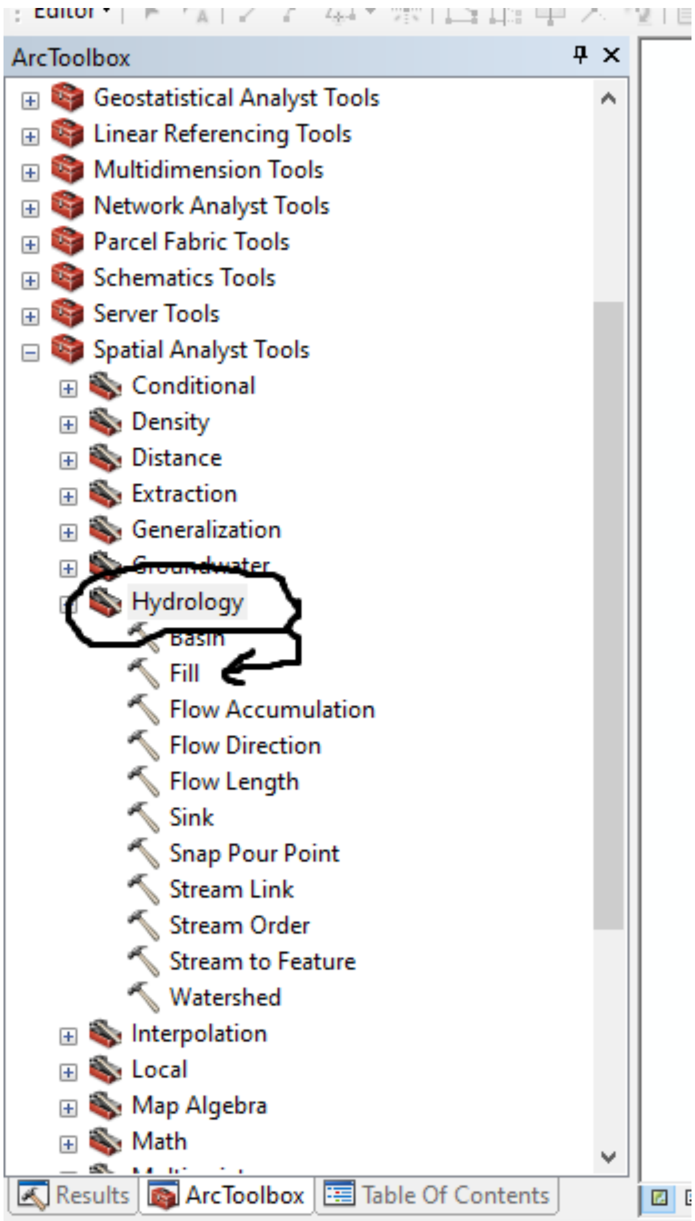

Figure 4: Arc Tool Dialog Box

STEP 1: The Fill tool in the Hydrology toolbox is used to remove any imperfections which is commonly referred to as sinks in the digital elevation model. A sink is a cell that does not have a defined drainage value associated with it as such there are no indications of the direction that water will flow out of the cell. They are assigned when creating a flow direction grid for the landscape. The resulting drainage network depends on finding the 'flow path' of every cell in the grid, so it is of utmost important that the fill step be performed prior to creating a flow direction grid.

On the hydrology toolbar, click the fill tool to open its dialog box shown in Figure 5.

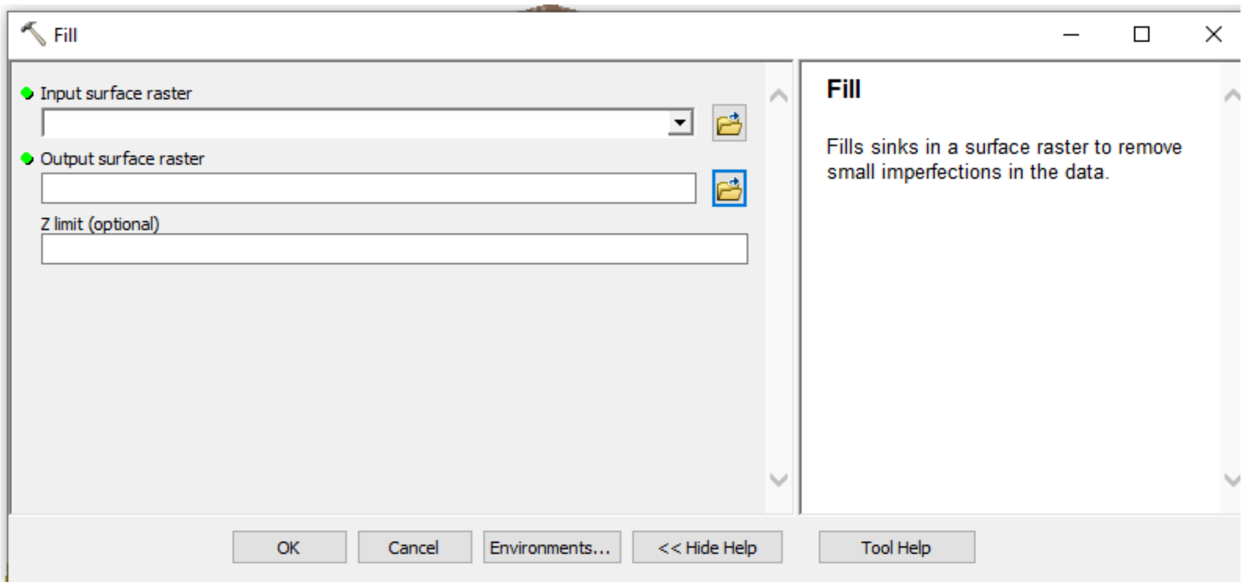

Figure 5: Dialog Box for Fill Option in Arc Toolbox

If you have the DEM loaded into your GIS, then click on the dropdown arrow on the Input Surface Raster box and select the desired DEM otherwise, load from folder.

The Output surface raster should default to the working directory specified in Step 1. You may accept the default name for the filled DEM or change it to a more descriptive name of your choice.

Leave the Z limit blank for this tutorial as it is only required when the difference between the pour points value and the sinks are known. Thus, click on the ***OK*** to run the tool. This process may take some time to run as it is CPU intensive. Depending on the processing power of your computer or workstation it may be faster or slow.

Once the fill process is complete, a new grid will be added to the data frame. There should be a difference in the lowest elevation value between the original DEM and the filled DEM.

Remove the original DEM layer from the map by right clicking on it and select the remove option.

It is important to build a depression less DEM for all subsequent hydrological analyses. Areas of internal drainage can cause problems later in the watershed delineation process.

STEP 2: FLOW DIRECTION

A flow direction grid assigns a value to each of the cells in the DEM that indicates the direction of flow. This value indicates the direction that water will flow from that particular cell. This is an extremely important step in hydrological modelling, as the direction of flow will determine the ultimate destination of the water flowing across the surface of the landscape.

Flow direction grids are created using the Flow Direction tool. For every 30x30m cell neighborhood, the grid processor finds the lowest neighboring cell from the center. Each number in the matrix below corresponds to a flow direction. If the center cell flows due north, its value will be 64 or if it flows northeast, its value will be 128, etc. These numbers have no numeric meaning but are simply a coded directional value that indicates the steepest descent based on elevation.

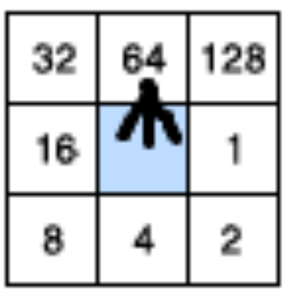

Figure 6: Flow direction matrix

Double-click the Flow Direction tool to open it.

The Input surface raster should be set to the filled DEM.

The Output flow direction raster should once again default to your working directory.

Open the Environment Settings using the Environments button and click on the Raster Analysis option and set the cell size to the same as your filled DEM.

Click OK to run the tool. This process will take some time to complete, and once it has run through a new flow direction layer will be added to your map.

STEP 3: FLOW ACCUMULATION

The Flow Accumulation tool calculates the flow into each cell by accumulating the cells that flow into each downslope cell. In other words, each cell's flow accumulation value is determined by calculating the number of upstream cells that flow into it.

Double-click the Flow Accumulation tool to open it.

The Input flow direction raster should be set to the flow direction grid created in Step 3. The Output accumulation raster will be set to you default working directory.

Accept all other defaults, check the Environment Settings to ensure that the Raster Analysis has its Cell Size property is set to the same as your filled DEM, and click OK to run the tool. This process may take quite some time to complete. The new flow accumulation raster will be added to your map after the processes is complete.

Each cell in the grid contains a value that represents the number of cells upstream from that particular cell. Cells with higher flow accumulation values should be located in areas of lower elevation, such as in valleys or drainage channels. It is very likely that the flow accumulation grid will appear dark and uninformative when first added to the map. This can be fixed by altering the symbolization of the layer. Flow accumulations are important because they allow us to locate cells with high cumulative flow. Each cell has an outlet point called a pour point that indicates the location where water would flow out of the cell. Pour points must be located in cells of high cumulative flow or the watersheds you delineate in the steps below will be very small.

STEP 4: STREAM DEFINITION

Stream is mostly defined base on the flow accumulation threshold within the watershed.

This stage will automatically generate the drainage network, through a conditional. Click on the Spatial Analyst toolbar and expand the Conditional tools, then click the con option to open the dialog box for the conditional statement. In the “Input Conditional Raster” portion, select your flow accumulation from step 3. In the Expression (optional) option, select a value that gives a desirable raster threshold as it depends on the size of the pixel and the raster, the larger the watershed the higher value it will be. As such enter “Value> 100” in this case. If the stream network is ok by you, continue to step 5 otherwise, keep varying the value and rerun this step.

STEP 5: STREAM TO FEATURE

As a next step to generate a vector of the result from the raster of accumulated flow and conditional, using the Stream to Feature tool. Expand the hydrology toolbar, then click on the steam to feature option to open its dialog box. in the Input Stream Raster portion, select the conditional stream generated in step 4 and enter the flow direction from step 2 in the input flow direction raster. In the Output flow direction raster option, it should set to the default database for the project as such just rename it.

STEP 6: CREATE OUTLET (POUR) POINTS

The placement of pour points is an important step in watershed delineation. A pour point should exist within an area of high flow accumulation because it is used to calculate the total contributing water flowing to that given point. In many cases you will already have a shape file containing the locations of your pour points, whether they are sampling sites, hydrometric stations, or another data source. However, it is also possible to create pour points yourself.

a) Creating pour points through visual inspection

Open the Arc Catalog window. Right-click on your working directory and select New then select Shape file. Create a new point shape file, give it a descriptive name and apply the appropriate projection information (the coordinate system should be the same as the DEM or Flow Direction Grid you will be using). Click OK. The new, empty point layer will be added to your map.

Zoom in to your area of interest so that you are able to see the individual flow accumulation cells. Use the Identify tool to examine the values of the flow accumulation grid. The chosen pour point cell should be a natural outlet for the streams flowing above it and must be on the high flow accumulation path. Your choice essentially determines the 'end' of your catchment; everything upstream from this point will define a single watershed.

To add a pour point, open the Editor toolbar go to Customize expand Toolbars look for the Editor option and choose Editor. This will bring a small moveable toolbar. Click on the editor dropdown arrow and click Start Editing.

On the start editing dialog, highlight the empty pour point layer and click ok. The create features window will open. Highlight the pour point shape file and then move your cursor onto your map. Add a pour point by clicking in the center of the high flow accumulation cell you have chosen as your outlet point. try to place points in the center of the cell. Also remember to place the points 1 or 2 cells away from stream confluences.

If you are defining only one watershed then save your edits, stop the editing session and move on to the next step.

If you are creating more than one watershed, add a pour point for each watershed then save your edits and exit the editing session. Open the attribute table for the layer by right-clicking the layer name and selecting Open Attribute Table. Click the Table Options icon and select Add Field. Create a field of type Integer, precision '0' and call it UNIQUEID. Start another editing session and enter an ID number for each individual pour point (1, 2, 3, and so on). Stop editing and choose to save your edits. Watersheds are delineated based on unique identification numbers, so this step ensures that a separate watershed will be delineated for each individual pour point.

STEP 7: SNAP POUR POINT

The Snap distance is the specified distance (in map units) that the tool will use to search around your pour points for the cell of highest accumulated flow. The snap distance should be based on the resolution of your data and may require some trial and error to determine the best value. If your pour point is not located on the high flow path, the tool will move it to the cell within the search radius with the highest accumulated value. If your pour point is already located on the high flow path, the tool will move the point to a downstream cell.

The Snap Pour Point tool accomplishes two things; it snaps the pour point(s) created or loaded in the previous step to the closest area of high flow accumulation, and it converts the pour points to the raster format needed for input to the Watershed tool. Double-click the Snap Pour Point tool to open its dialog box. Click Environments go to Raster Analysis Settings, go to Cell Size and ensure that the cell size is set to the same as your flow accumulation layer and then Click OK.

The Input raster or feature pour point data is the pour point layer created in Step 6. The Pour Point Field is the unique ID field created in Step 6 – this is only applicable if you are creating more than one watershed.

The Input accumulation raster is your flow accumulation layer. The Output raster

will default to your working directory.

NB; For delineation with the conditional raster, input the conditional raster instead of the flow accumulation raster.

STEP 8: WATERSHED DELINEATION

Watershed delineation Is accomplished with the combination of the results from the above steps. In this phase the following process will guide us to our watershed.

On the hydrology toolbar, select Watershed and click on it to open it dialog box. select the flow direction grid as the direction raster input and the raster version of the pour point as the input pour point data. Select an output directory and suitable name. the delineated watershed will be added to the map.

STEP 9: RASTER TO POLYGON

For area calculations and for later use to clip other datasets, convert the watershed raster to a polygon using the Conversion Tools of the Arc Toolbox. Go to the Arc Toolbox and search for the Conversion Tools and screw to 'From Raster' option. Click on the Raster to Polygon. This will enable you convert the raster to a vector map and then to compute the area of the watershed.

SAMPLE DELINEATED WATERSHED

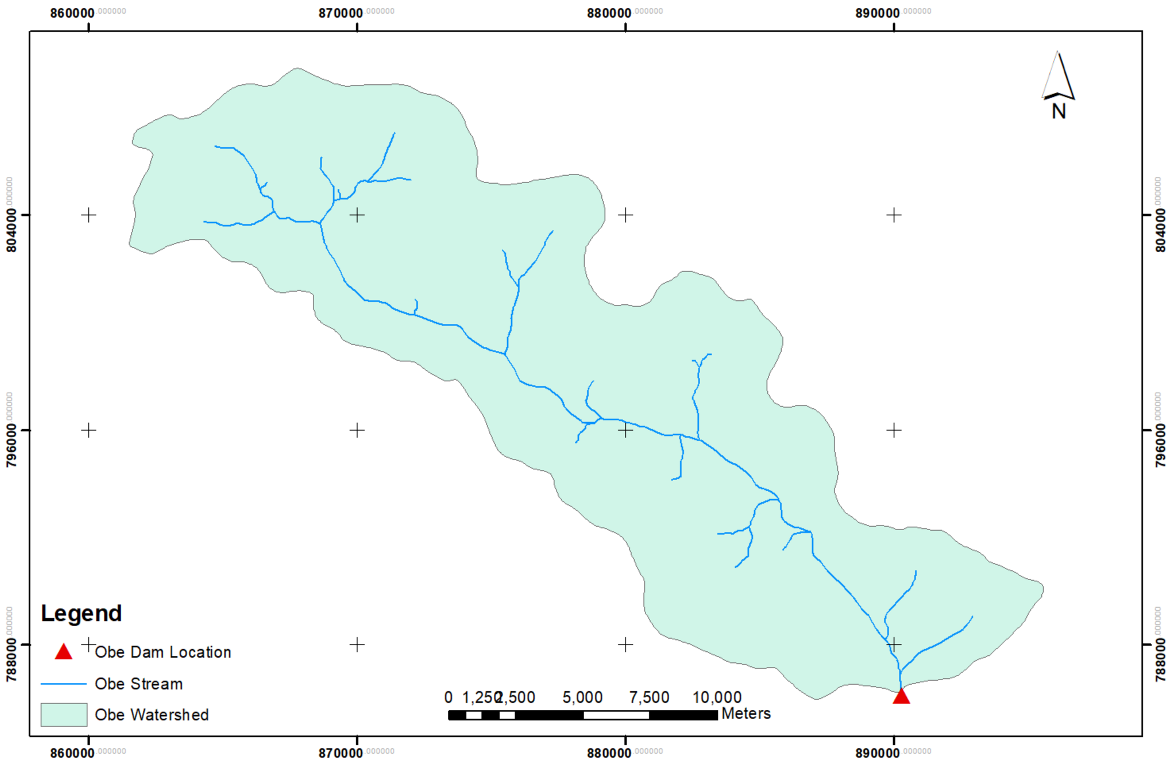

Figure 7: A Sample Delineated Watershed

A sample watershed is given in the figure above. The outlet or pour points is located on a stream network. The stream network and watershed area which is defined by the water divides or hydrologic boundaries were obtained by following the steps explained above. Other maps that can be generated are, DEM, contour map, stream network with stream order etc.

GIS Visualization

Data visualization is one of the most important steps to consider during any GIS project. The way in which your data is visualized will directly impact your audience's interpretation of the final product. Visualization elements include coloring, map extent, labels, boundaries, interactivity, 3D models, and more. Map Elements and Design

Below are some common map elements and design attributes to consider when visualizing your data:

Map Elements:

- Title
- Map Symbols
- Legend
- Map Scale
- North Arrow
- Map Area
- Labels
- Borders and Neat lines
- Graticule or Coordinate Grid

Map Design

- Colors and Shading
- Typography/Font
- Focus of attention
- Map element hierarchy/Figure-ground considerations

SPATIAL STATISTICS AND GIS

Spatial statistics analyze the pattern, process and relationship in spatial data. Although spatial statistics was built upon traditional statistical concepts and methods, they have some unique capacities that are beyond regular statistics.

Although their uses were limited in the past due to the problems of large volume of manual computations, advance in GIS and Software development on spatial statistics have made their applications and usage to stimulate greater interest for industries and researchers. Their most common usage includes measuring geographic distribution, special cluster analysis and spatial regression models.

Measuring geographic distribution allows users to capture the characteristics of a features distribution such as its center, compactness and orientation by descriptive statistic. Spatial cluster analysis helps to detect unusual concentration or non-randomness of event in space with a rigorous statistical test. One type of spatial cluster analysis examines patterns of feature location while another examines features values. The former requires a knowledge of the exact location of individual colour why did latter use aggregated rate in the area

Thus they are also referred to as point based and area based clusters analysis. Data availability dictates which method is to be used. Spatial cluster analysis is an essential and effective for step in any exploratory investigation. Non randomness of events in spatial distribution indicate the existence of spatial auto-correlation which is commonly encountered in analysis of geographic data spatial auto-correlation violate the assumption of independent observations in ordinary least square regression and this leads to the use of spatial regression models. spatial regression models include global models such as SPATIAL LAG and SPATIAL ERROR MODELS with constant coefficients. For exploratory variable and local model such as geographical weighted regression with coefficient varying across the study area such as a watershed.

Statistical Analysis in GIS Environment

Statistical analysis function in GIS software such as ArcGIS for Desktops are either Non Spatial (tabular) or Spatial (Location based).

Non spatial statistics are used to analyze attribute functions that are features related. The values are accessed directly from a layer's attribute table. In ArcGIS software for instance, the spatial statistics tool box contains statistical tools for analyzing spatial distribution, patterns, process, and relationship unlike traditional non-spatial statistical methods, they usually incorporate space (proximity, area, connectivity, and /or other spatial relationship directly into their mathematics).

The tools in the spatial statistical tool box allow you to summarize the main characteristics of a spatial distribution by identifying statistically significant spatial clusters or spatial outliers, assess overall pattern of clustering or dispersion, group features based on their attribute similarities identify an appropriate scale of analysis and then explore their spatial relationship.

ArcGIS 10.2 and other later versions provide some popular spatial statistics tools including the Centrographic mention the nearest neighbours index, and spatial cluster analysis indices based on feature values, and has in addition a GWR (Geographically Weighted Regression tool).

However, implementation of the spatial cluster analysis based on binary point feature all the spatial lag and spatial error regression model has to rely on some specialized software such as Satscan and GeoDa.

The spatial filtering methods developed by Getis (1995) and Griffith (2000) take a different approach to account for spatial auto-correlation in regression. The method separates the spatial effects from the variables total effects, and allow analysts to use conventional regression methods such as OLS to conduct the analysis according to (Getis and Griffith, 2002) in Wang 2014.

Compared to the maximum likelihood spatial regression, the major advantage of spatial filtering methods is that the results uncover individual spatial and non-spatial component contribution and are easy to interpret.

SPATIAL SMOOTHING AND SPATIAL INTERPOLATION

Spatial smoothing and spatial interpolation are closely related and both are used in visualizing spatial patterns and highlighting spatial trends.

Spatial interpolation uses known values at some locations to estimate unknown values at other location. Spatial interpolation uses Geostatistical tools based on the kriging model.

The Geostatistical analyst has been embedded into the GIS environment for spatial interpolation using Kriging model. Kriging is a geostatistical model for spatial interpolation.

Kriging differs from other local interpolation models because Kriging can assess the quality of prediction with estimated prediction errors.

It is an interpolation method that assumes that the spatial variation of an attribute includes a specifically correlated component.

The basic types of Kriging include;

- Ordinary or Simple Kriging which assumes that the mean of the data set is known. However, this assumption is unrealistic in many cases.
- Indicators Kriging which uses binary data (0 and 1) rather than continuous data. The interpolated values are therefore between 0 and 1 similar to probabilities.
- Disjunctive Kriging which uses a function of the attribute value for interpolation and is more complicated than other kriging method in terms of computation.
- Block Kriging estimates the average value of a variable over some small area or block rather than at a point.
- Cokriging uses one or more secondary variables which are correlated with the primary variable of interest in interpolation.
  It assumes that the correlation between the variables can improve the prediction of the value of the primary variable.

References

1. M. ANJI REDDY, 2008, Textbook of Remote Sensing and Geographical Information Systems Third Edition, BS Publications, Hyderabad, India

2. Kang-tsung Chang, 2014, Introduction to Geographic Information Systems 7th edition, McGraw-Hill, Singapore.

3. HYDROLOGY AND THE MANAGEMENT OF WATERSHEDS (4^{th} Edition) by Kenneth N. Brooks, Peter F. Ffolliott and Joseph A. Magner
4. WATERSHED HYDROLOGY, MANAGEMENT AND MODELING (2013) by Abrar Yousuf and Manmohanjit Singh

TRAINING COURSE 2:

Module 2:

Sub-Title 1: Electromagnetic Spectrum

Objectives: The objectives are to discuss the principle of electromagnetic spectrum.

Electromagnetic Spectrum

Classification of wavelength in ES

1.0 INRODUCTION

Remote sensing is the science and art of obtaining information about an object or in general, the Earth's surface, without actually being in physical contact with it. This is done by sensing and recording reflected or emitted energy and processing, analysing, and applying that information.

Remote sensing used sophisticated sensor to measure the amount of electromagnetic energy existing in objects or geographical area from a distance and extracted valuable information from the data using mathematical and statistical algorithms. It functions with other geographic information sciences, such as, Geographic Information Systems (GIS), Cartography, Surveying, etc.

1.1 ELECTROMAGNETIC SPECTRUM

In remote sensing, it is most common to categorize electromagnetic waves by their wavelength location within the electromagnetic spectrum. The most prevalent unit used to measure wavelength along the spectrum is the micrometer (μm). A micrometer equals $1x10^6$ m. Although names (such as “ultraviolet” and “microwave”) are generally assigned to regions of the electromagnetic spectrum for convenience, there is no clear-cut dividing line between one nominal spectral region and the next. Divisions of the spectrum have grown from the various methods for sensing each type of radiation more so than from inherent differences in the energy characteristics of various wavelengths. Also, it should be noted that the portions of the electromagnetic spectrum used in remote sensing lie along a continuum characterized by magnitude changes of many powers of 10. Hence, the use of logarithmic plots to depict the electromagnetic spectrum is quite common.

1.2 ENERGY SOURCES AND RADIATION PRINCIPLES

Visible light is only one of many forms of electromagnetic energy. Radio waves, ultraviolet rays, radiant heat, and X-rays are other familiar forms. All this energy is inherently similar and propagates in accordance with bas $c = v\lambda$ ry. As shown in Figure 1.2, this theory describes electromagnetic energy as traveling in a harmonic, sinusoidal fashion at the "velocity of light" c. The distance from one wave peak to the next is the wavelength *l*, and the number of peaks passing a fixed point in space per unit time is the wave frequency *v*. From basic physics, waves obey the general equation of the form:

Because *c* is essentially a constant (3 x10^8m/s), frequency *v* and wavelength λ for any given wave are related inversely, and either term can be used to characterize a wave.

The electromagnetic spectrum used in remote sensing lie along a continuum characterize by magnitude changes of many powers of 10. Hence, the use of logarithmic plots to depict the electromagnetic spectrum is quite common. The "visible" portion of such a plot is an extremely small one, because the spectral sensitivity of the human eye extends only from about 0.4 µm to approximately 0.7 µm. The color "blue" is ascribed to the approximate range of 0.4 to 0:5 µm, "green" to 0.5 to 0.6 µm, and "red" to 0.6 to 0.7 µm. Ultraviolet (UV) energy adjoins the blue end of the visible portion of the spectrum. Beyond the red end of the visible region are three different categories of infrared (IR) waves: near IR (from 0.7 to 1.3 µm), mid IR (from 1.3 to 3 µm; also referred to as shortwave IR or SWIR), and thermal IR (beyond 3 to 14 µm, sometimes referred to as longwave IR). At much longer wavelengths (1 mm to 1 m) is the microwave portion of the spectrum.

The sun is the most obvious source of electromagnetic radiation for remote sensing. However, all matter at temperatures above absolute zero (0 K, or 273^{0}C) continuously emits electromagnetic radiation. Thus, terrestrial objects are also sources of radiation, although it is of considerably different magnitude and spectral composition than that of the sun. How much energy any object radiates is, among other things, a function of the surface temperature of the object. This property is expressed by the Stefan‑Boltzmann law, which states that:

$$M = \sigma T^4$$

where

M = total radiant exitance from the surface of a material, watts Wm^{-2}

σ = Stefan–Boltzmann constant, 5.6697 x $10^{-8} Wm^{-2} K^{-4}$

T = absolute temperature (K) of the emitting material

The dominant wavelength, or wavelength at which a blackbody radiation curve reaches a maximum, is related to its temperature by Wien's displacement law:

$$\lambda_m = \frac{A}{T}$$

where

λm = wavelength of maximum spectral radiant exitance, μm

A = 2898 μm K

T = temperature, K

Consulted Reference Material

[1] Remote sensing and image interpretation by Thomas M. Lillesand, Ralph W. Kiefer, Jonathan W. Chipman. Seventh edition. ISBN 978-1-118-34328-9 (paperback) G70.4.L54 2015.

Module 2:

Sub-Title 2: **Satellite Remote Sensing Systems**

Objectives: **The objectives are to discuss relevant sub-headings with respect to satellite remote sensing systems**

- What is A Satellite?
- Classification of RS Systems
- Characteristics of RS Systems

1.0 WHAT IS A SATELLITE?

A satellite in general is any natural or artificial body moving around a celestial body such as a planet or a star. In the present context, reference is made only to artificial satellites orbiting the planet Earth. These satellites are put into the desired orbit and have payloads depending upon the intended application.

1.1 CLASSIFICATION OF SATELLITE REMOTE SENSING SYSTEMS

The various classification of RS systems available are going to be discussed in this section. The principles covered in this section apply equally well to ground-based and aerial platforms but here they will be described in conjunction with satellites. Remote sensing systems can be classified on the basis of (a) the source of radiation and (b) the spectral regions used for data acquisition.

(a) Based on the source of radiation, they can be classified as:

i. Passive remote sensing systems

ii. Active remote sensing systems

Passive remote sensing systems either detect the solar radiation reflected by the objects on the surface of the Earth or detect the thermal or microwave radiation emitted by them. ***Active remote sensing systems*** make use of active artificial sources of radiation generally mounted on the remote sensing platform. These sources illuminate the objects on the ground and the energy reflected or scattered by these objects is utilized here. Examples of active remote sensing systems include microwave and laser-based systems.

(b) Depending on the spectral regions used for data acquisition, they can be classified as:

i. Optical remote sensing systems (including visible, near IR and shortwave IR systems)

ii. Thermal infrared remote sensing systems

iii. Microwave remote sensing systems

(i) ***Optical Remote Sensing Systems***

Optical remote sensing systems mostly make use of visible (0.3-0.7 μ m), near IR (0.72-1.30 μ m) and shortwave IR (1.3-3.0 μ m) wavelength bands to form images of the Earth's surface. The images are formed by detecting the solar radiation reflected by objects on the ground (Figure 1) and resemble the photographs taken by a camera.

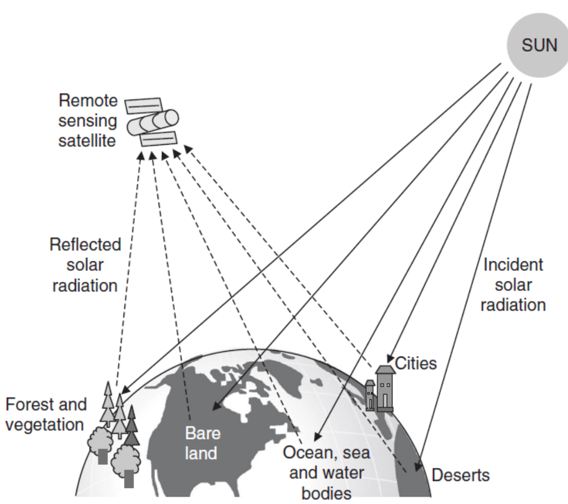

Figure 1: Optical remote sensing

However, some laser-based optical remote sensing systems are also being employed in which the laser beam is emitted from the active sources mounted on the remote sensing platform. The target properties are analysed by studying the reflectance and scattering characteristics of the objects to the laser radiation. Optical remote sensing systems employing solar energy come under the category of passive remote sensing systems and the laser-based remote sensing systems belong to the category of active remote sensing systems. Passive optical remote sensing systems work only during the day as they rely on sensing reflected sunlight. This phenomenon makes them weather dependent because during cloudy days the sunlight is not able to reach the Earth.

Table 1.1: Optical bands employed for various applications

0.45-0.52 µm	Sensitive to sedimentation, deciduous/coniferous forest colour discrimination, soil vegetation differentiation
0.52-0.59 µm	Green reflectance by heavy vegetation, vegetation vigour, rock soil discrimination, turbidity and bathymetry in shallow water
0.62-0.68 µm	Sensitive to chlorophyll absorption, plant species discrimination, differentiation of soil and geological boundary
0.77-0.86 µm	Sensitive to the green biomass and moisture in the vegetation, land and water studies, geomorphic studies

In the optical band, panchromatic or black and white images can also be taken, where different shades of grey indicate different levels of reflectivity. The most reflective surfaces are light or nearly white in colour while the least reflective surfaces are represented as black.

(ii) *Thermal Infrared Remote Sensing Systems*

Thermal infrared remote sensing systems employ the mid wave IR (3-5 μ m) and the long wave IR (8-14 μ m) wavelength bands. The imagery here is derived from the thermal radiation emitted by the Earth's surface and objects. As different portions of the Earth's surface are at different temperatures, thermal images therefore provide information on the temperature of the ground and water surfaces and the objects on them (Figure 2). As the thermal infrared remote sensing systems detect the thermal radiation emitted from the Earth's surface, they come under the category of passive remote sensing systems. The 10 μ m band is commonly employed for thermal remote sensing applications as most of the objects on the surface of the Earth have temperatures around 300K and the spectral radiance for a temperature of 300K peaks at a wavelength of 10 μ m. Another commonly used thermal band is 3.8 μ mfor detecting forest fires and other hot objects having temperatures between 500K and 1000 K.

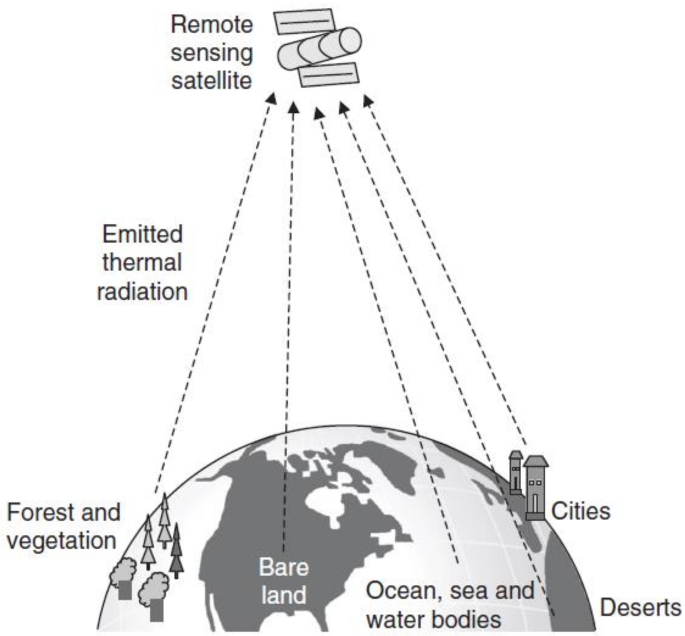

Figure 2: Thermal remote sensing

Colder surfaces appear darker in the raw IR thermal images, but the general remote sensing concept for IR images is to invert the relationship between brightness and the temperature so that the colder objects appear brighter as compared to the hotter ones. Hence, clouds that are colder than the Earth's surface appear in darker shades against the light background of the Earth in raw thermal images, but appear in lighter shades against the darker background in the processed thermal images.

(iii) ***Microwave Remote Sensing Systems***

Microwave remote sensing systems generally operate in the 1 cm to 1m wavelength band. Microwave radiation can penetrate through clouds, haze and dust, making microwave remote sensing a weather independent technique. This feature makes microwave remote sensing systems quite attractive as compared to optical and thermal systems, which are weather dependent. Microwave remote sensing systems work both during the day as well as at night as they are independent of the solar illumination conditions. Another advantage that a microwave remote sensing system offers is that it provides unique information on sea wind and wave direction that cannot be provided by visible and infrared remote sensing systems. However, the need for sophisticated data analysis and poorer resolution due to the use of longer wavelength bands are the disadvantages of microwave remote sensing systems.

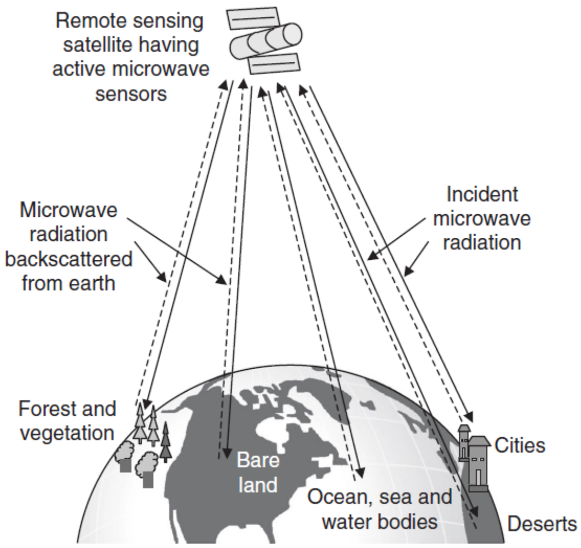

Figure 3: Microwave remote sensing

Shorter microwave wavelength bands are utilized for the analyses of hidden mineral resources as they penetrate through the Earth's surface and the vegetation, whereas longer wavelength bands are utilized for determining the roughness of the various features on the Earth's surface. Microwave remote sensing systems can be both passive as well as active. ***Passive microwave*** remote sensing systems work on a concept similar to that of thermal remote sensing systems and detect the microwave radiation emitted from the objects. The characteristics of the objects are then formed on the basis of the received microwave power as the received power is related to their characteristics, such as temperature, moisture content and physical characteristics. ***Active microwave*** remote sensing systems provide their own source of microwave radiation to illuminate the target object. Examples of passive microwave systems include altimeters and radiometers. Real aperture and synthetic aperture radar are active microwave remote sensing systems.

1.3 CHARACTERISTICS OF RS SYSTEMS

In particular, the design and operation of every real-world sensing system represents a series of compromises, often in response to the limitations imposed by physics and by the current state of technological development. When we consider the process from start to finish, users of remote sensing systems need to keep in mind the following factors.

1. **The Source of Energy.**

All passive remote sensing systems rely on energy that originates from sources other than the sensor itself, typically in the form of either reflected radiation from the sun or emitted radiation from earth surface features. As already discussed, the spectral distribution of reflected sunlight and self-emitted energy is far from uniform. Solar energy levels obviously vary with respect to time and location, and different earth surface materials emit energy with varying degrees of efficiency.

2. **The Atmosphere.**

The atmosphere normally compounds the problems introduced by energy source variation. To some extent, the atmosphere always modifies the strength and spectral distribution of the energy received by a sensor. It restricts where we can look spectrally, and its effects vary with wavelength, time, and place. The importance of these effects, like source variation effects, is a function of the wavelengths involved, the sensor used, and the sensing application at hand. Elimination of, or compensation for, atmospheric effects via some form of calibration is particularly important in those applications where repetitive observations of the same geographic area are involved.

3. **The Energy–Matter Interactions at the Earth's Surface.**

Remote sensing would be simple if every material reflected and/or emitted energy in a unique, known way. Although spectral response patterns such as those in Figure 4a-c play a central role in detecting, identifying, and analyzing earth surface materials, the spectral world is full of ambiguity. Radically different material types can have great spectral similarity, making identification difficult. Furthermore, the general understanding of the energy-matter interactions for earth surface features is at an elementary level for some materials and virtually nonexistent for others.

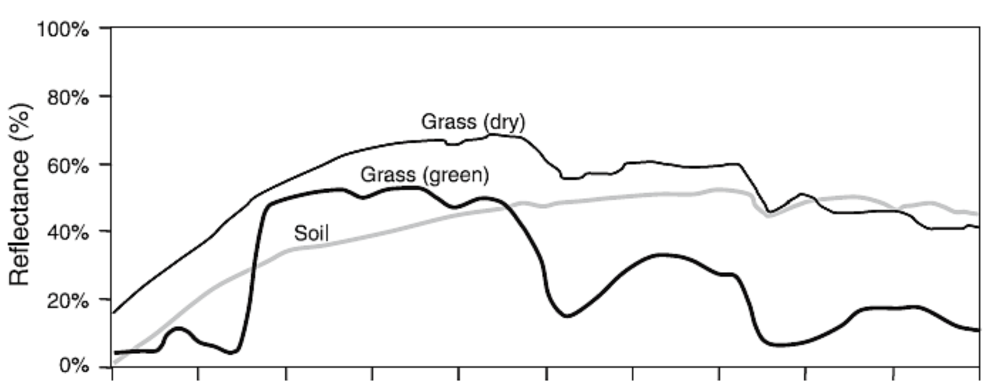

Figure 4a: Spectral (signature) reflectance curves for dry grass, green grass and soil

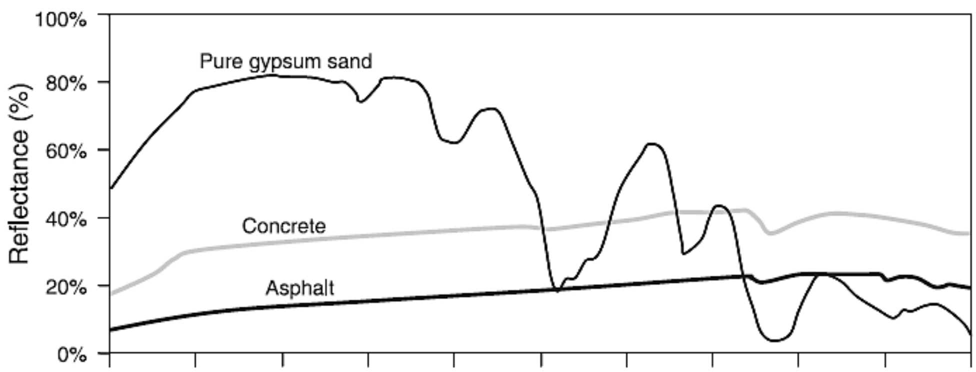

Figure 4b: Spectral (signature) reflectance curves for pure gypsum sand, concrete and asphalt

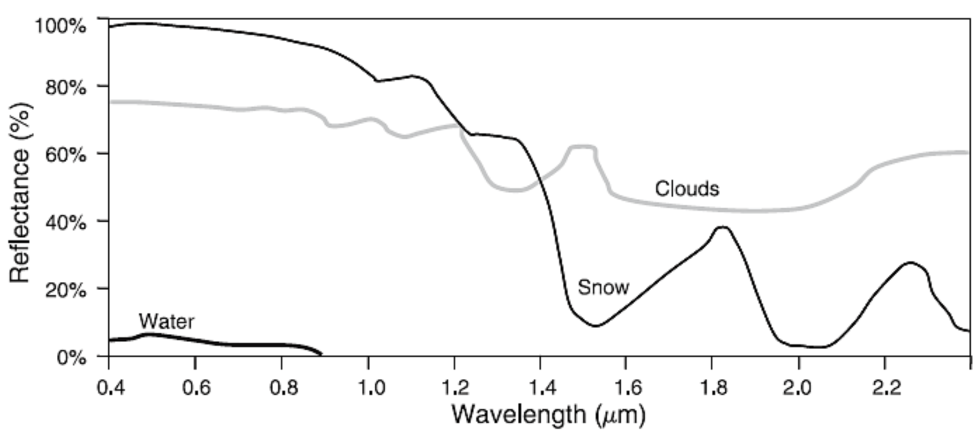

Figure 4c: Spectral (signature) reflectance curves for clouds and snow

4. The Sensor.

An ideal RS sensor would be highly sensitive to all wavelengths, yielding spatially detailed data on the absolute brightness (or radiance) from a scene as a function of wavelength, throughout the spectrum, across wide areas on the ground. This "supersensor" would be simple and reliable, require virtually no power or space, be available whenever and wherever needed, and be accurate and economical to operate. At this point, it should come as no surprise that an ideal "supersensor" does not exist. No single sensor is sensitive to all wavelengths or energy levels. All real sensors have fixed limits of spatial, spectral, radiometric and temporal resolution.

The choice of a sensor for any given task always involves trade-offs. For example, photographic systems generally have very fine spatial resolution, providing a detailed view of the landscape, but they lack the broad spectral sensitivity obtainable with non-photographic systems. Similarly, many non-photographic systems are quite complex optically, mechanically, and/or electronically. They may have restrictive power, space, and stability requirements. These requirements often dictate the type of platform, or vehicle, from which a sensor can be operated.

5. The Data Processing and Supply System.

The capability of current remote sensors to generate data far exceeds the capacity to handle these data. This is generally true whether we consider “manual” image interpretation procedures or digital analyses. Processing sensor data into an interpretable format can be and often is an effort entailing considerable thought, hardware, time, and experience. Also, many data users would like to receive their data immediately after acquisition by the sensor in order to make the timely decisions required in certain applications (e.g., agricultural crop management, disaster assessment). Finally, as discussed, most remote sensing applications require the collection and analysis of additional reference data, an operation that may be complex, expensive, and time consuming.

6. The Users of Remotely Sensed Data.

Central to the successful application of any remote sensing system is the person (or persons) using the remote sensor data from that system. The “data” generated by remote sensing procedures become “information” only if and when someone understands their generation, knows how to interpret them, and knows how best to use them. A thorough understanding of the problem at hand is paramount to the productive application of any remote sensing methodology.

Module 2:

Sub-Title 3: Remote Sensing Data Acquisition Platforms and Sensor Systems

Objectives: The objectives are to discuss relevant sub-headings with respect to remote sensing data acquisition platforms and sensor systems

- Remote sensing data acquisition platform concepts
- Different types of available platforms
- Sensor Systems
- Sensor parameters
- Radiometric Resolution

1.0 REMOTE SENSING DATA ACQUISITION PLATFORM CONCEPTS

Data acquisition platforms are largely dependent on the types of orbit the satellite is lunched to. However, there are basically three principal types of satellite orbit which are:

i. Geostationary - generally used for telecommunications satellites

ii. Polar - generally used for remote sensing satellites

iii. Low earth - generally used for spy satellites

(i) Geostationary Satellites

Geostationary satellites operate at high altitudes (approx 36,000 km) and move above the equator in synchronization with the earth's rotation, with the result that they remains in the same position above the Earth. They are used for meteorological and communications purposes, and some can monitor the weather over entire hemispheres of the Earth. This approach provides the same view of the Earth every 30 minutes, particularly appropriate for observation of rapidly-changing patterns such as weather.

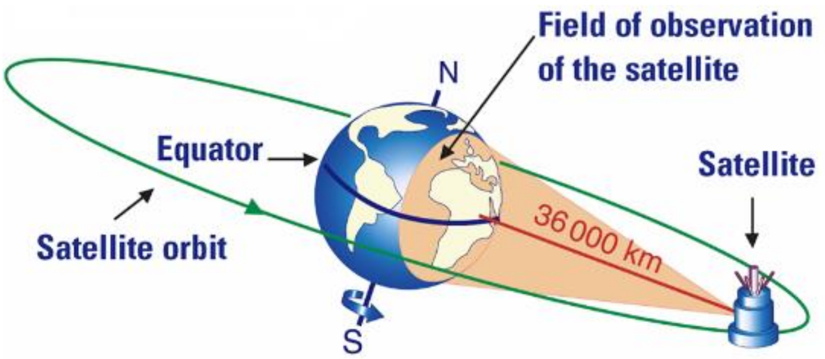

Figure 1: Geocentric satellite

(ii) Polar Orbiting Satellites

Polar orbiting satellites operate at low altitude (approximately 800km), moving from north to south so as to cover the Earth surface in a particular period. Low revisit intervals mean that it will be 2 weeks between successive coverage of the same region. This type of orbit is mostly used for remote sensing studies. Some polar orbiting satellites are sun-synchronous.

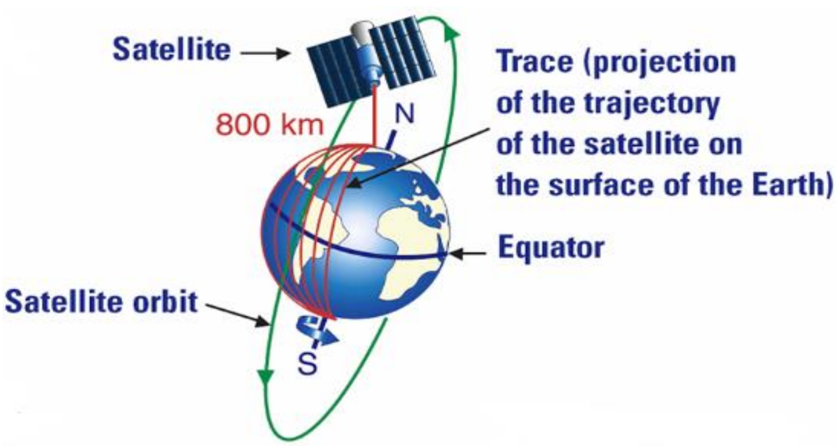

Figure 2: Polar satellite

(iii) Low Earth Orbit (LEO)

LEO is typically a circular orbit about 400 to 900 kilometres above the earth's surface and, correspondingly, has a much shorter period (time to revolve around the earth) of about 90 minutes. Because of their low altitude, these satellites are only visible from within a small area (about 1000 km radius) beneath the satellite as it passes overhead.

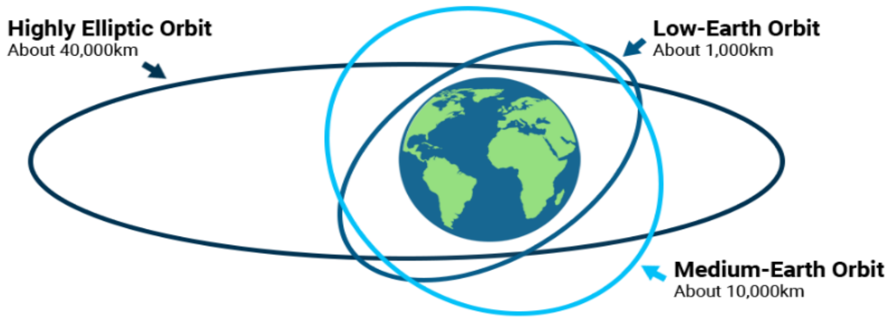

Figure 3: Low earth orbit satellite

1.2 REMOTE SENSING PLATFORMS

Remote Sensing Platforms are stages to mount sensors or camera to be used to acquire information about a target under investigation. RS platforms may be classified into different types based on their altitude with respect to the Earth's surface. The platform provides support for the sensor and platforms can be divided into three types:

i. Ground-based

ii. Airborne

iii. Spaceborne

(i) Ground-based Platforms

Ground-based platforms are mainly used to collect spectral information. They provide a basis for preliminary investigation and concept understanding. They are also used for the calibration and validation of airborne and spaceborne data.

Figure 4: examples of ground-based platforms

(ii) Airborne Platforms

Airborne remote sensing system may also be referred to as sub-orbital or aircraft, or aerial remote sensing system. At present, airplanes are the most common airborne platform. Other airborne observation platforms include balloons, kites, drones (UAVs) and high altitude sounding rockets. Helicopters are occasionally used. Fixed wing aircraft are the platform of choice for most applications as they provide a stable platform for small-area, high resolution surveys. Airborne platforms can also serve to test spaceborne sensors before they are placed into orbit.

Figure 5: Examples of airborne platforms

- **Balloon**

The balloon is a remote-sensing platform which permits the experiment or operation to define the shape, size, and performance required of the carrier; however, the use of balloons is restricted by meteorological factors, especially by wind influences.

Although balloons were used as camera platforms during the Civil War, it was not until the late 1950's that a serious program was initiated to utilize balloons for a wide variety of remote sensing experiments. By 1972, balloons had risen to above 49 km (160,000 ft) and carried a wide variety of sensors that looked at the Earth's surface, the atmosphere, and celestial bodies. Practically all remote-sensing balloon flights are unmanned, but manned balloon flights, particularly by astronomers, have also been successful.

- **Drones (UAVs)**

Drone is a miniature remotely piloted aircraft. It is designed to fulfill requirements for a low cost platform, with long endurance, moderate payload capacity and capability to operate without a runway or small runway. Drone includes equipment of photography, infrared detection, radar observation and TV surveillance. It uses satellite communication link. An onboard computer controls the payload and stores data from different sensors and instruments.

Drone was developed in Britain during World War-II, is the short sky spy which was originally conceived as a military reconnaissance. Now it plays important role in remote sensing. The unique advantage is that it could be accurately located above the area for which data was required and capable to provide both night and day data.

- **Aircraft**

Aerial platforms are primarily stable wing aircraft. Helicopters are also occasionally used for this purpose. Generally, aircraft are used to collect very detailed images. Helicopters can be for pinpoint locations but it vibrates and lacks stability. Special aircraft with cameras and sensors on vibration less platforms are traditionally used to acquire aerial photographs and images of land surface features. While low altitude aerial photography results in large scale images providing detailed information on the terrain, the high altitude smaller scale images offer advantage to cover a larger study area with low spatial resolution.

Low Altitude Aircraft: It is most widely used and generally operates below 9,144m (30,000 ft). They have single engine or light twin engine. It is suitable for obtaining image data for small areas having large scale. It acquires imagery for large areas (smaller scale). Aircraft platform acquire imagery under suitable weather conditions. It controls platform variables such as altitude. Time of coverage can also be controlled. However, it is expensive, less stable than spacecraft and has motion blurring.

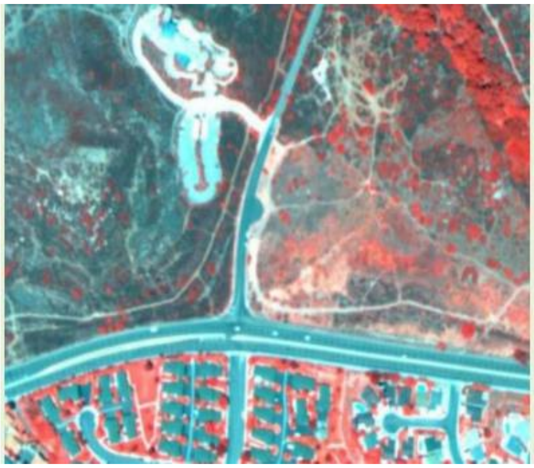

Figure 6: Image from low attitude aircraft

High Altitude: sounding rocket platforms are useful in assessing the reliability of the remote sensing techniques as regards their dependence on the distance from the target is concerned. Balloons have a maximum altitude of approximately 37 km, while satellites cannot orbit below 120 km. High altitude sounding rockets can be used to a moderate altitude above terrain. Imageries with moderate synoptic view can be obtained from such rockets for areas of some 500,000 square kilometers per frame. The high altitude sounding rocket is fired from a mobile launcher. During the flight its scanning work is done from a stable altitude, the payload and the spent motor are returned to the ground gently by parachute enabling the recovery of the data. One most important limitations of this system is to ensure that the descending rocket not going to cause damage.

Figure 7: Image from high altitude aircraft

Figure 8: Commonest platforms under airborne

(iii) Spaceborne Platforms

In space-borne remote sensing, sensors are mounted on-board a spacecraft (space shuttle or satellite) orbiting the earth. Space-borne or satellite platform are onetime cost effected but relatively lower cost per unit area of coverage, can acquire imagery of entire earth without taking permission. Space-borne imaging ranges from altitude 250 km to 36000 km. Space-borne remote sensing provides the following advantages: • Large area coverage; • Frequent and repetitive coverage of an area of interest; • Quantitative measurement of ground features using radiometrically calibrated sensors; • Semi-automated computerised processing and analysis; • Relatively lower cost per unit area of coverage. • Remote sensing is also conducted from the space shuttle or artificial satellites. Artificial satellites are manmade objects, which revolve around another object. • The 1960s saw the primary platform used to carry remotely sensed instruments shifted from airplanes to satellite. Satellite can cover much more land space than planes and can monitor areas on a regular basis. • Beginning with the first television and infrared observation Satellite (tiRoS-1) in 1960, early weather satellites returned rather poor views of cloud patterns and almost indistinct images of the earth's surface. Space photography becomes better and was further extended with the Apollo program. Then in 1973 SKYLAB, the first American space workshop was launched and its astronauts took over 35000 images of the earth with the earth Resource experiment Package (eReP) on board. Later on with LANDSAT and SPOT satellites program, space photography received a higher impetus.

There are two types of well recognized satellite platforms- ***manned satellite platform*** and ***unmanned satellite platform***.

Manned Satellite Platforms: Manned satellite platforms are used as the last step, for rigorous testing of the remote sensors on board so that they can be finally incorporated in the unmanned satellites. Crew in the manned satellites operates the sensors as per the program schedule. **Unmanned Satellite Platforms:** Landsat series, SPOT series and IRS series of remote sensing satellite, NOAA series of meteorological satellites, the entire constellation of the GPS satellites and the GOES and INSAT series of geostationary environmental, communication, television broadcast, weather and earth observation satellites etc. are examples of unmanned satellite category.

Figure 9: Common platforms under spaceborne.

1.3 SENSORS

Sensors detect the amount of energy reflected/emitted from the Earth surface and thereby provide information about its characteristics. Most remote sensing instruments (sensors) are designed to measure photons. Fundamental to this operation is a device known as a detector which works to measure radiation (a beam of photons) on the basis of the photo-electric effect. When a light-sensitive material is subject to a beam of photons, electrical energy is released and this energy is proportional to the amount of incoming radiation. A sensor thus provides a means of measuring radiation. This basic mode of operation is common to each of the sensors considered here.

(i) Active and passive sensors

Fundamentally, there are two types of sensor depending on the source of energy. Active sensors provide their own energy source for illumination. This means that measurements can be obtained at any time, regardless of the time of day or season. Such sensors may also allow examination of wavelengths that are not sufficiently provided by the sun (microwaves) and also provide better control of the way that a target is illuminated.

Passive sensors, by contrast, measure energy that is naturally available. They therefore are constrained by a requirement for sunlight or radiation emission from ground objects and offer limited control over the way that a target is illuminated.

(ii) Imaging and non-imaging sensors

Another distinction is between imaging and non-imaging sensors. A non-imaging sensor measures the radiation received from all points in the sensed target, integrates this and registers a single response value, hence no image can be made from the data. This may be considered a type of "point" data as only a single value is obtained for a single observation point. A hand-held doppler radar used by police forces to measure the speed of a vehicle is an example of an active, non-imaging sensor: it emits pulses of radiation (i.e. provides an energy source) and the readout is simply the speed of the vehicle (i.e. there is no image).

Imaging sensors measure radiation at different points on the target and this information can be processed in order to obtain an image. This is necessary when spatial information about the target is needed, in the form of a map.

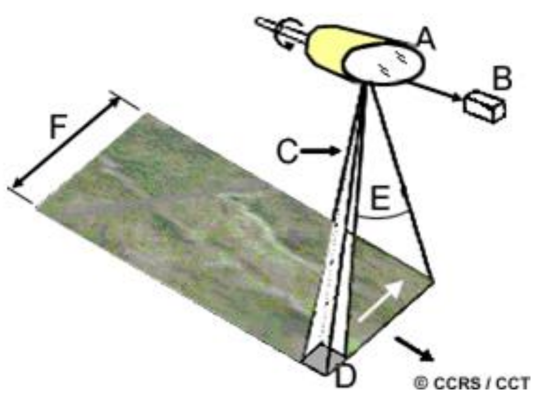

Figure 10: Sensor measurement

The detector - B operates through a rotating scan mirror - A

The field of view (FOV) is the total angle measured by the instrument in one scan - E

The instantaneous Filed of View (IFOV) is the solid angle extending from a detector to the area on the ground it measures at any instant - C

The ground resolution element (GRE) is the area measured by the sensor for each IFOV (broadly equivalent to the pixel) - D

Swath is the width of the area measured - F

The size of GRE is a function of IFOV and altitude of the platform, while the swath width depends on FOV.

- **Scanning systems**

A further characteristic of sensor systems is the operation of scanning, whereby a sensor with a narrow IFOV is swept across the terrain in order to build up a series of readings for different locations. Scanning can be undertaken either from airborne or spaceborne platforms (aircraft or satellites). Two principal mechanisms are employed to produce the scanning motion of the sensor:

- **Across-Track Scanning Sensor (Wiskbroom)**

Across track or wiskbroom scanning uses rotating and oscillating mirror which scans the entire terrain appearing at right angles to the line of flight. Successive scan lines are covered as aircraft moves forward, yielding a series of contiguous strips of a 2-D image. At any instant, the scanner detects energy within Instantaneous Field Of View (IFOV), which is normally expressed as cone angle within which incident energy is focused on detector. β is determined by instruments optical system and size of detectors.

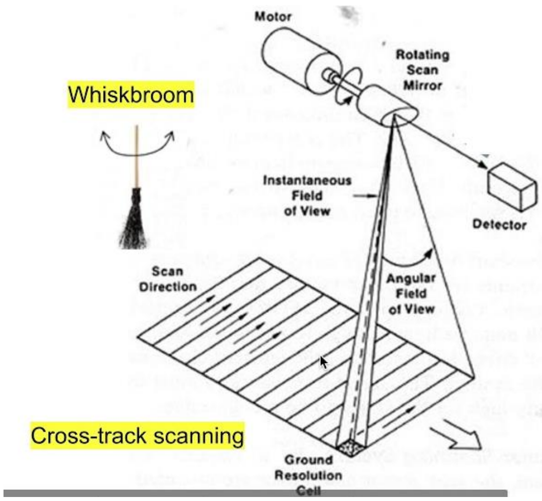

Figure 11: Across-Track Scanning Sensor

$$D = h'\beta \qquad (1)$$

where,

D = Diameter of circular ground viewed
h' = Flying height above terrain
β = IFOV in radians

The components are:

(1) a light gathering telescope, (2) appropriate optics (e.g. a lens) within the light path, (3) a mirror, which usually oscillates over small angles, (4) a device (spectroscope) to break the incoming radiation into spectral intervals, (5) a means to direct the light so dispersed onto a battery or bank of detectors, (6) other electronics to store data.

- **Along Track (Pushbroom) Sensor**

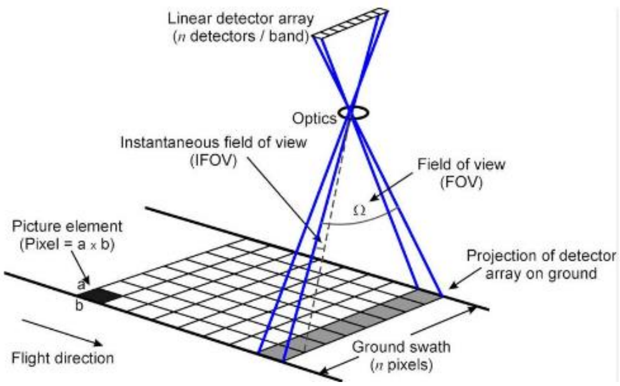

Figure 12: Along track scanning

The along track sensor scanning, system consists of a linear array of detectors, which has Charge Coupled Devices (CCD's). The direction of scanning is the same as the direction of motion of the imaging platform, hence the name, along track scanning.

- **Detector**

In both cases, each detector integrates the energy that strikes surface (irradiance) to form measurement at each pixel. Then integrated irradiance at each pixel is converted into electrical signal and quantized as integer value, called Digital Number (DN). A finite number of bits, Q, is used to code the continuous data measurements as binary numbers. The number of discrete item is given by,

$$N_{DN}=2^{Q} \tag{2}$$

and DN can be any integer in the range,

$$DN_{RANGE}= [0, 2^{Q}-1] \tag{3}$$

The larger the value of Q, the more closely the quantized data approximates the original continuous signal generated by detectors, and the higher will be the radiometric resolution of that sensor.

➢ **Mathematical Model of the Instrument**

Since no instrument can measure the signal sensed exactly with 100% accuracy, because the signal is always varying as a function of some parameter. This parameter, in the case of remote sensing, is usually time, or wavelength, space. In order to obtain the output signal, the instrument must integrate the signal over a non-zero parameter value as follows

$$o(z_0) = \int_W i(\alpha) r(z_0 - \alpha)$$

(4)

Where $i\alpha$ is the input signal r(z0−α) is the instrument response, inverted and shifted by z0 o(z0) is the output of the instrument at z=z0. W being the range over which the integral is significant, W also depends on the parameter of integration.

1.4 SENSOR PARAMETERS

Sensor parameters briefly described in the following paragraphs include:

1. Instantaneous field-of-view (IFOV), 2. Overall field-of-view, 3. S/N ratio, 4. Linearity, 5. Wavelength band, 6. Swath width, 7. Dwell time, 8. Resolution

1. **Instantaneous field-of-view (IFOV).** This is defined as the solid angle from which the electromagnetic radiation measured by the sensor at a given point of time emanates.

2. **Overall field-of-view.** This corresponds to the total size of the geographical area selected for observation. In the case of non-scanning sensors, the instantaneous and the total field of- view are equal and coincide with one another, whereas for scanning sensors, the overall field-of-view is a whole number multiple of the instantaneous field-of-view.

3. **S/N ratio.** This defines the minimum power level required by the sensor to identify an object in the presence of noise.

4. **Linearity.** Linearity refers to the sensor's response to the varying levels of radiation intensity. The linearity is generally specified in terms of the slope of the sensor's response curve and is referred to as 'gamma'. A gamma of one corresponds to a sensor with a linear response to radiation. A gamma that is less than one corresponds to a sensor that compresses the dark end of the range, while a gamma greater than one compresses the bright end. Sensors based on solid state circuitry like CCDs are linear over a wide range as compared to other sensors like vidicon cameras.

5. **Wavelength band.** Sensors employ three wavelength bands for remote sensing applications: the optical band, the thermal band and the microwave band.

6. **Swath width.** The swath width of the sensor is the area on the surface of the Earth imaged by it.

7. **Dwell time.** The sensor's dwell time is defined as the discrete amount of time required by it to generate a strong enough signal to be detected by the detector against the noise.

8. **Resolution.** Resolution is defined as the ability of the entire remote sensing system (including the lens, antenna, display, exposure, processing, etc.) to render a sharply defined image.

1.5 RESOLUTION OF REMOTE SENSING SYSTEM

Resolution of any remote sensing system is specified in terms of spectral resolution, radiometric resolution, spatial resolution and temporal resolution. These are briefly described as follows:

(a) Spectral resolution: This is determined by the bandwidth of the electromagnetic radiation used during the process. The narrower the bandwidth used, the higher is the spectral resolution achieved. On the basis of the spectral resolution, the systems may be classified as panchromatic, multispectral and hyperspectral systems. Panchromatic systems use a single wavelength band with a large bandwidth, multispectral systems use several narrow bandwidth bands having different wavelengths and hyperspectral systems take measurements in hundreds of very narrow bandwidth bands. Hyperspectral systems are the ones that map the finest spectral characteristics of Earth.

(b) Radiometric resolution: Radiometric resolution refers to the smallest change in intensity level that can be detected by the sensing system. It is determined by the number of discrete quantization levels into which the signal is digitized. The larger the number of bits used for quantization, the better is the radiometric resolution of the system.

(c) Spatial resolution: Spatial resolution is defined as the minimum distance the two point features on the ground should have in order to be distinguished as separate objects. In other words, it refers to the size of the smallest object on the Earth's surface that can be resolved by the sensor. Spatial resolution depends upon the instantaneous field-of-view of the sensor and its distance from Earth. In terms of spatial resolution, the satellite imaging systems can be classified as: low resolution systems (1 km or more), medium resolution systems (100m to 1 km), high resolution systems (5m to 100 m) and very high resolution systems (5mor less). It should be mentioned here that higher resolution systems generally have smaller coverage areas.

(d) Temporal resolution: This is related to the repetitive coverage of the ground by the remote sensing system. It is specified as the number of days in which the satellite revisits a particular place again. Absolute temporal resolution of the satellite is equal to the time taken by the satellite to complete one orbital cycle. (The orbital cycle is the whole number of orbital revolutions that a satellite must describe in order to be flying once again over the same point on the Earth's surface in the same direction.)

However, because of some degree of overlap in the imaging swaths of adjacent orbits for most satellites and the increase in this overlap with increasing latitude, some areas of Earth tend to be re-imaged more frequently. Hence the temporal resolution depends on a variety of factors, including the satellite/sensor capabilities, the swath overlap and latitude.

Consulted Reference Materials

[1] Remote sensing and image interpretation by Thomas M. Lillesand, Ralph W. Kiefer, Jonathan W. Chipman. Seventh edition. ISBN 978-1-118-34328-9 (paperback) G70.4.L54 2015.

[2] Remote Sensing Digital Image Analysis. An Introduction by John A. Richards Fifth Edition ISBN 978-3-642-30061-5 ISBN 978-3-642-30062-2 (eBook). DOI 10.1007/978-3-642-30062-2 © Springer Heidelberg New York Dordrecht London 2013.

[3] Satellite Technology Principles nd Applications by Anil K. Maini and Varsha Agrawal. Third Edition ISBN 978-1-118-63637-4 (ePub) -- ISBN 978-1-118-63641-1 (Adobe PDF) -ISBN 978-1-118-63647-3 (cloth) 2014.

[4] Raghuram D. R., Udhindra M. and Kulkarni S., (2012). Hyperspectral Signal Processing to Identify Land Cover Pattern. Project submitted in partial fulfillment of an award of BSc. Degree Department of Electrical and Electronics Engineering Amruta Institute of Engineering and Management Sciences Near Toyota Kirloskar, Bidadi Industrial Zone, Off Mysore Road, Bangalore – 562109.

Web materials

https://www2.geog.soton.ac.uk/users/trevesr/obs/rseo/types_of_sensor.html

https://webapps.itc.utwente.nl/librarywww/papers_2009/general/principlesremotesensing.pdf

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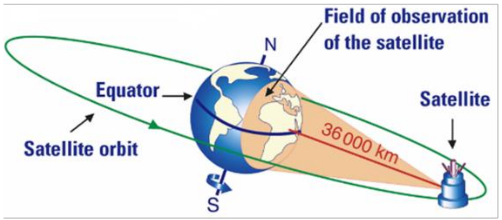


Figure 1: Geocentric Satellite

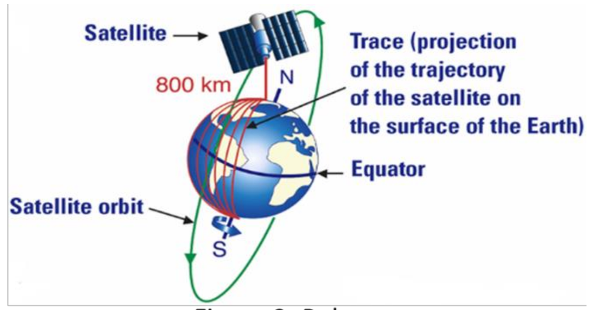


Figure 2: Polar

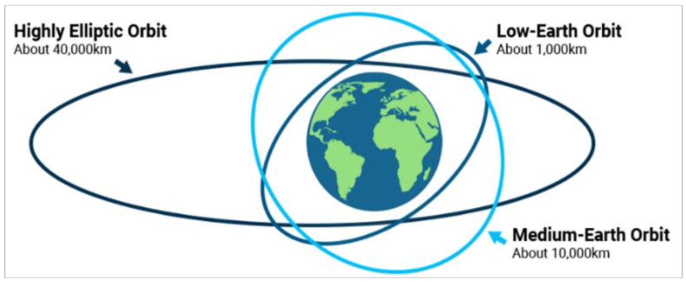


Figure 3: Low earth orbit satellite

1.2 REMOTE SENSING PLATFORMS

Remote Sensing Platforms are stages to mount sensors or camera to be used to acquire information about a target under investigation. RS platforms may be classified into different types based on their altitude with respect to the Earth's surface. The platform provides support for the sensor and platforms can be divided into three types:

i. Ground-based

ii. Airborne

iii. Spaceborne

(i) Ground-based Platforms

Ground-based platforms are mainly used to collect spectral information. They provide a basis for preliminary investigation and concept understanding. They are also used for the calibration and validation of airborne and spaceborne data.

Figure 4: examples of ground-based platforms

(ii) Airborne Platforms

Airborne remote sensing system may also be referred to as sub-orbital or aircraft, or aerial remote sensing system. At present, airplanes are the most common airborne platform. Other airborne observation platforms include balloons, kites, drones (UAVs) and high altitude sounding rockets.

- **Balloon**

The balloon is a remote-sensing platform which permits the experiment or operation to define the shape, size, and performance required of the carrier; however, the use of balloons is restricted by meteorological factors, especially by wind influences.

- **Drones (UAVs)**

Drone is a miniature remotely piloted aircraft. It is designed to fulfill requirements for a low cost platform, with long endurance, moderate payload capacity and capability to operate without a runway or small runway. An onboard computer controls the payload and stores data from different sensors and instruments. Drone includes equipment of photography, infrared detection, radar observation and TV surveillance. It uses satellite communication link.

- **Aircraft**

Aerial platforms are primarily stable wing aircraft. Helicopters are also occasionally used for this purpose. Generally, aircraft are used to collect very detailed images. Helicopters can be for pinpoint locations but it vibrates and lacks stability. Special aircraft with cameras and sensors on vibration less platforms are traditionally used to acquire aerial photographs and images of land surface features. While low altitude aerial photography results in large scale images providing detailed information on the terrain, the high altitude smaller scale images offer advantage to cover a larger study area with low spatial resolution.

1.3 SENSORS

Sensors detect the amount of energy reflected/emitted from the Earth surface and thereby provide information about its characteristics. Most remote sensing instruments (sensors) are designed to measure photons. Fundamental to this operation is a device known as a detector which works to measure radiation (a beam of photons) on the basis of the photo-electric effect. When a light-sensitive material is subject to a beam of photons, electrical energy is released and this energy is proportional to the amount of incoming radiation. A sensor thus provides a means of measuring radiation. This basic mode of operation is common to each of the sensors considered here.

(i) Active and passive sensors

Fundamentally, there are two types of sensor depending on the source of energy. Active sensors provide their own energy source for illumination. Passive sensors, by contrast, measure energy that is naturally available e.g. from Sun.

(ii)Imaging and non-imaging sensors

Another distinction is between imaging and non-imaging sensors. A non-imaging sensor measures the radiation received from all points in the sensed target, integrates this and registers a single response value, hence no image can be made from the data.

Imaging sensors measure radiation at different points on the target and this information can be processed in order to obtain an image.

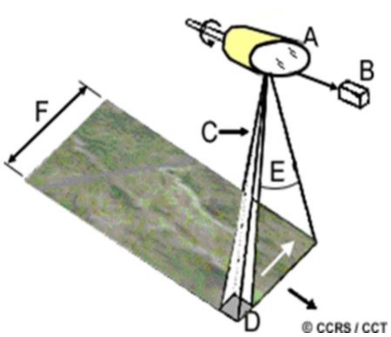


Figure 6: Sensor measurement

The detector - B operates through a rotating scan mirror - A

The field of view (FOV) is the total angle measured by the instrument in one scan - E

The instantaneous Filed of View (IFOV) is the solid angle extending from a detector to the area on the ground it measures at any instant - C

The ground resolution element (GRE) is the area measured by the sensor for each IFOV (broadly equivalent to the pixel) - D

Swath is the width of the area measured - F

The size of GRE is a function of IFOV and altitude of the platform, while the swath width depends on FOV.

- **Scanning systems**

A further characteristic of sensor systems is the operation of scanning, whereby a sensor with a narrow IFOV is swept across the terrain in order to build up a series of readings for different locations. Scanning can be undertaken either from airborne or spaceborne platforms (aircraft or satellites). Two principal mechanisms are employed to produce the scanning motion of the sensor:

- **Across-Track Scanning Sensor (Wiskbroom)**

Across track or wiskbroom scanning uses rotating and oscillating mirror which scans the entire terrain appearing at right angles to the line of flight. Successive scan lines are covered as aircraft moves forward, yielding a series of contiguous strips of a 2-D image. At any instant, the scanner detects energy within Instantaneous Field Of View (IFOV), which is normally expressed as cone angle within which incident energy is focused on detector. β is determined by instruments optical system and size of detectors.

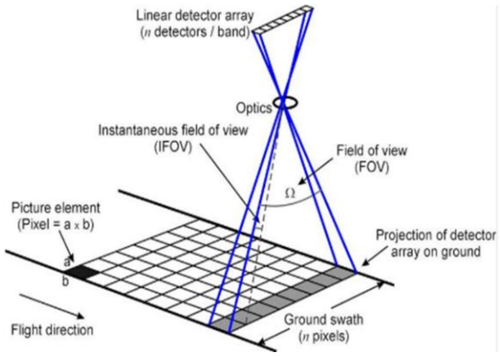


Figure 7: Across-Track Scanning Sensor

$$D = h'\beta \tag{1}$$

where,

D = Diameter of circular ground viewed

h' = Flying height above terrain

β = IFOV in radians

- **Along Track (Pushbroom) Sensor**

The along track sensor scanning, system consists of a linear array of detectors, which has Charge Coupled Devices (CCD's). The direction of scanning is the same as the direction of motion of the imaging platform, hence the name, along track scanning.

The components are:

(1) a light gathering telescope, (2) appropriate optics (e.g. a lens) within the light path, (3) a mirror, which usually oscillates over small angles, (4) a device (spectroscope) to break the incoming radiation into spectral intervals, (5) a means to direct the light so dispersed onto a battery or bank of detectors, (6) other electronics to store data.

Detector

In both cases, each detector integrates the energy that strikes surface (irradiance) to form measurement at each pixel. Then integrated irradiance at each pixel is converted into electrical signal and quantized as integer value, called Digital Number (DN). A finite number of bits, Q, is used to code the continuous data measurements as binary numbers. The number of discrete item is given by,

$$N_{DN} = 2^{Q} \tag{2}$$

and DN can be any integer in the range,

$DN_{RANGE} = [0, 2^{Q}-1]$ (3)

The larger the value of Q, the more closely the quantized data approximates the original continuous signal generated by detectors, and the higher will be the radiometric resolution of that sensor.

- **Mathematical Model of the Instrument**

Since no instrument can measure the signal sensed exactly with 100% accuracy, because the signal is always varying as a function of some parameter. This parameter, in the case of remote sensing, is usually time, or wavelength, space. In order to obtain the output signal, the instrument must integrate the signal over a non-zero parameter value as follows.

$$o(z_0) = \int_W i(\alpha) r(z_0 - \alpha)$$

Where $i\alpha$ is the input signal $r(z0 - \alpha)$ is the instrument response, inverted and shifted by z0 o(z0) is the output of the instrument at z = z0. W, being the range over which the integral is significant, W also depends on the parameter of integration.

1.4 SENSOR PARAMETERS

Sensor parameters briefly described in the following paragraphs include:

1. Instantaneous field-of-view (IFOV), 2. Overall field-of-view, 3. S/N ratio, 4. Linearity, 5. Wavelength band, 6. Swath width, 7. Dwell time, 8. Resolution

1.5 RESOLUTION OF REMOTE SENSING SYSTEM

Resolution of any remote sensing system is specified in terms of spectral resolution, radiometric resolution, spatial resolution and temporal resolution. These are briefly described as follows:

(a) Spectral resolution: This is determined by the bandwidth of the electromagnetic radiation used during the process. The narrower the bandwidth used, the higher is the spectral resolution achieved. On the basis of the spectral resolution, the systems may be classified as panchromatic, multispectral and hyperspectral systems. Panchromatic systems use a single wavelength band with a large bandwidth, multispectral systems use several narrow bandwidth bands having different wavelengths and hyperspectral systems take measurements in hundreds of very narrow bandwidth bands. Hyperspectral systems are the ones that map the finest spectral characteristics of Earth.

(b) Radiometric resolution: Radiometric resolution refers to the smallest change in intensity level that can be detected by the sensing system. It is determined by the number of discrete quantization levels into which the signal is digitized. The larger the number of bits used for quantization, the better is the radiometric resolution of the system.

(c) Spatial resolution: Spatial resolution is defined as the minimum distance the two point features on the ground should have in order to be distinguished as separate objects. In other words, it refers to the size of the smallest object on the Earth's surface that can be resolved by the sensor. Spatial resolution depends upon the instantaneous field-of-view of the sensor and its distance from Earth.

(d) Temporal resolution: This is related to the repetitive coverage of the ground by the remote sensing system. It is specified as the number of days in which the satellite revisits a particular place again. Absolute temporal resolution of the satellite is equal to the time taken by the satellite to complete one orbital cycle. (The orbital cycle is the whole number of orbital revolutions that a satellite must describe in order to be flying once again over the same point on the Earth's surface in the same direction.) However, because of some degree of overlap in the imaging swaths of adjacent orbits for most satellites and the increase in this overlap with increasing latitude, some areas of Earth tend to be re-imaged more frequently.

Consulted Reference Materials

[1] Remote sensing and image interpretation by Thomas M. Lillesand, Ralph W. Kiefer, Jonathan W. Chipman. Seventh edition. ISBN 978-1-118-34328-9 (paperback) G70.4.L54 2015.

[2] Remote Sensing Digital Image Analysis. An Introduction by John A. Richards Fifth Edition ISBN 978-3-642-30061-5 ISBN 978-3-642-30062-2 (eBook). DOI 10.1007/978-3-642-30062-2 © Springer Heidelberg New York Dordrecht London 2013.

[3] Satellite Technology Principles nd Applications by Anil K. Maini and Varsha Agrawal. Third Edition ISBN 978-1-118-63637-4 (ePub) -- ISBN 978-1-118-63641-1 (Adobe PDF) -ISBN 978-1-118-63647-3 (cloth) 2014.

[4] Raghuram D. R., Udhindra M. and Kulkarni S., (2012). Hyperspectral Signal Processing to Identify Land Cover Pattern. Project submitted in partial fulfillment of an award of BSc. Degree Department of Electrical and Electronics Engineering Amruta Institute of Engineering and Management Sciences Near Toyota Kirloskar, Bidadi Industrial Zone, Off Mysore Road, Bangalore – 562109.

Web materials

https://www2.geog.soton.ac.uk/users/trevesr/obs/rseo/types_of_sensor.html

https://webapps.itc.utwente.nl/librarywww/papers_2009/general/principlesremotesensing.pdf

Module 2:

Sub-Title 4: **Geo-morphology and image Interpretation**

Objectives: **The objectives are to discuss geo-morphology and image interpretation methods.**

- Geo-moprhology
- Digital Image Interpretation

1.0 Geomorphology

Geomorphology is the science of study of the landforms of the earth. Geomorphology as a science developed much later than geology although several aspects of geomorphology are embedded in geological processes. Geomorphology deals with the genesis of relief forms of the surface of the earth's crust. Certain natural processes are responsible for the forms of the surface of the earth. A thorough understanding of various processes leading to landforms is necessary to understand the environment in which we live. Remote sensing is an effective tool in this understanding, as aerospace images contain integrated information of all that is on the ground, the landform, the ecology, the resources contained in the area and the impact of human actions on the natural landscape. The dynamism with which changes occur in the landscape is brought out effectively by repeated coverage of images of the same area at different times.

- **Geomorphology - basic concepts**

The earth's surface forms are primarily due to hypogene or endogenous processes, which include diastrophism, leading to geologic structure, tectonic activity and volcanism leading to volcanic landforms. These forms are modified by epigene or exogenous processes, which include erosion and depositional activities of water, wind and ice. Other activities include weathering, mass wasting or movement of material by gravitational action, land-ocean interaction resulting in landforms due to waves, currents, tides and tsunamis. Climate is another important factor, which has relevance in shaping of the earth's surface because the processes that act upon the surface material are different in different climatic zones.

➢ Processes of Land form

Process	Form (of varying scales)	
	Local (Example)	Regional (Example)
Tectonic/Structural	Anticlinal Hill and synclinal valley	First order folded mountain systems
Volcanic	Cone, Crater, Lava tunnel	Volcanic fields
Denudational	Pediment-inselberg topography	Denudational Hills, pediplains
Fluvial (Riverine)	Alluvial fan, slough, Terrace/Oxbow	Deltas, flood plains, Alluvial plains
Marine	Beach ridge, terrace, lagoon, spit, bar	Coastal plain
Glacial	Cirque, drumlin, esker, moraine ridge	Outwash and moraine plains, glacial valleys
Aeolain	Sand dune, yardang	Dune fields
Solution	Sink hole	Karst topography
Antheropogenic	Quarry, mine dump	Urban sprawls, mine fields

➢ Geomorphological mapping

The first geomorphological map was prepared in 1914 but the main demand for the maps came cover form planner and agronomists after World War II. However, a formal mapping system was designed only during 1950s. Many systems were developed by European countries like France, Poland and Russia. The International Geographical Union's Sub-commission on geomorphological mapping was set up in 1960 to standardize legends for mapping. However, specific consensus was arrived at a modified legend. A geomorphological map must give information about morphology (appearance), morphometry (dimensions and slope values), morphogen (origin/genesis) and morphochronology (the age) of each form.

1.2 IMAGES INTERPRETATION

With few exceptions the reason we record images of the earth in various wavebands is so that we can build up a picture of features on the surface. Sometimes we are interested in particular scientific goals but, even then, our objectives are largely satisfied if we can create a map of what is seen on the surface from the remotely sensed data available. There are two broad approaches to image interpretation. One depends entirely on the skills of a human analyst a so-called photo-interpreter. The other involves computer assisted methods for analysis, in which various machine algorithms are used to automate what would otherwise be an impossibly tedious task.

➢ Photointerpretation

A skilled photointerpreter extracts information from image data by visual inspection of an image product composed from the data. The analyst generally notes large-scale features and, in principle, is not concerned with the spatial and radiometric digitisations present. Spatial, spectral and temporal cues are used to guide the analysis, including the spatial properties of shape, size, orientation and texture. Roads, coastlines, river systems, fracture patterns and lineaments are usually readily identified by their spatial properties. Temporal cues are given by changes in a particular object or cover type from one date to another and assist in discriminating, for example, deciduous or ephemeral vegetation from perennial types.

➢ Computer Aided Interpretation (CAI)

Starting with the set of measurements, a computer processing algorithm is used to provide a unique label, or theme, for all the pixels in the image. Once complete, the operation has produced a map of themes on the ground from the recorded image data. The map is called a thematic map and the process of generating it is called thematic mapping. Once they have all been labelled, it is possible to count the pixels of a given cover type and note their geographic distributions. Knowing the size of a pixel in equivalent ground metres, accurate estimates of the area of each cover type in the image can be produced. Because we are able to quantify the cover types in this manner, and because the procedures we use are inherently numerical and statistical, classification is referred to as quantitative analysis.

➢ Comparison of photo-interpreter and Quantitative Computer Analysis

Photointerpretation (human analyst)	Quantitative analysis (computer)
On a scale large compared with pixel size	Can work at the individual pixel level
Less accurate area estimates	Accurate area estimates are possible
Limited ability to handle many bands	Full multi-band analysis is possible
Can use only a limited number of brightness values in each band (about 16)	Can use the full radiometric resolution available (256, 1024, 4096, etc.)
Shape determination is easy	Shape determination is complex
Spatial information is easy to use in general	Spatial decision making in general is limited

➢ How to describe data for analysis

The first thing we have to do is to decide on a model for describing the data. Because each pixel is characterised by a set of measurements a useful summary tool is to collect those measurements together into column called a pixel vector which has as many elements as there are measurements. By describing the pixel in this manner we will, later on, be able to use the very powerful field of vector and matrix analysis when developing classification procedures. We write the pixel vector with square brackets in the form:

$$\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix}$$

The elements listed in the column are the numerical measurements (brightness values) in each of bands 1 through to N, and the overall vector is represented by the character in bold. Because we will be using concepts from the field of mathematical pattern recognition, note that the vector x is also sometimes called a pattern vector. To help visualise the concepts to follow it is of value now to introduce the concept of the spectral space or spectral domain. In the terminology of pattern recognition it is called a pattern space. This is a coordinate system with as many dimensions as there are measurements in the pixel vector. A particular pixel in an image will plot as a point in the spectral space according to its brightness along each of the coordinate directions.

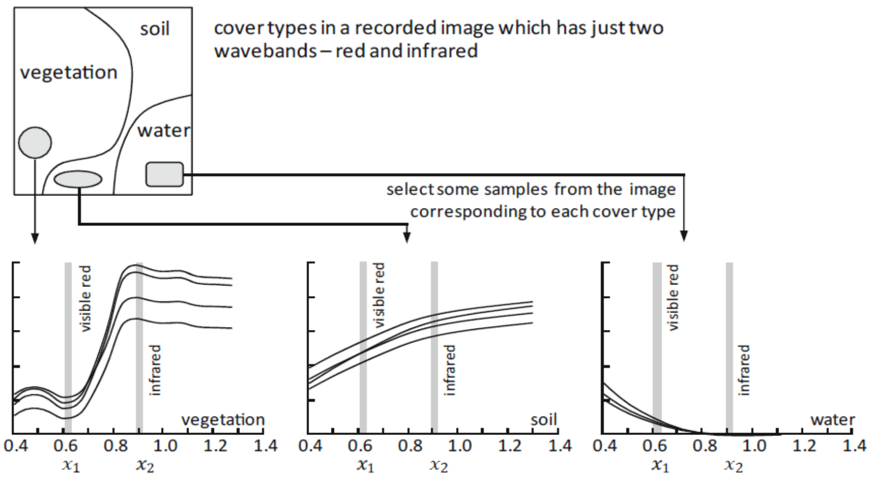


Figure 1: Fundamental of qualitative analysis

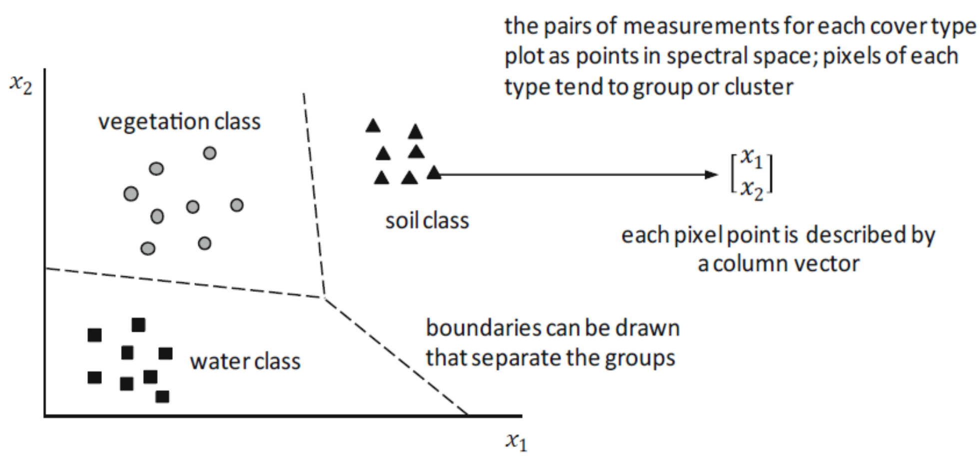


Figure 2: Fundamental of Qualitative Analysis Cont'd

Reference materials

[1] Remote Sensing Digital Image Analysis. An Introduction by John A. Richards Fifth Edition ISBN 978-3-642-30061-5 ISBN 978-3-642-30062-2 (eBook). DOI 10.1007/978-3-642-30062-2 © Springer Heidelberg New York Dordrecht London 2013.

[2] D.P. RAO, (2002) Remote sensing application in geomorphology. Tropical Ecology 43(1): 49-59, 2002 © International Society for Tropical Ecology. ISSN 0564-3295

Module 2:

Sub-Title 5: **Digital Image Processing and Map Production**

Objectives: **The objectives are to discuss digital image processing, and production of digital map.**

- Digital Image Processing
- Digital Map Production

1.0 DIGITAL IMAGE PROCESSING

The central idea behind digital image processing is quite simple. One or more images are loaded into a computer. The computer is programmed to perform calculations using an equation, or series of equations, that take pixel values from the raw image as input. In most cases, the output will be a new digital image whose pixel values are the result of those calculations. The procedures for digital image processing may be categorized into one (or more) of the following seven broad types of computer-assisted operations:

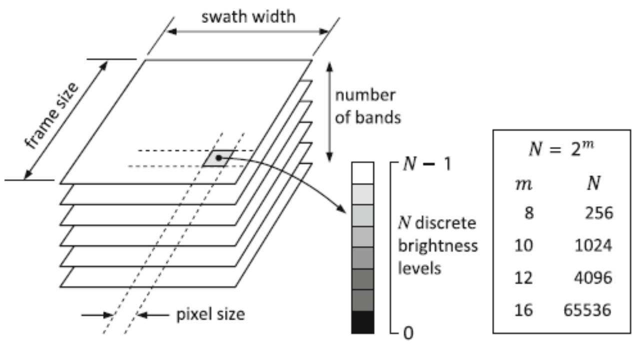
1. **Image preprocessing.** These operations aim to correct distorted or degraded image data to create a more faithful representation of the original scene and to improve an image's utility for further manipulation later on.

2. **Image enhancement.** These procedures are applied to image data in order to more effectively render the data for subsequent interpretation. In many cases, image enhancement involves techniques for heightening the visual distinctions among features in a scene, ultimately increasing the amount of information that can be interpreted from the data.
3. **Image classification.** The objective of image classification is to replace visual interpretation of image data with quantitative techniques for automating the identification of features in a scene.
4. **Analysis of change over time.** Many remote sensing projects involve the analysis of two or more images from different points in time, to determine the extent and nature of changes over time.

5. Data fusion and GIS integration. These procedures are used to combine image data for a given geographic area with other geographically referenced data sets for the same area.

6. Hyperspectral Image analysis. While most multispectral sensors merely discriminate among various earth surface features, hyperspectral sensors afford the opportunity to identify and determine many characteristics about such features. However, these sensors have their disadvantages as well, including an increase in the volume of data to be processed, relatively poor signal-to-noise ratios, and increased susceptibility to atmospheric interference if such effects are not corrected for.

7. Biophysical modeling. Digital remote sensing data have been used extensively in the realm of quantitative biophysical modeling. The intent of such operations is to relate quantitatively the data recorded by a remote sensing system to biophysical features and phenomena measured on the earth's surface. For example, remotely sensed data might be used in applications as varied as crop yield estimation, defoliation measurement, biomass prediction, water depth determination, and pollution concentration estimation.



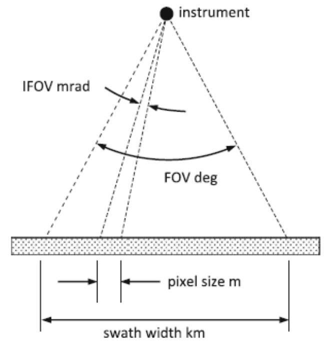


Figure 2: Definition of image spatial properties, with common units indicated

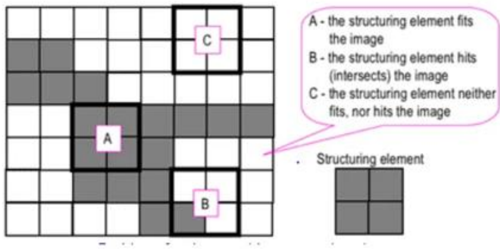
Figure 1: Technical characteristics of digital image data

The properties of digital image data of importance in image processing and analysis are the number and location of the spectral measurements (bands or channels), the spatial resolution described by the pixel size, and the radiometric resolution. Frequently, radiometric resolution is expressed in terms of the number of binary digits, or bits, necessary to represent the range of available brightness values. Data with an 8 bit radiometric resolution has 256 levels of brightness, while data with 12 bit radiometric resolution has 4,096 brightness levels.

The size of the recorded image frame is also an important property. It is described by the number of pixels across the frame or swath, or in terms of the numbers of kilometres covered by the recorded scene. Together, the frame size of the image, the number of spectral bands, the radiometric resolution and the spatial resolution determine the data volume generated by a particular sensor. That sets the amount of data to be processed, at least in principle.

Classic image processing algorithms

1. Morphological Image Processing



2. Gaussian Image Processing

$$G(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{x^2}{2\sigma^2}}$$

3. Fourier Transform in image processing

$$F(u, v) = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y)\, e^{-j2\pi(\frac{ux}{M}+\frac{vy}{N})}$$

$$f(x, y) = \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u, v)\, e^{j2\pi(\frac{ux}{M}+\frac{vy}{N})}$$

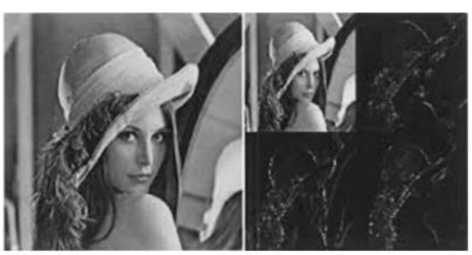
4. Edge Detection in image processing

$$Gx = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} * Image\ matrix \qquad Gy = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} * Image\ matrix$$

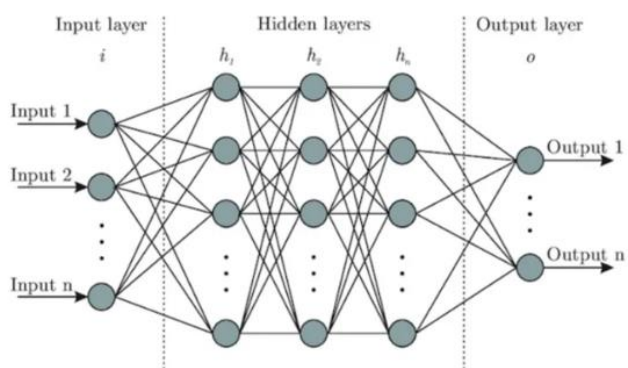
$$G = sqrt(Gx^2 + Gy^2)$$

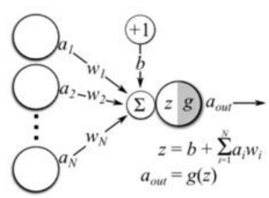
5. Wavelet Image Processing

Wavelets take both time and frequency into the consideration.



6. Image processing using Neural Networks





1.2 DIGITAL MAP PRODUCTION

- **Ten Things to Consider When Making a Map**

- Geographic Bounds. The extent of the geographic area mapped will affect a whole slew of cartographic choices from the **map** projection used to data and symbology choices.
- Background Data Elements.
- Symbolization.
- Labels.
- Legend.
- Incorporating **Map** Elements.
- Metadata.
- **Map** Layout.
- Locator map
- Peer review

➢ **Metric properties of digital maps**

Maps assume that the viewer has an orthogonal view of the map (they are looking straight down on every point). This is also called a perpendicular view or normal view. The metric properties or a map are:

- area
- shape
- direction
- distance
- scale

2.3 PROJECTION CONSIDERATION FOR DIGITAL MAP MAKING

There are several different types of projections that aim to accomplish different goals while sacrificing data in other areas through distortion.

Area preserving projection – equal area or equivalent projection

Shape preserving – conformal, orthomorphic

Direction preserving – conformal, orthomorphic, azimuthal (only from a the central point)

Distance preserving – equidistant (shows the true distance between one or two points and every other point)

Reference materials

[1] Remote sensing and image interpretation by Thomas M. Lillesand, Ralph W. Kiefer, Jonathan W. Chipman. Seventh edition. ISBN 978-1-118-34328-9 (paperback) G70.4.L54 2015.

[2] Remote Sensing Digital Image Analysis. An Introduction by John A. Richards Fifth Edition ISBN 978-3-642-30061-5 ISBN 978-3-642-30062-2 (eBook). DOI 10.1007/978-3-642-30062-2 © Springer Heidelberg New York Dordrecht London 2013.

[3] Satellite Technology Principles nd Applications by Anil K. Maini and Varsha Agrawal. Third Edition ISBN 978-1-118-63637-4 (ePub) -- ISBN 978-1-118-63641-1 (Adobe PDF) -ISBN 978-1-118-63647-3 (cloth) 2014.

https://www.gislounge.com/map-projection/

https://neptune.ai/blog/image-processing-in-python-algorithms-tools-and-methods-you-should-know

Module 2:

Sub-Title 6: Remote sensing data source for GIS in water resources

Objectives: The objectives are to discuss remote sensing data source for GIS in water resources.

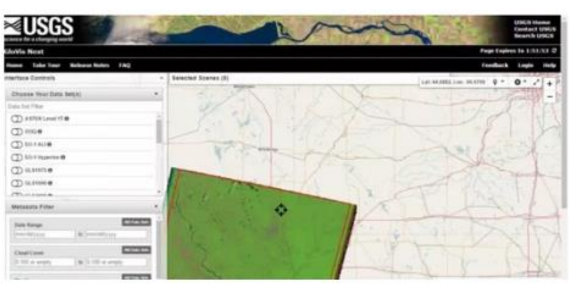
- **Example of where data can be source**
- **Requirement for data download and utilization**

1.0 REMOTE SENSING DATA SOURCE FOR GIS IN WATER RESOURCES

The need for high quality remote sensing data is daily increasing, as such, an increase in the application of remote sensing techniques in water resources with numerous number of researches carried out each day by various researchers around the world. Every remote sensing analysis revolves around the term DATA with specified resolution, location, sensor and above all it should be FREE OF COST. The following are the 10 top remote sensing data source sites providing data for free as well as for commercial purposes.

1. GLOVIS

The USGS Global Visualization Viewer (GloVis) is one of the quick and easy online search and order tool for selected satellite and aerial data

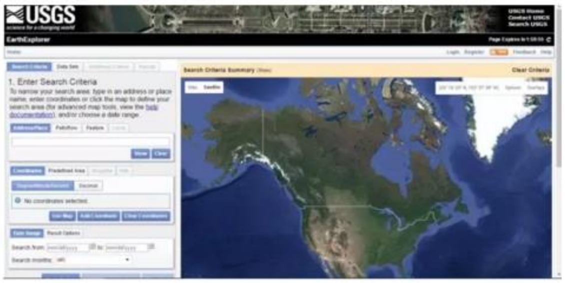


2. NASA Earth Observation (NEO)

NASA Earth Observation has more than 50 datasets on atmosphere, land, Ocean, energy, environment and much more on a daily, weekly and monthly frequency. The datasets are available in the form of JPEG, PNG, Google Earth and GeoTIFF.

3. USGS Earth Explorer

USGS Earth Explorer will stay the best portal for fetching Remote sensing data for a variety of reasons.



4. ESA's Sentinel data

The Copernicus Open Access Hub (previously known as Sentinels Scientific Data Hub) provides complete, free and open access to: Sentinel-1, Sentinel-2 and Sentinel-3 user products, starting from the In-Orbit Commissioning Review (IOCR). The ESA's sentinel data is chasing the USGS Earth Explorer with more bands and crisper resolution.

5. NASA Earth Data

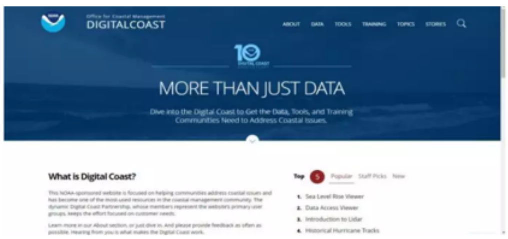
Earth data Search uses Client's natural language processing-enabled search tool to quickly narrow down to relevant collections

6. NOAA Class

NOAA (National Oceanic and Atmospheric Administration) Class has a distinct online data library system, a pool of free top quality and valuable geographic data sets which set them apart

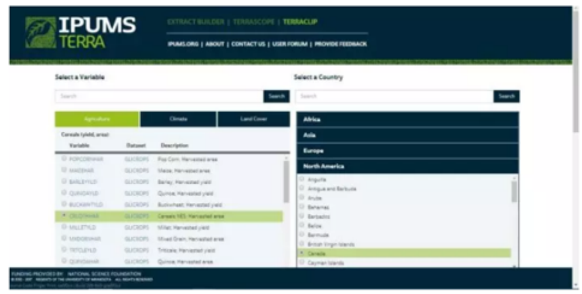
7. NOAA Digital Coast

If Coastal data is your only requirement, there is no better portal to reach than NOAA's Digital Coast. Simply define your choice of interest and select from the range of free satellite imagery dataset such as infrared, radar and true colour composite to download. Apart from the coastal data you shall as well get imagery, land cover, elevation, socio-economic and benthic data.



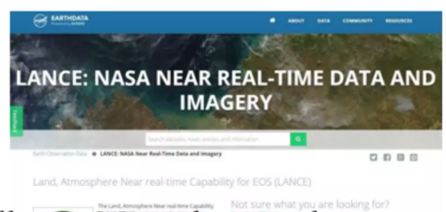
8. IPPMUS Terra

IPUMS Terra integrates population census data from around the world with global environmental data, allowing users to obtain customized datasets that incorporate data from multiple sources in a single coherent structure. The country specific data can be obtained from Terraclip featuring MODIS data.



9. LANCE

The Land, Atmosphere Near real-time Capability for EOS (LANCE) supports application users interested in monitoring a wide variety of natural and man-made phenomena. Near Real-Time (NRT) data and imagery from the AIRS, AMSR2, MISR, MLS, MODIS, OMI and VIIRS instruments are available much quicker than-routine processing allows. Most data products are available within 3 hours from satellite observation. NRT imagery are generally available 3-5 hours after observation.



10. VITO Vision

The VITO Vision provides coarse vegetation data from PROBA-V, SPOT-Vegetation and METOP. These coarse resolution satellites carves out vegetation patterns of the Earth's surface. The easy-to-use interface and delivers free low resolution satellite data. This type of data is a good for large-scale applications that doesn't need the finer details.

1.2 REQUIREMENT FOR DATA DOWNLOAD AND UTILIZATION

Various general and specific data are available from the 10 listed sites. However user are requires to register before download of data can be made. Examples of data available for download are:

Digital Orthophoto Quadrangle (DOQs), EO-1 ALI (Earth Observing-1 Advanced Land Imaging), EO-1 Hyperion (Earth Observing-1 Hyperion), Global Land Survey (GLS), Landsat 4-5 TM (L4-5 TM C1 Level-1), Landsat 7 ETM+ (L7 ETM+ C1 Level-1), Landsat 8 OLI/TIRS (L8 OLI/TIRS C1 Level-1), Sentinel-2, ISRO ResourceSAT 1 and 2 – AWIFS Sensor, ISRO ResourceSAT 1 and 2 – LISS-3 Sensor, GeoEye's OrbView-3 (OrbView-3) etc.

Reference Materials

[1] Remote sensing and image interpretation by Thomas M. Lillesand, Ralph W. Kiefer, Jonathan W. Chipman. Seventh edition. ISBN 978-1-118-34328-9 (paperback) G70.4.L54 2015.

[2] Remote Sensing Digital Image Analysis. An Introduction by John A. Richards Fifth Edition ISBN 978-3-642-30061-5 ISBN 978-3-642-30062-2 (eBook). DOI 10.1007/978-3-642-30062-2 © Springer Heidelberg New York Dordrecht London 2013.

[3] Satellite Technology Principles nd Applications by Anil K. Maini and Varsha Agrawal. Third Edition ISBN 978-1-118-63637-4 (ePub) -- ISBN 978-1-118-63641-1 (Adobe PDF) -ISBN 978-1-118-63647-3 (cloth) 2014.

Vinithra Rajendran. https://geoawesomeness.com/list-of-top-10-sources-of-free-remote-sensing-data/

Module 2:

Sub-Title 7: Application of RS in Water Resources Planning and Management

Objectives: The objectives are to discuss water resources, planning and management strategies.

- What are water resources?
- Planning of water resources
- Management of water resources

1.0 WATER RESOURCES

Water resources are sources of water that are useful or potentially useful to humans. It is important because it is needed for life to exist. Many uses of water include agricultural, industrial, household, recreational and environmental activities. Virtually all of these human uses require fresh water.

Only 2.5% of water on the Earth is fresh water, and over two thirds of this is frozen in glaciers and polar ice caps. Water demand already exceeds supply in many parts of the world, and many more areas are expected to experience this imbalance in the near future. It is estimated that 70% of world-wide water use is for irrigation in agriculture. Climate change will have significant impacts on water resources around the world because of the close connections between the climate and hydrologic cycle.

Due to the expanding human population competition for water is growing such that many of the worlds major aquifers are becoming depleted. Many pollutants threaten water supplies, but the most widespread, especially in underdeveloped countries, is the discharge of raw sewage into natural waters.

- **Application of Remote Sensing In Water Resources, Planning & Mgt.**

Introduction: Water is the essential ingredient for almost every human activity. At the outset of the 21st century, scarce water resources were already in high demand for agriculture, domestic consumption, hydropower, sanitation, industrial manufacturing, transportation, recreational activities, and ecosystem services. Yet new needs for water continue to evolve particularly in mining and petroleum resource development, where vast quantities of water are now being employed in everything from extraction and processing of unconventional oil from tar sands to

hydraulic fracturing ("fracking") in which high-pressure fluids are injected into wells to expand networks of fractures in the bedrock, allowing oil and natural gas to be collected from formations where they would otherwise be unobtainable. At the same time, water can also be a hazard whether from flooding, pollution, or the spread of waterborne disease. The uses of remote sensing in managing water resources are numerous and important.

Water is therefore of central importance to development and has been recognized as one of the United Nations (UN) Sustainable Development Goals (SDG6) Clean water and sanitation. Remote Sensing, coupled with Geographic Information System (GIS), is a powerful tool for monitoring of water quality and water pollution. Satellite imageries have been used successfully in determination of various water quality parameters like Total Suspended Solids, turbidity, chlorophyll content, colour, temperature etc. by using the Visible, Reflected Infrared and occasionally Thermal Infrared bands of the Electro Magnetic Spectrum.

Remote Sensing techniques have been used in sustainable management of water resources, which include runoff and hydrological modeling, flood management, watershed management, drought management and management of Irrigation Command Areas. Satellite imageries obtained from Landsat Thematic Mapper (TM), Linear Imaging and Self Scanning (LISS) and Wide Field Sensor (WiFS) have been used extensively by various researchers for the calculation of drainage basin area, drainage density, Normalized Difference Vegetation Index (NDVI) and Leaf Water Content Index (LWCI).

1.2 Planning Of Water Resources

(1) Planning in terms of the process

- Linear planning (old approach). The major components of water master planning: water resources, water demand analyses, Types of

Planning system design and socio-economic justification follow each other Sequentially

- Cyclic planning (new approach). The sequence of the activities of the planning components is repeated several times (Inception, Mid-term, Draft Final, Final Plan)

(2) Planning in terms of scope or purpose

- Single purpose plan It has to do with single activity such as water supply or irrigation or flood control….etc.
- Multi-purpose plan It aims at satisfying a number of purposes at the same time

(3) In terms of the scope of planning

- such as irrigation, hydropower, water supply , environmental management.
- Comprehensive or integrated plan

- It is either multi-unit, multi-purpose and multi-objective plan
- It include economical, financial, political, social, and environmental objectives
- Consider both structural and non-structural (institutional) alternative
- It does not include feasibility studies of individual projects

(4) Planning In terms of areal extent

- National Plan - To determine the national priorities for the allocation of scarce water resources in view of the national objectives and constraints (National Water Plan)
- Regional Plan - At regional level which depend of the country - In principle it does not differ from a national plan
- River Basin Plan - it use the hydrological boundaries as the planning limits - It is an integrated plan

(5) In terms of time frame of plan

- Short term planning - Its advantages the uncertainty in the scenario is small - It disadvantages is the lakes vision on future development
- Long term planning - Try to set out long term perspective and guidelines for the future development of a nation, region or river

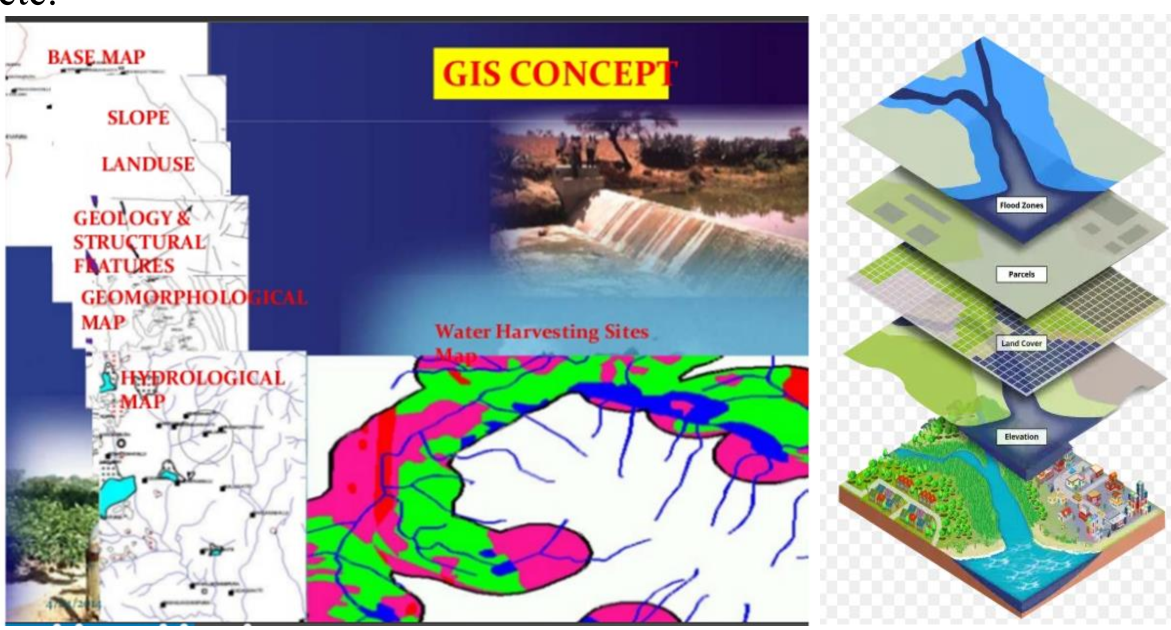
basin - It has a large of uncertainty - It is a long term policy or tactical planning

- Strategic Planning (open end approach) - it is a combination of short term and long-term planning - Wide possible range of future option should remain open - A plan exclude future development options is not strategic, not flexible and not robust

1.2.1 STEPS INVOLVED IN (RSWR) PLANNING

Statement of Objectives –:

Before any project planning, a clear-cut statement of the objectives of the projects must be made such as: Method of data collection - Hydrological data - Geological data - Demographic data - Economic Data - Ecological Data - Public opinion and political opinion data - Spatial and temporal data (agriculture data, municipal and industrial uses data, pollution data) etc.



Remote sensing and GIS concept of data integration

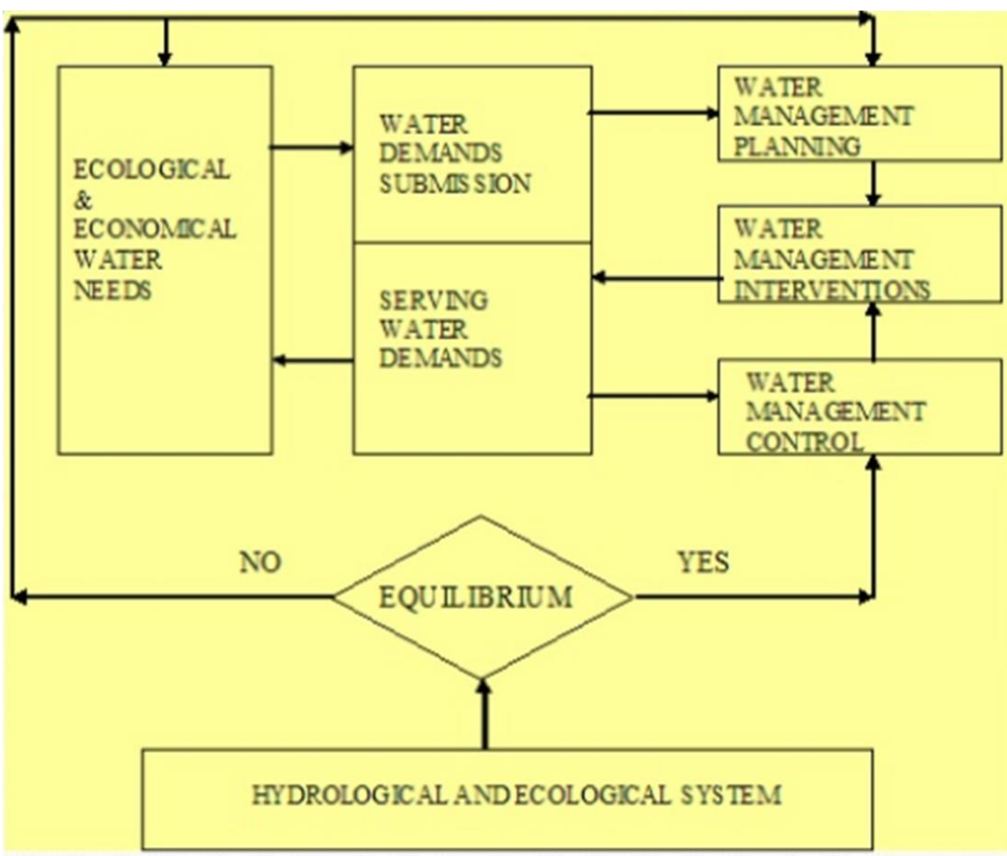
1.3 Water Resources Management

- The water resources management includes:
  - The quantitative and qualitative exploration of water resources
  - Water needs and inventory records
  - Measurement and matching of the water resources and water needs (demands) in a special system
  - Decision support depending with light of the results

Water resources management decision	Water-related data products used to make decision	Traditional data sources
Planning and design		
Design of flood control (design of flood storage, routing, and alleviation)	Long-term records (decades) of precipitation and streamflow; long-term records of SWE in cold regions	Rain gauge networks; stream gauge networks; snow courses and pillows
Design of hydropower systems (for reliable power production given available resources)	Long-term records (decades) of streamflow; long-term records of SWE in cold regions	Rain gauge networks; stream gauge networks; snow courses and pillows

Water resources management decision	Water-related data products used to make decision	Traditional data sources
Design of irrigation systems (including extraction and distribution and water use)	Long-term records (decades) of precipitation, streamflow and groundwater. Estimates of crop water use	Rain gauge networks; stream gauge networks; wells, piezometers; meteorological networks
Design of wastewater treatment systems (capture, treatment, reuse, and release)	Records of feed sources such as streamflow and groundwater	Stream gauge networks; wells, piezometers
Design of water supply systems (for effcient supply of desired quality water)	Records of precipitation, streamflow, and groundwater	Rain gauge networks; stream gauge networks; wells, piezometers

Flow diagram for water resources management



Conclusion

Remote sensing techniques have been widely used to delineate the surface water bodies, estimate meteorological variables like temperature and precipitation, estimate hydrological state variables like soil moisture and land surface characteristics, and to estimate fluxes such as evapotranspiration. Today, near-real time monitoring of flood, drought events, and irrigation management are possible with the help of high resolution satellite data.

Reference Materials

[1] Remote sensing and image interpretation by Thomas M. Lillesand, Ralph W. Kiefer, Jonathan W. Chipman. Seventh edition. ISBN 978-1-118-34328-9 (paperback) G70.4.L54 2015.

[2] Remote Sensing Digital Image Analysis. An Introduction by John A. Richards Fifth Edition ISBN 978-3-642-30061-5 ISBN 978-3-642-30062-2 (eBook). DOI 10.1007/978-3-642-30062-2 © Springer Heidelberg New York Dordrecht London 2013.

[3] Satellite Technology Principles nd Applications by Anil K. Maini and Varsha Agrawal. Third Edition ISBN 978-1-118-63637-4 (ePub) -- ISBN 978-1-118-63641-1 (Adobe PDF) -ISBN 978-1-118-63647-3 (cloth) 2014.

[4] D. Nagesh Kumar and T.V. Reshmidevi, (2013) Remote Sensing Applications in Water Resources. Journal of the Indian Institute of Science. A Multidisciplinary Reviews Journal ISSN: 0970-4140 Coden-JIISAD© Indian Institute of Science Journal of the Indian Institute of Science 93(2) Apr.–Jun. 2013 journal.iisc.ernet.in

[5] D. Bagchi & R. Bussa, (2011) Application of Remote Sensing in Water Quality and Water Resources Management An Overview Bhujal News Quarterly Journal, July-Dec, 2010 & Jan-Dec, 2011. https://hindi.indiawaterportal.org/

https://www.sciencedaily.com/terms/water_resources.htm

Module 2:

Sub-Title 8: Cloud Based GIS/RS Analysis

Objectives: The objectives are to discuss web based analysis and Google Application etc.

- Web/cloud based analysis
- Terminologies used in cloud GIS/RS analysis

1.0 CLOUD BASED ANALYSIS

Business analytics and wider research has increasingly been moving to cloud-based services and providers. For geospatial analysis, the transition has been somewhat slow but we may now begin to see the pace increasing. Companies are now beginning to develop platforms that enable geospatial analytics to be cloud-based, while other options developed by analysts are also available. Increasingly, challenges are seen at large spatial scales, where researchers are conducting analysis not only at global scales but their research needs also require fine-grained analytics as well as improved visualization at multiple time and spatial scales. Increasing access to multiple data platforms, from satellites to different land-based sensors, means that researchers can conduct assessments at large and small spatial scales, but limitations had been the lack of access to computing resources that have high throughput, data storage, visualization, and analytics that make it easy for a researcher or analyst.

For Example, Descartes Labs, based in New Mexico, has created a cloud-based geospatial analytics platform, focusing on enterprise and real-time data cataloging and modeling, to facilitate cloud-based geospatial analysis for its users. The intent is to facilitate data access and sharing to enable rapid deployment of models and analysis that would be difficult otherwise, given the increasingly large volume of data available for analytics. The analytical tools combine petabyte-scale geospatial data, a workbench composed of varied visualization and modeling tools, including machine learning methods, and application builder to customize user-driven analysis and experiences to enable new forms of assessment to be made. The move to more cloud-based solutions had been developing for some time and spatial analysis had already been utilizing high performance computing (HPC).

For example, the Virtual Fire platform was developed with the idea that managers and analysts interested in assessing fire probability in given areas require model output that is not complex to put together and that attaining the needed computational capability be easy. Virtual Fire allows this by moving analysis to an HPC system; however, its capabilities could be improved by moving data to cloud-based platforms that allow data storage and transfer for the analyses deployed in forecasting fire movements and impact. A recent study looking at landscape ecology and landscape change due to human-environment interactions did use a cloud-based approach for data storage and analytics that allowed a detailed visualization to be developed over a fine spatial scale (down to a few meters) that can also be scaled to larger, country-level visualization, such as the entire United States. This was done using Amazon's EC2 cloud resource, with analysis, visualization, and data storage all combined in one system rather than having to split these tasks and applications as had been done previously.

The high rate of data transfer create problems of throughput and connectivity between cloud and user ends. New forms of cloud-based computing used for geospatial analysis include Fog-based computing, which attempts to increase throughput and reduce latency for clients accessing cloud-based data and analytics. This, in effect, helps to minimize slow transmission of data that may occur due to connectivity of clients and bandwidth. This is done by optimizing what data are sent to the cloud, in part using machine learning to determine data packets needed, and reducing data transmission to the most useful parts.

The overall landscape analysis framework with three functional components: (1) data pre-processing, (2) data analysis, and (3) visual analytics, produced by Deng, Desjardins, & Delmelle, 2019 is shown.

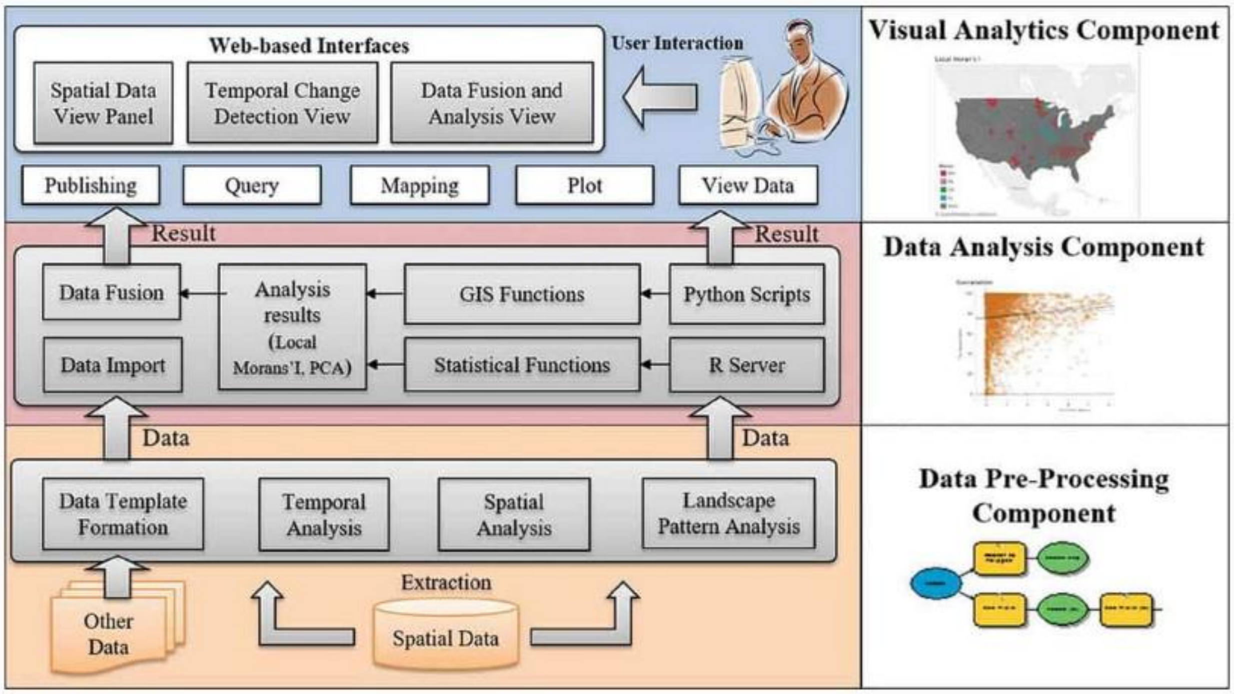


Figure 1: Three components of landscape analysis

The cloud is seen as a likely solution for challenges in spatial processing of large volumes of data, while providing the ease of visualization and analysis to be conducted from a simple workstation. Companies such as Descartes Lab are emerging as leaders in providing platform solutions, but open source and other options are available for users. Very likely, we will see more migration of spatial and GIS work to cloud-based platforms in the near future. Accessibility will likely become a major issue as researchers will increasingly want the ease of access to cloud-based solutions without having to pay large fees to use these powerful systems.

1.2 CLOUD GIS/RS ANALYSIS TERMINOLOGIES AND THEIR MEANING

- **Amazon Elastic Compute Cloud (EC2)**

EC2 is a cloud computing service from Amazon that allows renting of virtual computers and run your own computer applications. It also provides an environment for running the ArcGIS Server.

- **ArcGIS Explorer**

This is a free downloadable application from ESRI, to access online GIS content and capabilities (free, ready-to-use datasets hosted by ESRI). You can combine with your own maps, search and visualize your data, create custom maps, perform spatial analysis, and display presentations.

- **ArcGIS Mobile**

ArcGIS Mobile is a cloud extension of ArcGIS to enable field operations with your Windows Mobile. It allows you to sync field data with the GIS data across your organization. You can create or update geospatial data in the field, discover and explore maps, find places and more.

- **ArcGIS Online Service**

An offering from ESRI with 2D map services, 3D globe services, task-based functional services, including online map layers, to support your GIS work. With ArcGIS Online Service, you can find, create, and share web maps instantly.

- **ArcGIS Server in the Cloud**

Part of the ESRI Managed Cloud Services, the ArcGIS Server software service can be deployed in the cloud (or on-premise) on various platforms – Amazon Web Services, Microsoft Azure, IBM SoftLayer, VCE. You can deploy the infrastructure, software, data management and app development capabilities for your organizational needs.

- **Cloud Computing**

It refers to hosted services on the internet, for storage and access of your data and programs, instead of your computer hard drive or local storage device. The technology makes use of internet, central remote servers and a virtual infrastructure to manage your data, applications and computing needs. The cloud offers instant access and computing of any volume of workload on demand, from any location and any device. There are various working models for easy access and operations; namely service and deployment models.

- **Cloud GIS**

This refers to hosted services on the internet meant for users of GIS technology or members of public who want to access maps. Services include map service, data storage and access, powerful analysis with applications, to manage assets and information. Learn more about GIS in the Cloud.

❖ **Cloud Status**

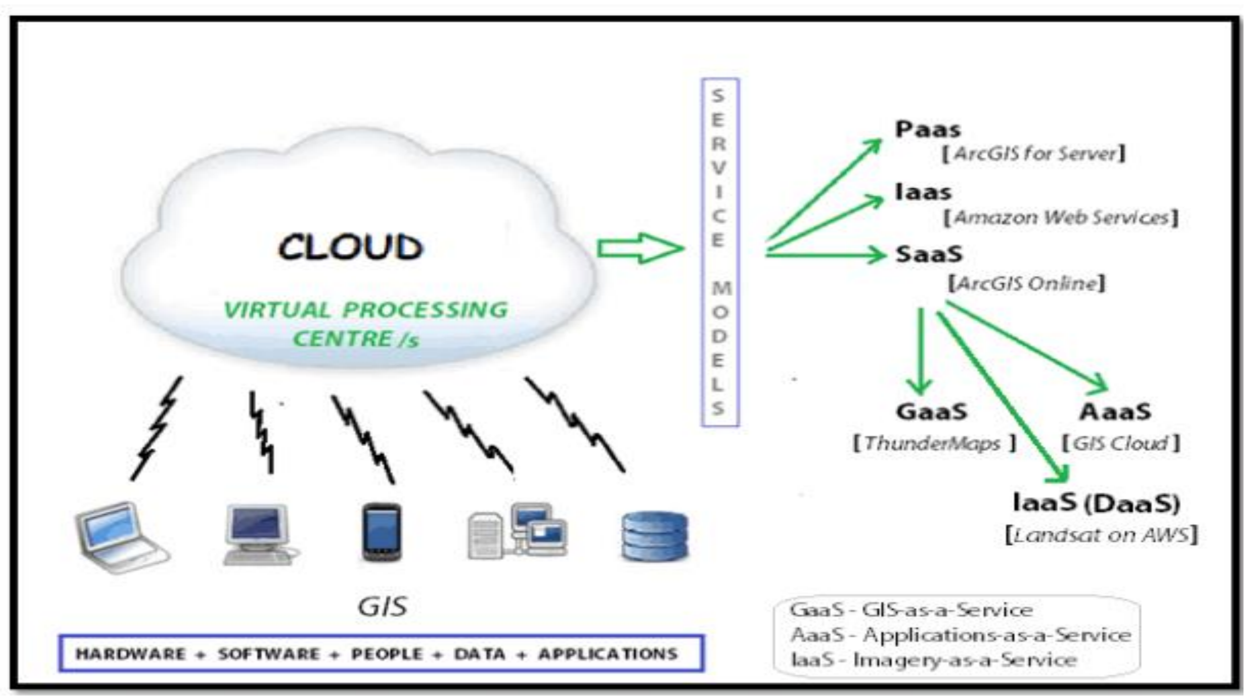
This refers to the real-time view of the performance and uptime of cloud products and services, visible on a dashboard, showing status updates of cloud performance and latency.

❖ **Community Cloud**

Community Cloud is a cloud deployment multi tenant model (multiple clients /organizations on a single server) on shared infrastructure; managed and secured by the participating organizations, with common or shared goals.

❖ **GIS-as-a-Service**

This is an extension of the Software-as-a-Service model for providing GIS solutions as a service, usually offering specializations in areas like incidence reporting, disaster and transport management. Many companies have developed products and apps offered as a service for a seamless management and integration of GIS workflows. This SaaS based solution is expected to become a dominant delivery method for geospatial capabilities as it also integrates BI in the service.



Cloud computing process

- **GIS Cloud Publisher**

It is an ArcMap extension that moves your maps and data from desktop GIS into the GIS Cloud with a single click.

- **Hybrid Cloud**

The hybrid cloud is a cloud computing environment in which an organization combines the security of private cloud while running applications from the public cloud. The public and private cloud infrastructures operate in tandem, using an encrypted connection for communication. A hybrid cloud environment can also be a combination of two or more clouds (Private, Public or Community) connected by proprietary technology.

- **Platform-as-a-Service (PaaS)**

PaaS is a type of cloud computing service model in which the provider hosts hardware and tools on its proprietary underlying infrastructure. This enables users to create software applications using the existing tools in a provider managed environment.

- **Private Cloud**

Private Cloud is a cloud deployment model where the cloud infrastructure is accessible by a single organization, for greater data control and security.

- **Public Cloud**

Public Cloud is a cloud deployment model made available over a public network to multiple clients, with shared infrastructure and pooled physical resources.

- **Infrastructure-as-a-Service (IaaS)**

A type of cloud computing service model in which the provider hosts virtualized computing infrastructure over the Internet. Facilities offered include processing, storage, networks, and other computing resources for the consumer to run arbitrary software, operating systems and applications.

- **Managed Cloud Service**

Managed Cloud offers benefits of dedicated private cloud services, with add-on services of high network security, constant availability, automated resource balancing and failover.

- **Software-as-a-Service (SaaS)**

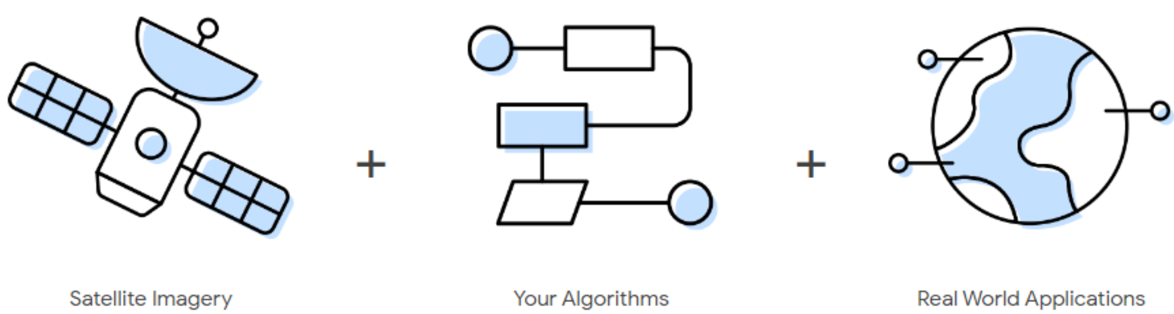
SaaS is a type of cloud computing service model where the provider delivers software and applications remotely over a network. This enables the user to leverage the underlying software for hosted application or software on demand.

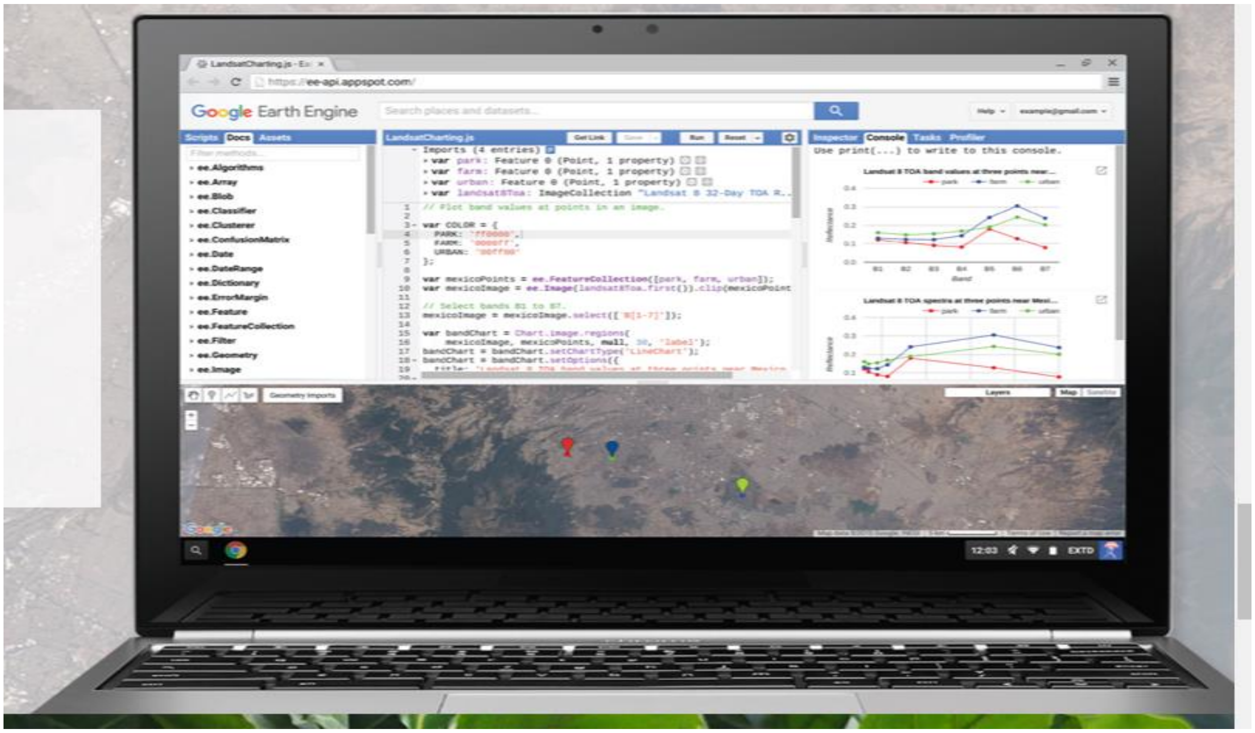
- **Spatial Cloud Computing (SC2)**

This is the geography component in cloud computing, delivering on-demand geo-intelligence. SC2 delivery also includes base spatial data, GIS as a web service, hosted geodatabases and solutions.

1.2 Google Earth Engine

Google Earth Engine combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities and makes it available for scientists, researchers, and developers to detect changes, map trends, and quantify differences on the Earth's surface.





Conclusion

“Google Earth Engine has made it possible for the first time in history to rapidly and accurately process vast amounts of satellite imagery, identifying where and when tree cover change has occurred at high resolution. Global Forest Watch would not exist without it. For those who care about the future of the planet Google Earth Engine is a great blessing!” says Dr. Andrew Steer, President and CEO of the World Resources Institute.

Reference Materials

[1] For more on challenges in analyzing digital Earth ‘big data’, see: Li, Y., Yu, M., Xu, M., Yang, J., Sha, D., Liu, Q., Yang, C., 2020. Big Data and Cloud Computing, in: Guo, H., Goodchild, M.F., Annoni, A. (Eds.), Manual of Digital Earth. Springer Singapore, Singapore, pp. 325–355. https://doi.org/10.1007/978-981-32-9915-3_9.

[2] For more on the Descartes Lab Platform for cloud-based geospatial analytics, see: https://medium.com/descarteslabs-team/introducing-the-descartes-labs-platform-dfe308a68364.

[3] For more on using parallel computing and HPC, including benefits to moving to a cloud-based system for fire modeling, see: Kalabokidis, K., Athanasis, N., Gagliardi, F., Karayiannis, F., Palaiologou, P., Parastatidis, S., Vasilakos, C., 2013. Virtual Fire: A web-based GIS platform for forest fire control. Ecological Informatics 16, 62–69. https://doi.org/10.1016/j.ecoinf.2013.04.007.

[4] For more on using cloud-based analyses, data processing, and visualization for landscape change, see: Deng, J., Desjardins, M.R., Delmelle, E.M., 2019. An interactive platform for the analysis of landscape patterns: a cloud-based parallel approach. Annals of GIS 25, 99–111. https://doi.org/10.1080/19475683.2019.1615550.

MODULE 3: APPLICATION OF GIS AND RS IN WATER RESOURCES PLANNING AND MANAGEMENT

3.0) INTRODUCTION

Remote sensing has found it integration with the geographical information system (GIS) since time past. This has helped to improve the extent of application of GIS in resolving related society problems. Remote sensing found its integration with GIS in three main ways which are;

(1) Appplication of remote sensing as a tool for gathering data for GIS analysis and assessments,

(2) Application of GIS data as ancillary information to improve the products derived from remote sensing.

(3) Integration of remote sensing and GIS for modelling and analysis.

3.1) REMOTE SENSING AS A TOOL FOR GATHERING DATA FOR GIS

A) Extraction of Thematic Information: Remotely sensed data can be used to extract thematic information to create GIS layers. There are three ways to incorporate so derived thematic layers. First, manual interpretation of aerial photographs or satellite images produces a map or a set of maps that depict boundaries between a set of thematic categories (e.g., soil or land-use classes). These boundaries then are digitized to provide digital files suitable for entry into the GIS. Second, digital remote sensing data are analysed or classified using automated methods to produce paper maps and images that are then digitized for entry into the GIS. Finally, digital remote sensing data are analysed or classified using automated methods and then retained in digital format for entry into GIS. Alternatively, digital remote sensing data are entered directly in their raw form for subsequent analyses. In more than three decades, the remote sensing community has been continuously making efforts to extract thematic information more effectively and efficiently from digital remote sensing imagery.

B) Extraction of Cartographic Information: The automated extraction of cartographic information has been another major application of remote sensing imagery as data input to GIS. Extraction of lines, polygons, and other geographic features has been achieved from satellite images using pattern recognition, edge extraction, and segmentation algorithms. Further developments in integration will produce smoother lines and boundaries (i.e., not having a stepped appearance), hiding their raster origin. Therefore, satellite images show a great potential in producing and revising base maps. The production of base maps by means of remote sensing imagery will make it easier to track error propagation in GIS layers because of reliable map metadata. In addition, the extracted cartographic information can be used to improve image classification. Image segmentation polygons derived from optical imagery, for instance, could be very useful for stratifying radar data, which traditionally are difficult to segment digitally owing to their noise. Aerial photography is a popular data source for feature extraction owing to its high resolution. Recently available high resolution satellite imagery, such as IKONOS and QuickBird imagery, has provided a potential to acquire effective and efficient feature information with automated extraction methods. These images have been applied to topographic mapping and three-dimensional (3D) object reconstruction. Many GIS databases use these high accuracy geopositioning images as base maps, providing both metric and thematic information. A new data source, light detection and ranging (LiDAR) data, is also being used increasingly in the extraction of cartographic information, and it provides land surface elevation information with vertical and horizontal accuracy to less than 1 m. Recent developments in sensor and computer technologies have made object-oriented image analysis a new focus in digital image processing. When combined with high spatial-resolution imagery and/or LiDAR data, an object-oriented analysis shows great potential for extracting the earth surface features, including both thematic and metric information.

C) Remotely Sensed Data Used to Update GIS: It is crucial to update GIS databases and maps in a timely manner. Remotely sensed data provide the most cost-effective source for such updates. Another area of the application of remotely sensed data as input to GIS is change detection. satellite images could be used to interactively update a land-use database by comparing the database with image statistics within the areas defined in a vector database. Today, the integration between remote sensing and GIS allows for querying raster pixels within vector areas and for performing analyses without format conversions and overlays. Image statistics within vector polygons then can be used to examine changes that have occurred and update maps.

D) Remotely Sensed Data as a Backdrop for GIS and Cartographic Representation: Cartographic representation is the fourth area of application of remote sensing imagery as an input to GIS. Terrain visualization using satellite images in association with digital elevation models (DEM) has long been explored as a promising tool in environmental studies. Progress in cartographic animation in recent years changes terrain visualization from a static to a dynamic state. DEM generation from satellite imagery using image correlation also has demonstrated its feasibility for deriving further topographic information for GIS applications. A DEM developed from Landsat Thematic Mapper (TM) images of a rugged terrain in north Georgia yielded a root-mean-square (rms) error in Z of ±42 m. With a more favourable base-to-height ratio and a higher resolution of 10 m, SPOT data produced better DEMs with rms errors between ±6 and ±18 m. An appropriate bias correction method (e.g., an affine model), a stereo QuickBird image can yield a geopositioning accuracy as high as 0.5 m in planimetry and 1m in height in Shanghai, China. In addition, the production of an orthophotograph or orthoimage requires the use of a DEM to register properly to the stereomodel so as to provide correct height data for differential rectification of the image. Orthoimages are employed increasingly to provide the base maps for GIS databases on which thematic data layers are overlaid. All these developments have implications for extending traditional two-dimensional (2D) to 3D GIS, which is crucial for applications in the fields of marine science, geology, soil modelling, and climatology.

3.2) GIS DATA AS ANCILLARY INFORMATION TO IMPROVE THE PRODUCTS DERIVED FROM REMOTE SENSING.

A) Use of Ancillary Data in Image Classification: GIS data can be used to enhance the functions of remote sensing image processing at various stages: selection of the area of interest for processing, pre-processing, and image classification. Ancillary data are those collected independently of remotely sensed data. Ancillary data have long been useful in the identification and delineation of features on manual interpretation of aerial photos; for digital remote sensing, ancillary data must be incorporated into the analysis in a structured, formalized manner that connects directly to the analysis of remotely sensed data. Ancillary data may be used to enhance image classification in three stages, namely, pre-classification stratification, classifier modification, and post-classification sorting. In the pre-classification method, ancillary data are used to assist the selection of training samples or to divide the study scene into smaller areas or strata based on some selected criteria or rules. When ancillary data are used during an image classification, two methods can be used. The first is a logical channel method. The ancillary data were incorporated into remote sensing images as additional channels. The second method is a classifier modification that involves altering a priori probabilities of the classes in a maximum likelihood classifier according to estimated areal composition or known relationships between classes and ancillary data. In the post-classification sorting approach, ancillary data are used to modify misclassified pixels based on established expert rules. Integration of DEM-related data and remotely sensed data for forest classification in mountainous areas has been demonstrated to be effective for improving classification accuracy. In urban studies, DEM data are rarely used to aid image classification because urban regions often locate in relatively flat areas. Other ancillary data, such as soil type, temperature, and precipitation, also can be used in assisting image classification.

B) Use of Ancillary Data in Image Pre-processing: At the stage of geometric and radiometric correction, GIS data such as vector points, area data, and DEMs are used increasingly for image rectification. High resolution topographic data play an important part in radar image interpretation. The impacts of varying topography on the radiometric characteristics of digital imagery can be corrected with the aid of DEMs. The DEM-derived variables may be used at the stage of image pre-processing for topographic correction or normalization so that the impact of terrain on land-cover reflectance can be removed. Perhaps, the most frequently used vector data sets are ground control points in image rectification, where the most identifiable points are selected from an existing map with a defined coordinate system and used to register an image. With advances in pattern recognition and line-following techniques, extracted lines from satellite images could be registered to roads, rivers, and railways in vector datasets for more accurate image registration.

C) Use of Ancillary Data for Selection of the Area of Interest: The use of vector polygons to restrict the area of an image to be processed is possible in today's image processing software (e.g., ERDAS IMAGINE). This permits masking operations without raster masks, making image processing much more efficient because of faster processing times, no need to store intermediate data, and a reduction in data integrity problems. However, there are a few practical and conceptual problems in using ancillary data in remote sensing image analysis. Ideally, ancillary data should possess compatibility with remotely sensed imagery with respect to scale, level of detail, accuracy, geographic reference system, and date of acquisition. Sometimes ancillary data are presented as discrete classes (i.e., nominal or ordinal data), whereas remote sensing data represent ratio or interval data. The compatibility between the two types of data must be addressed.

D) Use of GIS to Organize Field/Reference Data for Remote Sensing Applications: In addition to enhancing the functions of remote sensing image processing at various stages, GIS technology provides a flexible environment for entering, analysing, managing, and displaying digital data from the various sources necessary for remote sensing applications. Many remote sensing projects need to develop a GIS database to store, organize, and display aerial and ground photographs, satellite images, and ancillary, reference, and field data. Global Positioning Systems (GPS) technology also is essential when remote sensing projects need to collect in situ samples and observations.

3.3) DIGITAL DATA SOURCES FOR WATER RESOURCES

Data of various types are increasingly being made available for download from the U.S. Geological Survey, other federal agencies, and various corporations. Following are descriptions of some of these.

1) DIGITAL ELEVATION MODELS

Three-dimensional (3-D) surfaces are a special category of surfaces where the data are best suited for representation in 3-D form over an area. The most common example is land surface terrain represented by DEMs (digital elevation models), represented as elevation grids in the field model and as TINs (triangulated irregular networks) or contours in the vector model. A raster of elevation is alternatively called a digital terrain model (DTM). Other field data are often derived from satellite and other imagery; these data sources are increasingly available as the number and variety of imagery sensors grow. Digital elevation models are generally produced by photogrammetric techniques from stereo photo pairs, stereo satellite images, or interpolation of digitized elevation data. The most widely produced DEM structures are the square-grid DEMs and contour digital line graphs (DLGs).

DEMs as grid structures comprise a square grid with the elevation of each grid square (Figure 3). Each grid element is called a pixel (for picture element). Location is established by the row and column locations within the grid, given information on the grid boundary coordinates. National Elevation Datasets are available online from the USGS EROS Data Center (http://ned. usgs.gov). For TIN structures, a continuous surface is generated from interconnected triangles with known elevation values at the vertices of the triangles (Figure 3.7b). For each triangle, the location (x,y) and elevation (z) of the vertices are stored along with topological information identifying adjacent triangles. Triangles vary in size, with smaller triangles clustered in areas of rapidly changing topography and larger triangles in areas of relatively smooth topography. For TINs, the elevation data may be initially developed using photogrammetric procedures for spot elevations and break lines, such as streams and ridgelines. Contour-based structures consist of digitized contour lines defined by a collection of x, y coordinate pairs for contours of specified elevations. Contours are commonly obtained by computerized digitization of map contours or by interpolation from gridded TINs. Reverse interpolation is also used to generate grids or TINs from contours.

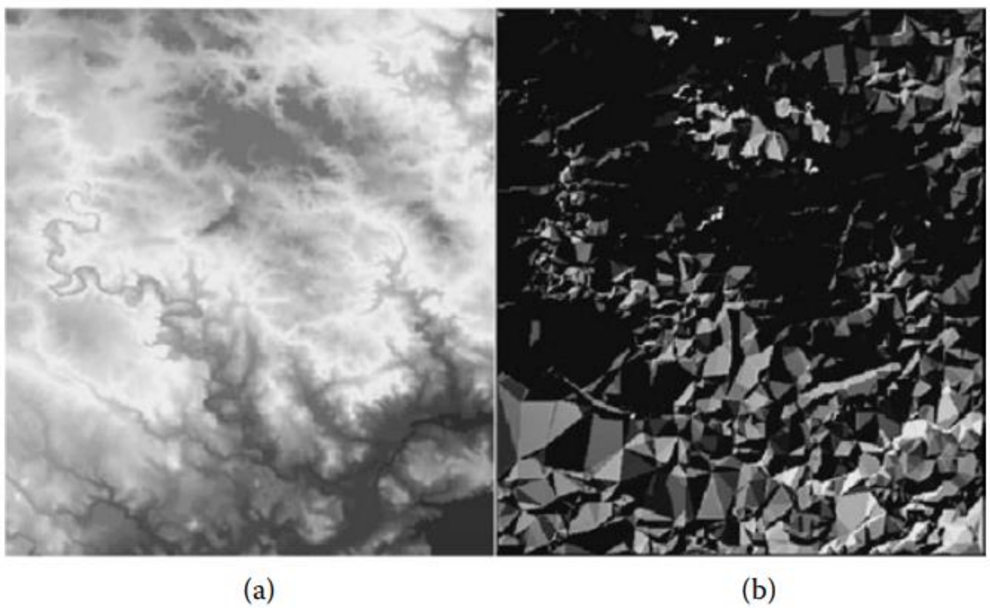


Figure 3: (a) DEM sample as grid format (b) DEM reproduced as TIN

There are advantages and disadvantages associated with each of the DEM structures. Square-grid DEMs are the most widely used because of their simplicity, processing ease, and computational efficiency. Disadvantages include the grid-size dependency of certain computed landscape parameters and the inability to adjust the grid size to changes in the complexity of landscape characteristics. TINs are preferred for complex topography, such as urban drainage features (e.g., street crown lines). However, the computations using TINs are more complex than for square-grid DEMs. Contour-based structures are considered by some to provide better visualizations of surface features than grid DEMs. However, contours are one-dimensional (1-D) features, and the representation of the 2-D landscape continuum with DLGs generally requires considerably more data than does representation by grid DEMs. The stated advantages and disadvantages of DEM structures are relative, in the sense that what is considered an advantage for data storage may be a disadvantage for data processing. Most GISs provide functions to convert between the different surface representations, depending on the application requirements.

For highly detailed terrain mapping, such as that required to define floodplain details, the use of light detection and ranging (LIDAR) data has increased. These data are collected with aircraft-mounted lasers capable of recording elevation measurements at a rate of 2000 to 5000 pulses per second and have a vertical precision of 15 cm (6 in.). The LIDAR instruments only collect elevation data. To make these data spatially relevant, the positions of the data points must be known. A high-precision global positioning system (GPS) antenna is mounted on the upper aircraft fuselage. As the LIDAR sensor collects data points, the location of the data is simultaneously recorded by the GPS sensor. After the flight, the data are downloaded and processed using specially designed computer software. The end product is accurate, geographically registered longitude, latitude, and elevation (x,y,z) positions for every data point. These x,y,z data points allow the generation of a digital elevation model (DEM) of the ground surface.

A major cost for LIDAR, for example in floodplain mapping, is vegetation removal, which involves the postprocessing of the data to generate bare-Earth digital information. To get these bare-Earth elevation data, automated and manual postprocessing are used to eliminate points that impinged on elevation features. This creates data voids, so that the data set becomes more irregular with regard to point spacing on the ground. Automated postprocessing includes computerized procedures that detect elevation changes that appear to be unnatural. For example, rooftops are identified with relative ease because there are abrupt elevation changes between the yard and the rooftop. However, vegetation provides more difficult challenges for automated procedures. Manual postprocessing is more accurate (and more costly) and normally includes the overlay of data points on digital imagery, enabling the analyst to see where the laser points hit the ground.

2) DIGITAL LINE GRAPHS

Digitized stream and channel network data can be obtained from the U.S. Geological Survey (USGS) in the form of digital line graphs (DLGs). DLGs are available in several categories, including political boundaries, roadways, and hydrography. Hydrography data provide information on flowing water (streams and channels), standing water (lakes), and wetlands. The information is provided in the form of digital vectors that were developed from maps and related sources. The hydrographic data can be obtained for large, intermediate, and small scales. The hydrography data contain full topological linkages in node, line, and area elements. Thus, channel connectivity information in upstream and downstream directions is available.

Surface drainage and channel network configuration are important landscape attributes for hydrologic modelling of runoff processes. Both attributes can be determined from field surveys, stereo photos, and detailed topographic contour maps. However, these approaches are resource and time consuming, particularly for large watersheds. A more expedient approach consists of purchasing previously digitized channel data or deriving the information from readily available digital elevation data.

3) SOIL DATA

Soil data are available from the soils-mapping agencies, typically those dealing with the agriculture sector. In the United States, soil survey data are available in digital formats from the Natural Resources Conservation Service (NRCS), including the State Soil Geographic (STATSGO) and Soil Survey Geographic (SSURGO) databases. Soil Data Base for the World can be derived from other organizations as listed below,

a) The FAO-UNESCO Soil Map of the World

The FAO-UNESCO Soil Map of the World (FAO-UNESCO, 1971-1980) is presently the only, fully consistent, harmonized soil inventory at the global level which is readily available in digital format. It was published between 1974 and 1980 in 19 separate sheets at a mapping scale of 1:5 million. The map was based on information contained in some 11000 separate large-scale maps. Its development started as a project originated by a motion of the ISSS at the Wisconsin congress in 1960. It was first digitized by ESRI in vector format in 1984. The paper map contains 26 major soil groups, which are further subdivided into 106 individual soil units (FAO-UNESCO, 1974). The map was later digitized by FAO (1995) with a grid resolution of 5’ x 5’ (or 9 km x 9 km at the equator). The digitized version, known as Digital Soil Map of the World (DSMW), contains a full database in terms of composition of the soil units, topsoil texture, slope class, and soil phase in each of its more than 5000 mapping units. The map is downloadable at: http://www.fao.org/geonetwork/srv/en/resources.

b) The Harmonized World Soil Database

The Harmonized World Soil Database (HWSD) contains a digital soil map of the world, with soil units classified in the Revised FAO Legend at a fixed grid resolution of 1km by 1km, with associated soil properties and soil qualities. This digital global dataset is not fully harmonized, as it is based 40% on the original DSMW and 60% on regional and national updates undertaken after the DSMW was completed. Figure 4

Figure 4: Harmonized World Soil Data Base

It should be acknowledged that the 1km grid resolution used in the DSMW parts of the database is not fully justified given the lower resolution of the base material used in the DSMW part of the map. Presently, the HWSD contains over 16000 mapping units, which are used to link to a database of soil attribute data. The result is a 30 arc-second raster database consisting of 21600 rows and 43200 columns with each grid cell linked to the harmonized soil property data. This linkage of mapping units to the soil attribute data offers the opportunity to display or query the database in terms of soil units or in terms of selected soil parameters (such as Organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry both for topsoil as subsoil layers). Although not fully harmonized and consistent, the HWSD contains the most up-to-date and consistent global soil information that is currently available and continuously updated. The Harmonized World Soil Database v1.2, is downloadable at: http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/. In addition, the website contains freely downloadable software for visualising, querying, and retrieving the data. Figure 5 is an example of the database as visualized through the data viewer.

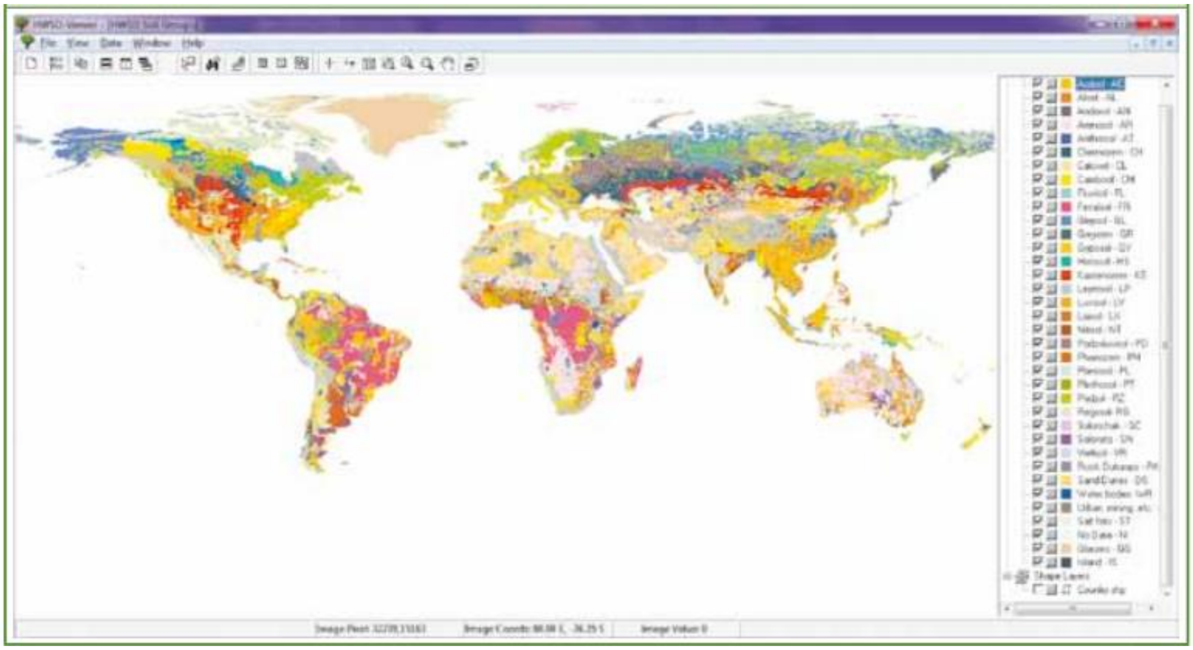


Figure 5: HWSD Viewer for Visualizing and Interacting with the Soil Database.

c) The WISE global soil profile database

The International Soil Reference and Information Centre (ISRIC) World Inventory of Soil Emission Potential (WISE) International soil profile database is presently the only freely available and comprehensive repository of global primary data on soil profiles. ISRIC was established in 1966 with a focus of serving the international community with information about the world's soils. Through its WISE project, ISRIC has consolidated select attribute data for over 10,250 soil profiles, with some 47,800 horizons, from 149 countries in the world. Profiles were selected from data holdings provided by the Natural Resources Conservation Service (USDA-NRCS), the Food and Agriculture Organization (FAO-SDB), and ISRIC itself (ISRIC-ISIS).

The location of the WISE soil profiles worldwide is illustrated in Figure 6. The data can be downloaded at http://www.isric.org/data/isric-wise-global-soil-profile-data-ver-31.

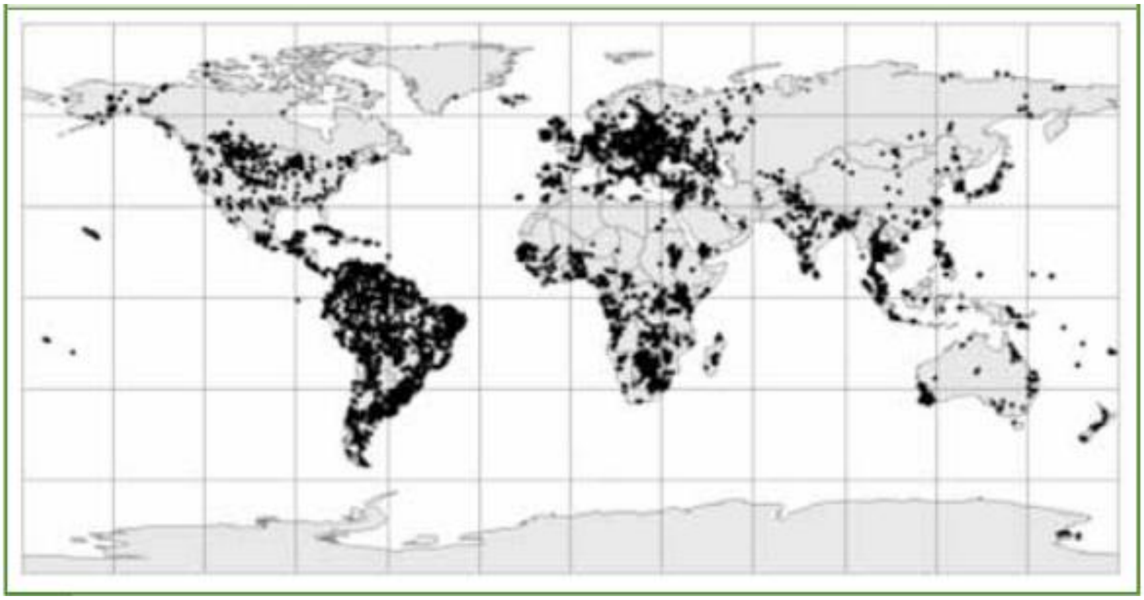


Figure 6: Location of WISE Soil Database

Individual profiles in the ISRIC-WISE database were sampled, described, and analysed according to the methods and standards in use in the countries from where the data originated. In order to harmonize the data, ISRIC developed criteria to streamline analytical methods, soil classification scheme, data formatting, and documentation. This harmonization was an important step towards achieving data quality control and building a relational database that can be linked with other secondary data attributes such as mapping units of derived soil maps. Apart from data quality control, ISRIC has also developed a metadata service that allows soil data users to search and retrieve on-line soil data from the depository (http://www.isric.org/data/metadata-service). This is a powerful soil information service tool that helps data users to quickly locate and retrieve the kind of data they need. The tool is also an efficient way of managing soil information for a large pool of data users. It is important to note that all the data at ISRIC are held under the General Public Licence (GPL) (http://www.isric.org/data/data-policy), to encourage wide application of soil information.

4) LAND-USE DATA

Digital land-use data can be obtained from city and county governments that maintain a digital parcel database. In most of these types of databases, a land-use classification is attached to the parcel information. These land-use codes will vary from agency to agency, but all should have the different classes of residential, commercial, industrial, agricultural, and undeveloped land represented. When available, these local parcel databases are the best source of land-use information, since they are usually maintained on a constant basis by the local assessor's office, are positionally accurate, and are recorded as large-scale data at the detailed parcel level. Planning or zoning databases may also be maintained by some local agencies that provide future scenarios of possible land uses that may affect the hydrologic characteristics of an area.

3.4) REMOTE SENSING AND GIS IN WATER RESOURCES PLANNING AND MANAGEMENT

Two basic processes involved in remote sensing data collection and data analysis.

a) The elements of data collection include energy sources.

b) Energy propagation through the atmosphere.

c) Interaction of energy with the earth surface features.

d) Retransmission of energy through the atmosphere, using airborne and space borne sensors resulting in generation of sensor data in Pretoria and digital formats.

The elements of data analysis include computer viewing and interpretation using reference data. Reference data may be in different forms and may be obtained from a variety of sources. This may include existing aerial photographs, ground survey control points, information from existing maps and charts, water quality laboratory report or other field measurements including measurements of physical and chemical properties of various features e.g. ground or surface water satellite images can be analyzed using either visual or digital techniques.

Computer processing enables us to process satellite imagery and carry out quantitative analysis of all spectrum bands simultaneously.

Remote sensing as for applications in practically every major field of human endeavor including water resources management, agriculture, particularly soil mapping, crop yield estimation, and pest control planning as well as forest ecology.

3.4.1) APPLICATION OF REMOTE SENSING TO WATER RESOURCES PROBLEM

Remote sensing data have become major tools for water resources planning and management. The areas of remote sensing application in hydrology include flood zone mapping, precipitation and evapotranspiration studies, irrigation water management and hydrologic modelling. In most cases the remotely sensed data are stored as raster data in a GIS environment. The above area of application is further discussed below:

A) FLOOD ZONE MAPPING

Remote sensing data can be used to map flood inundated area.

Data from metrological satellites from National oceanic and atmospheric administration/advanced very high-resolution radiometer (NOAA/AVHRP) INSAT very high resolution radiometer (INSAT/AVHRR) and GMS Has contributed immensely to improve rainfall forecasting Ground condition changes rapidly during flooding and these satellites provide repetitive data for updating ground conditions for flood inundation studies.

As a result of cloud cover in some study areas however microwave systems may be used to supplement radar data.

B) PRECIPITATION ESTIMATION

Direct measurements of rainfall from satellite data has not been very accurate. The same goes for indirect method of deriving the spatial distribution of rain producing clouds, temperature and other cloud characteristics from remote sensing data. At the moment geostationary metrological satellites are used for this purpose.

Major research output in this area has emerged from the collaborative efforts of the United States global precipitation climatology Project (GPCP) and the Japanese national space development agencies NASDA of Japan. Satellite data can be combined with metrological data to develop a cloud index which identifies different types of rain clouds and estimates the rainfall based on the number and duration of clouds. Temperature threshold method has been widely used to estimate monthly rainfall from satellite IR image.

C) IRRIGATION WATER MANAGEMENT

Over the years a large number of remote sensing satellites data have been used to study various aspects of irrigation water management. The use of remote sensing for irrigation water management stem from the fact that remotely sensed images provide a repetitive and distributed agricultural and hydrological status of the study area. In watersheds, irrigation is the main consumer of freshwater, hence is in view of water scarcity in most countries including many parts of Nigeria this study is very important. The use of remotely sensed image allow us to carry out land-use mapping, crop types studies, crop water requirements, soil salinity and identification of waterlogged areas.

D) EVAPOTRANSPIRATION

Satellite data can be used to measure variables that are useful in the energy and moisture balance method of computing evapotranspiration. The variables that are estimated using remote sensing include incoming solar radiation, vegetation areas and vegetation properties.

It is to be noted that evapotranspiration (ET) is one of the most important processes of the hydrological cycle. Depending on the climatic condition it may account for up to 40% of the moisture lost from a catchment and its measurement is of great importance.

E) CATCHMENT MODELLING

Remote Sensing is needed in obtaining the input data for catchment modelling and this may include land use land cover and soil cover etc.

Satellite image data are used for preparing accurate topographic map of catchment. All the needed special and land use data are captured and used for catchment modelling.

A number of software have been developed for analysis and data extraction from images for GIS modelling.

3.4.2) APPLICATION OF REMOTE SENSING AND GIS IN WATER RESOURCES PLANNING AND MANAGEMENT

Water is a fundamental requirement for the existence of both living and non-living organism including human on earth. Without water, human cannot survive, plants cannot grow, industries cannot function. Hence, assessing the quality and quantity of water resources is of great importance.

The areas where remote sensing can be used in water resources applications include:

1. Direct interpretation of imageries for assessment and existing water resources.
2. Quantifying the land area and geological features that influence watershed runoff, evapotranspiration and soil moisture etc.
3. Estimation of hydrological parameters through correlation analysis of remotely sensed images and in situ field measurements. The parameters for such measurements will normally include soil moisture, sediment load, precipitation etc.

Remotely sensed data and maps are useful tools for water resources planning, management and monitoring. Map produced from satellite imageries can be utilized to identify land-water boundaries, delineate geological and geomorphic characteristics of an area to determine land use with respect to water consumption level.

Other notable areas of application with respect to water resources planning, management and monitoring include:

1) Groundwater assessment
2) Run off estimation.

3) Precipitation estimation

4) Floodplain mapping

5) Wetland mapping

6) Monitoring lakes and reservoirs volume

7) Irrigated land assessment

8) Hydrological modelling

A) GROUND WATER

Ground water is one of the most widely distributed and significant resources required for existence and survival of life. Ground water is that part of surface water which is stored beneath the surface of the earth in aquifers. Aquifers are geological formations having good permeability and porosity. It is thus necessary to locate the aquifer, map, its size, extent and depth and then estimate recharge and discharge rates of water. Much of the information can be obtained from the records of wells, boreholes and other in situ methods. These methods are, however, time consuming and uneconomical with data to be collected over sparse locations.

Remote sensing is a very cost-effective approach for preliminary surveys. The relatively coarse spatial resolution data are suitable for obtaining the general aquifer information. Thus, remote sensing data map information from either surface or relatively shallow layer (a few cms) of earth. Because of this, deep ground water aquifers can not be detected directly. Nevertheless, indirect inferential methods may be adopted. Most of these methods depend either on the recognition of surface water or moisture conditions and their related vegetation conditions as the indicators of possible presence of ground water. The interpretation of geological characteristics, topography, land use, land cover and surface hydrology also assist in location of ground water in an area.

Landforms, drainage patterns, vegetation characteristics, land use patterns, linear and curvilinear features and texture can be inferred from remote sensing data using visual image interpretation. The interpretation of these landscape characteristics indicates the presence or absence of ground water in an area. Examples includes the followings:

i. Landforms are recognizable physical features on the earth surface (i.e., bedrock mountains, alluvial fans, etc.). For instance, ground water may be assumed to move down the lower slopes and down alluvial fans in the same direction as the surface streams.

ii. Lineaments are straight to slightly curving features formed in many different types of landscape. It is assumed that lineaments mark the location of joints and faults.

iii. Drainage features include size and shape of basin, drainage patterns and density, valley shape, channel location and angles of tributaries. It is generally assumed that the joints and faults in the bedrock influence the development of these drainage patterns.

iv. Texture is manifested in the density of drainage patterns. Fine texture drainage systems indicate fine-grained sediments and areas where infiltration is relatively low. Maximum infiltration will occur along the major streams and in areas characterized by medium and coarse textured drainage.

v. Dense vegetation in valleys or basins indicates the availability of adequate water where the ground water may be closed to the surface.

The images with low sun angle, in which landform and general topography may be enhanced due to presence of shadows, can be selected. Landsat images may be useful for delineating many landscape features. A set of aerial or satellite based stereo images can be used to map difference in heights for identifying slopes and landforms.

The microwave data also has a great potential for groundwater exploration especially in arid regions. The penetrating capability of radar and its usability to detect soil moisture make this data a valuable tool for ground water exploration in arid regions. Shallow groundwater can be inferred by soil moisture measurements and by detecting changes in the vegetation types and patterns. Differences in temperature measured by thermal remote sensing data can also be used to infer or identify shallow groundwater and springs or seepage. These temperature differences are the result of high heat capacity of the groundwater that produces a heat sink in the dry season and heat source in the cold.

The remotely sensed derived information when combined with other ancillary data such as topographical, meteorological and geophysical data also increases the accuracy of ground water assessment in a region. Therefore, GIS based studies are frequently conducted for qualitative and quantitative assessment of ground water.

B) RUNOFF

The definition of a catchment boundary of a stream is one of the major problems for the hydrologists because it affects the runoff. A catchment area can be defined as the area above a point that contributes to the runoff. Thus, accurate determination of catchment area is necessary for runoff prediction, river management, flood prediction and control. There are several factors that need to be considered while selecting a catchment. These include:

i. Size and shape of catchment
ii. Topography
iii. Geology
iv. Drainage characteristics
v. Rainfall intensity

Size and shape of the catchment signify the area of the watershed. The larger the drainage basin, the greater is the runoff. The area of catchment can be determined using georeferenced aerial photographs and satellite images. For medium and high relief watersheds, a single photograph or a satellite image acquired in any region of EMS may be used.

Topography is important for runoff estimation because on steep surfaces the water flows quickly thereby leading to large runoff. Measurements on a stereo satellite data can be used for determination of topographic characteristics such as slope and aspect. A DEM is an excellent source for deriving such information. The surface characteristics of the catchment also have substantial bearing on the runoff estimation. For instance, a bare surface will produce more runoff than the cultivated and impervious surfaces.

From geological point of view, both the lithological characteristics (e.g., rocktype, its composition and texture) and structural characteristics (e.g., faults, folds, joints and fractures) are important. These characteristics affect the permeability conditions of the geological strata and also the water movement and drainage patterns. Detailed geological mapping can be carried out using remote sensing data. Various types of drainage patterns in terms of their density and frequency can be identified easily on remote sensing data.

Thus, you may see that most of the characteristics related to catchment area, which ultimately lead to runoff estimation and its delineation, can be identified from remote sensing data.

The amount of precipitation (i.e., rainfall and snow) occurring on the surface of earth can also be estimated using remote sensing techniques aided suitably with field measurements. The amount of rainfall can be assessed from remote sensing data by measuring the cloud brightness on a visible image and cloud temperature on an infrared image.

C) SOIL MOISTURE

Soil moisture is a key variable in numerous fields, including hydrology, meteorology and agriculture. It is an environmental descriptor that integrates surface hydrology and acts as an interface between earth surface and the atmosphere. The most important role of soil moisture is in controlling and regulating the interaction between the atmosphere and the land surface as well as partitioning of precipitation into runoff and ground water storage. For programmes such as forecasting of river flows resulting due to rainfall storm event planning, designing and scheduling of an irrigation system, and soil conservation programmes etc., spatial distribution of soil moisture in a particular region must be known.

Soil moisture can directly be measured at selected locations by using gravimetric method but it provides information on point basis and thus can not be used at spatial scales because of the varying nature of soil moisture. Due to greater penetration depth of microwaves (compared to optical waves) in areas with thick vegetation and high surface roughness radar remote sensing techniques have the potential for providing estimates of soil moisture quantitatively on barren land and short vegetated surfaces. The microwave sensing of earth in the form of backscatter coefficient depends on target as well as sensor parameters. The target parameters include dielectric constant, topography and surface roughness whereas sensor parameters include incidence angle, polarization and frequency.

Dielectric constant is the property of a material that determines the relative speed at which an electrical signal will travel through that material. The electrical characteristics of terrain features (e.g., soil) work closely with their geometric characteristics determine the intensity of signal propagation through them. In the microwave region, natural soils have a dielectric constant in the range from 3 to 8 when dry, whereas, water has a dielectric constant of approximately 80. Thus, the presence of moisture in the soil can significantly change the strength of the electrical signal (i.e., radar reflectivity in case of active microwave sensors). In fact changes in signal strength from one material to another are often linked to changes in moisture content much more closely than the changes in the materials themselves.

Roughness refers to surface irregularities which combine to form surface texture. It is an important characteristic that influences the appearance of a target or feature on radar images. Variations in roughness scale influence the image interpretation. In microwave domain, the roughness is a function of the wavelength or frequency and the look angle of the radar sensing system that determines the image tone or the magnitude of backscatter.

The depth to which the volume scattering occurs is known as penetration depth. In principle, radar signals are capable of penetrating what would normally be considered as solid features, including vegetative cover and the soil surface. It is a function of sensor frequency and soil moisture. Penetration is assessed by specifying the skin depth; defined as the depth to which the strength of the signal is reduced to 1/c (e-2.703) of its surface magnitude, or about 37%. In the absence of soil moisture, skin depth or penetration depth increases with the increase in wavelength. Penetration is also related to surface roughness and incidence angle, in such a way that, it is greater at steeper angles and decreases with the increase in incident angle, L band signals, which have much longer wavelengths, are capable of higher degree of penetration, to reach branches, trunks, and even below the terrain surfaces to some extent.

Thus, in order to estimate soil moisture from radar images, the above parameters need to be considered appropriately.

D) HYDROLOGICAL MODELLING

Hydrological models are developed to represent the hydrologic system from precipitation to stream flow in a mathematical form. These models vary from simple statistical techniques that use graphical methods for the solution to physically based models that require simulations of the complex three-dimensional nature of a watershed. The development of more complex physically distributed models has tremendously increased the demand for spatial data. All these models require an input of a series of data such as:

i. Hydro-meteorological data (precipitation, evapotranspiration, temperature, solar radiation, wind speed, humidity etc.)
ii. Topography
iii. Land use land cover
iv. Drainage patterns

These data can be collected with the aid of remote sensing and DEM, which can be analysed in a GIS.

The hydro-meteorological data can be obtained from field based equipment. The remotely sensed satellite images can be used to distinguish major land use, land cover types that are utilized to estimate parameters for the hydrological model. Moreover, by classifying several images from different years over a decade, it is possible to observe and use changes over that period. By delineation of model parameters, in turn, it is feasible to estimate the influence of changes on the hydrological processes.

The use of DEM allows us to determine various geomorphologic characteristics of a catchment. It also helps in the extraction of drainage network. Several other attributes such as drainage density, slope of catchment etc. can also be inferred from the DEM.

The processing of spatially distributed data, as identified from remote sensing data, the

analysis of DEM and additional maps enables the generation of new information by means of GIS overlaying and intersection techniques. For example, by overlaying slope, aspect and Land

Use maps, the radiation to be input to evapotranspiration estimation can be computed.

Remote sensing and GIS have very important application in water resources modelling. GIS is particularly very useful in distributed modelling where they are used for data modelling and management. GIS also very powerful tools for modelling hydrological processes in catchment and watershed. Since surface water flows, in downslope direction to overland and channels floor direction can be determined using elevation data or DEM.

Comparable flow paths procedures can be done in a vector GIS but the topologies of the network chain will have to be used to determine the direction of flow from point of origin to the outlets.

In watersheds, catchment delineation are easily done in a GIS environment.

Water flow data layers can be used to determine the flow path of a watershed. This is very useful for tracking the paths of a pollutant for points or non-point source through the drainage basin.

3.5) SOIL WATER ASSESSMENT TOOL (SWAT) OVERVIEW

SWAT is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple subwatersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the subwatershed area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only subwatersheds that are characterized by dominant land use, soil type, and management.

3.5.1) SWAT INPUT

I) CLIMATIC INPUTS AND HRU HYDROLOGIC BALANCE

Climatic inputs used in SWAT include daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data, which can be input from measured records and/or generated. Relative humidity is required if the Penman-Monteith or Priestly-Taylor, evapotranspiration (ET) routines are used; wind speed is only necessary if the Penman-Monteith method is used. Measured or generated sub-daily precipitation inputs are required if the Green-Ampt infiltration method is selected. The average air temperature is used to determine if precipitation should be simulated as snowfall. The maximum and minimum temperature inputs are used in the calculation of daily soil and water temperatures. Generated weather inputs are calculated from tables consisting of 13 monthly climatic variables, which are derived from long-term measured weather records. Customized climatic input data options include: (1) simulation of up to ten elevation bands to account for orographic precipitation and/or for snowmelt calculations, (2) adjustments to climate inputs to simulate climate change, and (3) forecasting of future weather patterns, which is a new feature in SWAT2005. The overall hydrologic balance is simulated for each HRU, including canopy interception of precipitation, partitioning of precipitation, snowmelt water, and irrigation water between surface runoff and infiltration, redistribution of water within the soil profile, evapotranspiration, lateral subsurface flow from the soil profile, and return flow from shallow aquifers. Three options exist in SWAT for estimating surface runoff from HRUs, which are combinations of daily or sub-hourly rainfall and the USDA Natural Resources Conservation Service (NRCS) curve number (CN) method or the Green-Ampt method. Canopy interception is implicit in the CN method, while explicit canopy interception is simulated for the Green-Ampt method. A storage routing technique is used to calculate redistribution of water between layers in the soil profile. Bypass flow can be simulated for soils characterized by cracking, such as Vertisols. SWAT2005 also provides a new option to simulate perched water tables in HRUs that have seasonal high-water tables. Three methods for estimating potential ET are provided: Penman-Monteith, Priestly-Taylor, and Hargreaves. ET values estimated external to SWAT can also be input for a simulation run. The Penman-Monteith option must be used for climate change scenarios that account for changing atmospheric CO2 levels. Recharge below the soil profile is partitioned between shallow and deep aquifers. Return flow to the stream system and evapotranspiration from deep-rooted plants (termed “revap”) can occur from the shallow aquifer. Water that recharges the deep aquifer is assumed lost from the system.

II) CROPPING, MANAGEMENT INPUTS, AND HRU-LEVEL POLLUTANT LOSSES

Crop yields and/or biomass output can be estimated for a wide range of crop rotations, grassland/pasture systems, and trees with the crop growth submodel. New routines in SWAT2005 allow for simulation of forest growth from seedling to mature stand. Planting, harvesting, tillage passes, nutrient applications, and pesticide applications can be simulated for each cropping system with specific dates or with a heat unit scheduling approach. Residue and biological mixing are simulated in response to each tillage operation. Nitrogen and phosphorus applications can be simulated in the form of inorganic fertilizer and/or manure inputs. An alternative automatic fertilizer routine can be used to simulate fertilizer applications, as a function of nitrogen stress. Biomass removal and manure deposition can be simulated for grazing operations. SWAT2005 also features a new continuous manure application option to reflect conditions representative of confined animal feeding operations, which automatically simulates a specific frequency and quantity of manure to be applied to a given HRU. The type, rate, timing, application efficiency, and percentage application to foliage versus soil can be accounted for simulations of pesticide applications. Selected conservation and water management practices can also be simulated in SWAT. Conservation practices that can be accounted for include terraces, strip cropping, contouring, grassed waterways, filter strips, and conservation tillage. Simulation of irrigation water on cropland can be simulated on the basis of five alternative sources: stream reach, reservoir, shallow aquifer, deep aquifer, or a water body source external to the watershed. The irrigation applications can be simulated for specific dates or with an auto- irrigation routine, which triggers irrigation events according to a water stress threshold. Subsurface tile drainage is simulated in SWAT2005 with improved routines. The simulated tile drains can also be linked to new routines that simulate the effects of depressional areas (pot- holes). Water transfer can also be simulated between different water bodies, as well as “consumptive water use” in which removal of water from a watershed system is assumed. HRU-level and in-stream pollutant losses can be estimated with SWAT for sediment, nitrogen, phosphorus, pesticides, and bacteria. Sediment yield is calculated with the Modified Universal Soil Loss Equation (MUSLE), USLE estimates are output for comparative purposes only. The transformation and movement of nitrogen and phosphorus within an HRU are simulated in SWAT as a function of nutrient cycles consisting of several inorganic and organic pools. Losses of both N and P from the soil system in SWAT occur by crop uptake and in surface runoff in both the solution phase and on eroded sediment. Simulated losses of N can also occur in percolation below the root zone, in lateral subsurface flow including tile drains, and by volatilization to the atmosphere. Accounting of pesticide fate and transport includes degradation and losses by volatilization, leaching, on eroded sediment, and in the solution phase of surface runoff and later subsurface flow. Bacteria surface runoff losses are simulated in both the solution and eroded phases with improved routines in SWAT2005.

3.5.2) FLOW AND POLLUTANT LOSS ROUTING, AND AUTO-CALIBRATION AND UNCERTAINTY ANALYSIS

Flows are summed from all HRUs to the subwatershed level, and then routed through the stream system using either the variable-rate storage method or the Muskingum method, which are both variations of the kinematic wave approach. Sediment, nutrient, pesticide, and bacteria loadings or concentrations from each HRU are also summed at the subwatershed level, and the resulting losses are routed through channels, ponds, wetlands, depressional areas, and/or reservoirs to the watershed outlet. Contributions from point sources and urban areas are also accounted for in the total flows and pollutant losses exported from each subwatershed. Sediment transport is simulated as a function of peak channel velocity in SWAT2005, which is a simplified approach relative to the stream power methodology used in previous SWAT versions. Simulation of channel erosion is accounted for with a channel erodibility factor. In-stream transformations and kinetics of algae growth, nitrogen and phosphorus cycling, carbonaceous biological oxygen demand, and dissolved oxygen are performed on the basis of routines developed for the QUAL2E model. Degradation, volatilization, and other in-stream processes are simulated for pesticides, as well as decay of bacteria. Routing of heavy metals can be simulated; however, no transformation or decay processes are simulated for these pollutants. A final feature in SWAT2005 is a new automated sensitivity, calibration, and uncertainty analysis component.

3.5.3) SPECIFIC SWAT APPLICATIONS

SWAT applications reported in the literature can be categorized in several ways. For this study, most of the peer-reviewed articles could be grouped into nine subcategories listed in table 1, and then further broadly defined as hydrologic only, hydrologic and pollutant loss, or pollutant loss only. Reviews are not provided for all of the articles included in the table 1 summary; a complete list of the SWAT peer-reviewed articles is provided at the SWAT web site, which is updated on an ongoing basis.

1) HYDROLOGIC ASSESSMENTS

Simulation of the hydrologic balance is foundational for all SWAT watershed applications and is usually described in some form regardless of the focus of the analysis. The majority of SWAT applications also report some type of graphical and/or statistical hydrologic calibration, especially for streamflow, and many of the studies also report validation results. A wide range of statistics has been used to evaluate SWAT hydrologic predictions. By far the most widely used statistics reported for hydrologic calibration and validation are the regression correlation coefficient (R2) and the Nash-Sutcliffe model efficiency (NSE) coefficient. The R2 value measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion. The regression slope and intercept also equal 1 and 0, respectively, for a perfect fit; the slope and intercept are often not reported. The NSE ranges from $-\infty$ to 1 and measures how well the simulated versus observed data match the 1:1 line (regression line with slope equal to 1). An NSE value of 1 again reflects a perfect fit between the simulated and measured data. A value of 0 or less than 0 indicates that the mean of the observed data is a better predictor than the model output. Till date, no absolute criteria for judging model performance have been firmly established in literature. However, the NSE values should exceed 0.5 in order for model results to be judged as satisfactory for hydrologic and pollutant loss evaluations performed on a monthly time step (and that appropriate relaxing and tightening of the standard be performed for daily and annual time step evaluations, respectively).

2) APPLICATIONS ACCOUNTING FOR BASE FLOW AND/OR FOR KARST-INFLUENCED SYSTEMS

Although there are digital filter techniques that can be used for determining separation of base and groundwater flow from overall streamflow, SWAT groundwater recharge and discharge (base flow) estimates for specific 8-digit watersheds compared well with filtered estimates.

3) SOIL WATER, RECHARGE, TILE FLOW, AND RELATED STUDIES

It was observed that SWAT has the tendency to overpredict soil water in dry soil conditions and to underpredict in wet soil conditions. Overall, the model was adequate in simulating soil water patterns for all three watersheds with a daily time step. Another study used SWAT to document 30-year (1962-1991) long-term average soil moisture conditions and variability, and topsoil variability. The model was judged to be able to accurately estimate the relative magnitude and variability of soil moisture in the study region.

4) APPLICATIONS INCORPORATING WETLANDS, RESERVOIRS, AND OTHER IMPOUNDMENTS

In a study which simulated wetland with SWAT, it was found that the wetland needed to be above 85% capacity for 60% of a 14-year simulation period, in order to continuously function over the entire study period. SWAT performed well in a simulating wetlands conversion to dry land but could not represent all of the discharge details impacted by land use alterations.

5) POLLUTANT LOSS STUDIES

SWAT has been applied in several studies that reported simulation results of one or more pollutant loss indicators. Many of these studies describe some form of prediction accuracy for verifying pollutants. However, the results reported on some studies were poor, especially for daily comparisons, this can be ascribed to the fact that some of the weaker results were due in part to inadequate characterization of input data, uncalibrated simulations of pollutant movement and uncertainties in observed pollutant levels.

6) SEDIMENT STUDIES

Several studies showed the robustness of SWAT in predicting sediment loads at different watershed scales. Like the pollutant loss study, it was found that SWAT predicted monthly sediment losses correlate positively with measured data but that of the daily output was poor.

3.5.4) SENSITIVITY, CALIBRATION, AND UNCERTAINTY ANALYSES

Sensitivity, calibration, and uncertainty analyses are vital and interwoven aspects of applying SWAT and other models. Numerous sensitivity analyses have been reported in the SWAT literature, which provide valuable insights regarding which input parameters have the greatest impact on SWAT output. SWAT input parameters are physically based and are allowed to vary within a realistic uncertainty range during calibration. Sensitivity analysis and calibration techniques can be carried out either manually or automated and can be evaluated with a wide range of graphical and/or statistical procedures. Uncertainty is defined as "the estimated amount by which an observed or calculated value may depart from the true value." They discuss sources of uncertainty in depth and list model algorithms, model calibration and validation data, input variability, and scale as key sources of uncertainty.

1) SENSITIVITY ANALYSES

A study performed manual sensitivity/calibration analysis of 15 SWAT input parameters for a 5.5 km2 watershed with karst characteristics in Kentucky, which showed that saturated hydraulic conductivity, alpha base flow factor, drainage area, channel length, and channel width were the most sensitive parameters that affected streamflow. Another study showed surface runoff, base flow, recharge, and soil ET sensitivity curves in response to manual variations in the curve number, soil available water capacity, and soil evaporation coefficient (ESCO) input parameters for three different 8-digit watersheds within their upper Mississippi River basin SWAT study.

A two-step sensitivity analysis which consists of: (1) a "Morris" screening procedure that is based on the one factor at a time (OAT) design, and (2) the use of a Fourier amplitude sensitivity test (FAST) method. The screening procedure is used to determine the qualitative ranking of an entire input parameter set for different model outputs at low computational cost, while the FAST method provides an assessment of the most relevant input parameters for a specific set of model output.

2) CALIBRATION APPROACHES

The manual calibration approach requires the user to compare measured and simulated values, and then to use expert judgment to determine which variables to adjust, how much to adjust them, and ultimately assess when reasonable results have been obtained. Several statistical tests that was used to evaluate SWAT streamflow output during a manual calibration process recommended the NSE and R2 coefficients for analysing monthly output and median objective functions, sign test, autocorrelation, and cross-correlation for assessing daily output, based on comparisons of SWAT streamflow results with measured streamflow.

Another calibration method is the Automated Techniques which involve the use of Monte Carlo or other parameter estimation schemes that determine automatically what the best choice of values are for a suite of parameters, usually on the basis of a large set of simulations, for a calibration process. The automated calibration scheme can execute up to several thousand model runs to find the optimum input data set.

3.6) DECISION-SUPPORT SYSTEMS

A decision-support system (DSS) is a “system that supports technological and managerial decision making by assisting in the organization of knowledge about ill-structured, semi-structured or unstructured issues”. The term unstructured refers to the nature of the decision problem; initially, the alternatives, their impacts, or the procedures for evaluation and selection may not be fully understood. The primary components of a DSS include subsystems for database management, model management, and dialog generation. In the context of a GIS, each of these components exists, although the interface for dialog generation may need to be customized for a given organization or decision-support situation. Within the GIS field, there are many examples of the use of GIS software to provide decision support, and some argue that a GIS is a DSS. However, GISs are general-purpose systems, are not focused on a particular decision, and lack the support that customized models can provide. Decision-support systems encompass a wide variety of approaches that can aid in decision making through the use of computers, database management systems, and visual interactive modeling techniques. Water resources management DSS data subsystems have been strongly influenced by the low-cost availability of GIS data sets and the proliferation of low-cost microprocessor datacollection platforms (DCPs). Interactive displays are used to aid data validation and review tasks, as well as to provide a medium for communicating results of analyses to non-computer-oriented managers. The user-friendly criterion is most important in allowing system managers to bypass intermediary computer operators—a situation that is inconvenient and lessens user confidence. DSSs differ from traditional record-keeping and transaction-processing uses of computers primarily because they require a symbiosis between the users and the system in order to be effective. That is, a DSS has a decision focus in contrast to the information and data focus associated with earlier data-processing and management-information systems. The integration of GIS with decision-support systems is referred to as a spatial decision-support system (SDSS). Spatial DSSs make second-order uses of spatial data and provide additional processing or integration with the nonspatial models required to fully support the decision maker. Software advances are making GIS increasingly appropriate as a generator for an SDSS. It is now easier to interact with models using GIS as a sophisticated interface for spatial information. Even limited-functionality GIS software provides the ability to zoom and to display or highlight different features. GIS provides database support designed to allow for effective storage of spatial data. Furthermore, GIS software provides a link between the interface and database to allow the user to easily query spatial data. However, for the full range of potential uses of a spatial data in decision making, a GIS is not a complete DSS until problem-specific models are integrated that address the organization's decision needs in a flexible and interactive manner

REFERENCE

1) P. W. Gassman, m. R. Reyes, c. H. Green, j. G. Arnold, (2007). “The Soil and Water Assessment Tool: Historical Development, Applications, And Future Research Directions”. American Society of Agricultural and Biological Engineers ISSN 0001-2351
2) Christian Omuto, Freddy Nachtergaele and Ronald Vargas Rojas (2013). “State of the Art Report on Global and Regional Soil Information: Where are We? Where to go?”. Food and Agriculture Organization of the United Nations.
3) Remote Sensing and Geographical Information Systems (2008) by M. Anji Reddy