CHAPTER II

IMPORTANT ASPECTS RELATED TO THE PRESENT STUDY

“Water from wells, rivers, rain and from any other source on earth should be used wisely as it is gift of nature for well being of all” – Yajur Veda (X. 64.9)

2.1 Introduction

Now a days, Remote Sensing (RS) and Geographical Information Systems (GIS) techniques are being widely used for planning, development, management and monitoring various resources. Integration of Remote Sensing and conventional data results in decision support system for effective management of land and water resources in a basin. These techniques have certain advantages over the conventional surveys, such as fast and cost effective, provide synoptic coverage, multi spectral capability, provide data of inaccessible areas, enables data storage in digital format and helps in retrieval and updation, facilitates overlay of number of thematic layers and integration of spatial and aspatial data and capable to analyze large quantity of attribute data etc. As such RS and GIS techniques are utilized in the present study in conjunction with conventional surveys and hence some of the relevant aspects of Remote Sensing and GIS in reference to groundwater evaluation, quantitative assessment using GIS, 3-D modeling and quality aspects to develop spatial distribution map of Groundwater Quality Index (GWQI) are discussed.

2.2 Remote Sensing (RS)

Remote Sensing is the technique of gathering information about objects without being in physical contact with them and is an excellent tool for survey of natural resources as it possesses unique possibilities of vividly displaying the gathered information. In addition, its multispectral nature
provides appropriate contrast between various natural resources, and its repetitive coverage provides spatial and temporal information in a GIS environment.

In general, Remote Sensing systems are of two types: Passive Remote Sensing and Active Remote Sensing. Passive Remote Sensing system completely relies on energy reflected or emitted from earth surface features and operates in visible, infrared and microwave portions of the electromagnetic spectrum. Active Remote Sensing works with its own source of energy. A typical Remote Sensing system is shown in Fig. 2.1.

![FIG. 2.1 TYPICAL REMOTESENSING SYSTEM](image)

2.2.1 Electromagnetic Spectrum

Sunlight is a continuum of electromagnetic radiation of different wavelengths. It is represented in the form of electromagnetic spectrum. (Fig. 2.2).
2.2.2 Satellites and Sensors

A satellite is an electronic device, sent into space to obtain required information. Satellites in the space are capable of providing stable platform covering a large area.

Satellites mainly may be Polar orbiting or Geo-stationary satellites. Polar orbiting satellites rotate around the earth from North to South with the orbit near pole. This facilitates covering the entire earth surface at periodic intervals. Most of the remote sensing satellites fall under this category. Geo-stationary satellites are positioned in space such that the satellite orbit is synchronized with the rotation of the earth. Due to this the same spot on the equatorial plane of earth can be observed continuously. Communication Satellites come under this category.

A sensor is a device that receives electromagnetic radiation, converts it into a signal and presents it in a form suitable for obtaining information about an object. There are two types of sensors i.e. Active and Passive. Active sensors supply energy from their own source to illuminate features of interest. Passive sensors sense the features from naturally available energy.
2.2.3 Image Rectification and Restoration, Merging and Enhancement

Image rectification and restoration aim to correct distorted or degraded image data to create a more reliable representation of the original scene. This involves the correction of raw image data for geometric distortions, to calibrate the data radiometrically and to eliminate noise present in the data. Image to image rectification can be carried out using software like ERDAS IMAGINE software.

Image merging is the process of combining images obtained from a single sensor or two different sensors having same resolution or different resolutions. Image enhancement is the process of making an image more interpretable for a particular application for increasing the visual distinction between features in a scene. New images can be created from the original image data in order to increase the amount of information that can be visually interpreted from the data. Radiometric, spatial and spectral enhancements are the three important enhancement techniques that are involved in digital image processing. These techniques are explained in brief:

**Radiometric Enhancement**

The raw digital data often occupy very small portions of the dynamic range and appear very dull. With the contrast enhancement technique, the original brightness values are expanded to make use of the total dynamic range. Depending upon the application, this contrast stretch can be linear or non-linear. A linear contrast stretch uniformly stretches the brightness values where as in the non-linear stretch the brightness values of particular class of interest can be stretched to any range of the total dynamic range. In simple words, radiometric enhancement is an enhancement technique that deals with the individual values of pixels in an image.

**Spatial Enhancement**

Spatial enhancement modifies pixel values based on the surrounding pixel values. That means it deals with the spatial frequency, which is the difference between highest and lowest values of a continuous set of pixels.
**Spectral Enhancement**

Spectral enhancement is the process of modifying the pixels of an image, based on the original values of each pixel, independent of the values of surrounding pixels. The environmental effects like shadows, seasonal changes in sun light, illumination angle often cause differences in brightness values from similar surface materials and affect the ability of the interpreter to correctly identify the features from image. In such situation, band-rationing method can be applied to reduce the environmental effects.

2.2.4 **Photo Interpretation and Resolution**

On screen feature extraction will be carried out using visual interpretation techniques based on elements of image interpretation and various thematic maps. Elements of photo interpretation are tone, size and shape of objects, texture, shadow, pattern, location, association and aspect.

Tone corresponds to the variations in the intensity of recorded, reflected or emitted radiations by sensors. In black and white imageries objects appear in various shades of gray tone. Due to maximum absorption of radiation, water bodies appear in black gray color on imagery while due to reflectance of light, snow cover or clouds appear in light gray tone. The variations in gray tone can be transformed into corresponding colors of various shades on False Color Composite (FCC). Color imagery provides better thematic information than black and white imagery with single band.

Size of an object is one of the most useful clues to its identity. It is primarily a function of scale and is measurable. This factor in combination with shape of objects and scale of photograph helps to identify the object to a great extent.

Shape of some objects is so distinctive that their images can be identified solely based on this parameter. For good interpretation, one must have the ability to understand and make use of plan view. It is a powerful tool
for conclusive identification of object. Shape can be regular or irregular depending upon the nature and type of object.

Texture is the frequency of tonal change on the photographic image. It is defined as a repetition of a basic pattern. Texture is a valuable clue in interpretation.

Shadows are formed due to sensor viewing angle and are important in interpretation. Shape and profile of shadows help in identifying different surface objects and clouds, natures of hill slopes, aspect, apparent relief etc. They also help in determining heights of trees, hills or buildings.

Pattern refers to spatial arrangement of objects. It is one of the characteristics of many manmade objects and of some natural features. Pattern of objects is an important clue to their origin or function or both. Outcrop patterns provide clues to geologic structure and drainage pattern provide clues to structures, lithology and soil types.

Location of objects with respect to terrain features or other objects is often helpful in identifying the object. Aspect, topography, geology, soil, vegetation and the varied imprints of man’s culture are the distinctive factors that should be used when examining a site.

Some objects are so commonly associated with other objects that one tends to indicate or confirm the other. Association is one of the most helpful clues in identification of landforms and also manmade installations. For example a floodplain is associated with several features such as river terraces, natural levees, back swamp etc. School with playground is an example to manmade installations.

Aspect refers to the direction in which a mountain slope faces. Aspect has marked influence on the shifting of vegetation, settlements and cultivation.
Resolution is the ability of the system to discriminate the closely spaced objects in the subject area. Resolution is of four types - Spatial, Spectral, Radiometric and Temporal resolutions. Spatial Resolution is defined as the smallest elemental object that can be captured by the sensor for imaging. It is also defined as the minimum separation between two objects to be identified unambiguously as two different targets and not as one. Spatial resolution depends upon on reflecting capabilities and contrast against a certain background. Spectral Resolution is defined as the minimum separation between two bands in the electromagnetic spectrum. For example, the visible region in spectrum is subdivided into 3 bands in case of LANDSAT 1-2-3 and in the LANDSAT 4-5 the same region is subdivided into 5 bands. That means, if a given region of a spectrum is separated into as many number of divisions as possible, the spectral resolution will be greater. Regarding radiometric resolution, in the visible region, the light energy reflected or scattered from objects reaches the sensors where it is converted into electrical energy. The smallest change in voltage that represents the sensed energy is defined as radiometric resolution. In general, the gray levels correspond to the radiometric resolution in the black and white image. Interval between two successive observations is defined as temporal resolution. In other words, it is the frequency of observations made.

2.3 Remote Sensing Applications in Water Resources

Various applications of Remote Sensing in the field of water resources are briefly described below:

Surface Water Inventories

High resolution Near Infrared sensors are used to measure the extent of surface water. This is because, these sensors present a clear contrast between water and adjacent land. Studies indicate that water bodies as small as 0.01 Sq. Km can be delineated. This makes the monitoring of surface water using repetitive Remote Sensing data feasible, even on small inaccessible watersheds.
Flood Assessment and Flood Plain Mapping

Areas inundated are detected in the Near Infrared bands as areas of reduced reflectivity due to standing water, excessive soil moisture and vegetation moisture stress. Most important fact is that the observations as late as two weeks after the flood crest will still show the characteristics, reduced Near Infrared reflectivity of the previously inundated areas, which essentially reduces the need for obtaining satellite observations at the time of peak flooding. Areas likely to be flooded, known as flood prone areas, tend to have multi spectral signatures, different from those of the surrounding non flood prone areas.

Snow Mapping

Extraction of snow covered area from satellite using visible and near infrared imagery has been tested successfully. Extraction of other meaningful snow pack parameters such as water equivalent depth is still in research stage, although water equivalent values obtained by measuring the snow’s attenuation of natural gamma radiation from extremely low altitude aircraft have been very promising.

Hydrologic Land use Analysis

Knowledge of watershed landuse is important because a record of surface cover characteristics can be used to refine estimates of the quantity, quality and timing of water yield in response to a particular precipitation event or watershed treatment. Various watershed models require up-to-date land use inputs for calibration purposes and hence better stream flow simulations. Various levels of Remote Sensing data can meet these landuse requirements.

Physiographic Characterization

Physiographic observations such as basin area and shape, stream network organization, drainage density, drainage pattern and specific
channel characteristics can enable an investigator to estimate the mean annual discharge and mean annual flood flows from a watershed, as well as the rapidity of watershed response to a particular rainfall event. In general, the kind of dynamic hydrologic information available from the repetitive coverage of satellite images cannot be obtained from topographic maps. Further, in some areas single satellite images offer more geographic information than is available on comparable scale maps.

**Resource Mapping in Watershed**

Remote Sensing technique in evolving characteristics of the watershed has demonstrated that this medium is very useful in providing hydrological information in spatial and temporal scale. Synoptic coverage of satellite imagery permits fairly easy identification of basin extent and broad physical features such as stream network, landuse, vegetation, surface water bodies etc. Hydrologists and water resources engineers were handicapped with lack of reliable survey data of mapping of watershed characteristics. Satellite remote sensing now enables easy, accurate, timely and cost effective mapping and updating of several resources information of the watershed such as stream network map, vegetation map, erosion intensity map, groundwater prospects map etc. These maps and information can be geo-referenced with conventionally measured topographic maps through Geographic Information Systems for meaningful synthesis of the watershed.

National Remote Sensing Agency has taken up a number of remote sensing projects on natural resources in which geology, geomorphology, soils, hydrology, landuse etc., are the principal themes. Thematic maps used such as landuse/landcover, hydrogeomorphology, drainage, soil, slope, rainfall, transport network, settlements and socio-economic data with an objective of preparing action plan maps.
2.4 Geographical Information System (GIS)

Geographical Information System is a powerful tool for collecting, storing, retrieval and manipulation of spatial data. It allows integration of spatial and aspatial data and also overlay of layered information that are beyond the capability of manual methods. GIS made it possible to map, model, query and analyze large quantities of data, all held together within a single database. GIS is defined as an organized collection of computer hardware, software, geographic data and personnel, designed to efficiently capture, store, update, manipulate, analyze and display all forms of georeferenced information.

2.4.1 Components of GIS

Important components of GIS are Computer hardware, Software module and Trained personnel. The components of GIS are represented in pictorial form in Fig. 2.3.
Computer hardware consists of the following:

- Central Processing Unit (CPU).
- Digitizer or any other input device to convert data into computer readable form.
- Monitor to display the information and results.
- An output device to present the results.

Software module should perform the following key functions:

- Data input processing
- Data storage, retrieval and data base management
- Data manipulation and analysis
- Display and output generation

Data input includes all aspects of transforming spatial and non-spatial data into a GIS database. Method of data entry includes digitization, scanning and keyboard entry. Data may be obtained from many sources such as existing analogue maps, aerial photographs and Remote Sensing surveys and other information systems. Hence prior operations like format conversion, data reduction and generalization, error detection and editing, merging, edge matching, rectification and registration etc. have to be performed. Data Base Management System (DBMS) controls the creation of and access to the database itself. Non-spatial attribute information is stored in a relational database management system and the spatial information in a separate sub system that enables to deal with spatial data and spatial queries.

Spatial data processing is performed with vector, raster or the combination of these two data formats. The most important feature in a GIS is its ability to manipulate and analyze spatial data.

Some simple spatial operations performed by GIS are:

- Geometric calculation such as distance, length, perimeter, area etc.
- Topological operators such as neighbourhood, next link in a polyline network, start and end nodes of polyline etc.
Multi layer spatial overlay.
Network analysis.

Display and output generation may be in various forms such as statistical reports, maps and graphics of various kinds depending on the final outputs generated from GIS.

**Note:** GIS (ArcGIS 9.2 used in the present study) is very efficient in data storage, retrieval and graphic display. Its capabilities for more sophisticated forms of spatial analysis and decision making, make it the best suitable technology for natural resources management.

Trained people are integral part of GIS. Although hardware, software and data are essential, trained people constitute the most important component of GIS.

### 2.4.2 Structure of GIS

Data structures of GIS are of two types namely Raster data model and Vector data model. A raster based system displays, locates and stores graphical data by using a matrix of cells. A unique reference coordinate represents each pixel either at a corner or at the centroid. Each pixel has discrete attribute data assigned to it. Raster data resolution is dependent on the pixel size and may vary from sub-meter to many kilometers. Remote Sensing image data is an example to raster data model. A vector based system displays graphical data as points, lines, curves or areas with attributes. Cartesian coordinates and computational algorithms of coordinates define points in a vector system. Lines or arcs are a series of ordered points. Same node will be given to the beginning and end points so that the polygon is closed and defined. Vector systems are capable of very high resolution and graphical output is similar to hand drawn maps. It is less compatible with Remote Sensing data and requires complex data structures. Vector data require less computer storage space and maintaining topological relationships are easier in this system. GIS stores various data in different
layers. Generally raster data requires less processing than vector data, but consumes more computer storage space. Figure 2.4 represents GIS data structure and its types.

**FIG. 2.4 GIS DATA STRUCTURE AND ITS TYPES**

**Attributes**

An attribute is a characteristic of an entity. Attributes are non-spatial and do not have permanent locations with respect to other entities and are invariant to changes in scale and projection. Attribute value is the actual measurement that is stored in the database.

**Map Overlays**

Overlaying of maps leads to the creation of a new map where in the values assigned to every location on that map are computed as a function of independent values associated with that location on two or more existing maps. New polygons are created by the overlay of multiple layers. These polygons have multiple attributes i.e., the attributes that are given to each separate layer before the overlay operation occurred. Arithmetical and logical overlay operations are in common use. Arithmetical overlay includes operations such as addition, subtraction, division and multiplication of each
value in a data layer. Logical overlay involves the selection of an area where a set of conditions are satisfied.

2.4.3 Analysis of GIS Data

The most important characteristic of GIS is the capability for spatial analysis functions utilising the spatial and non-spatial or attributes in the database. A few GIS functions like format transformations, geometric transformations, transformation between map projections, edge matching, editing of graphic elements etc. are under analysis of the spatial data. Attribute editing functions, attribute query functions etc. are under the analysis of attribute / non-spatial data. Retrieval, classification, measurement, overlay operations, neighborhood operations, topographic functions, Theissen polygons, interpolation, contour generation, contiguity measures, proximity, network, intervisibility, perspective view etc. are performed under integrated analysis of spatial and attribute data. GIS also performs map annotation, text labels, texture pattern and line styles, graphic symbols etc. under map production. Figure 2.5 represents the flow of GIS analysis.

FIG. 2.5 FLOW OF GIS ANALYSIS
2.4.4 Applications of GIS

GIS are widely applied in variety of fields by government departments, business groups and research sectors for resource analysis, landuse planning, transport planning, surface water mapping, groundwater investigations, soil mapping, disaster management, military applications, forestry and agriculture analysis, location analysis, tax appraisal, utility and infrastructure planning, real estate analysis, marketing and demographic analysis etc. GIS tools and their applications are note worthy especially in planning, development and management of natural resources and supports decision-making.

Regarding the application of GIS in the present study, it is used in demarcating study area from the surroundings. Various maps are created and their integration and analysis is carried out using GIS for quantification of groundwater resources.

2.5 Groundwater Quantity

Rapid industrial development, urbanization and increase in agricultural production have led to fresh water shortage in many parts of the world. Water resources of the basins remain almost constant while the demand for water continues to increase. For sustainable development of water resources, it is imperative to make a quantitative estimation of the available water resources. Increasing population and growing demands threaten the sustainability of water resources. Hence, estimation of groundwater resources and status of groundwater development should be carried out at basin level. More than 50% of domestic water supply and 40% of irrigation water supply is obtained from groundwater in India, and therefore it is very important to preserve and improve the quality and quantity of ground water. Proper development of water resources involves economic and best utilization of available water. This will have to include forward planning and action, which can specifically address both the existing and emerging human and environment problems.
Quantification of groundwater resources is often critical and no single comprehensive technique is yet identified which is capable of estimating accurate groundwater assessment. The 'National Water Policy' adopted by Government of India regards water as one of the most crucial elements in developmental planning. It emphasizes that the efforts to develop, conserve, utilize and manage this resource have to be guided by national perspective and also enunciates periodic assessment of groundwater potential on scientific basis.

In order to quantify the groundwater potential of an aquifer, it is necessary to have the details of area extent of the aquifer, thickness of each layer of formation and the corresponding porosity of each formation.

The areal extent of an aquifer is obtained from the R.S. imagery of the study area. The details of vertical stratification of the soil formation are obtained by carrying out Vertical Electrical Sounding (VES) at different points spread across the study area. With the known stratification, thickness of each layer of sub soil is determined. Profiling combined with sounding over the study area yields the vertical stratification of the study area.

The data pertaining to areal extent and vertical stratification are then used to compute the volume of each layer of the soil formation, using Triangulated Irregular Network (TIN) module.

Three Dimensional (3D) models represent any object using a set of points in space, connected by various geometric entities such as triangles, lines and curved surfaces. 3-D modeling is the process of developing a representation of an object via specialized software used in a computer simulation of physical phenomena. Three data structures are used to store differences in elevations of various points on the surfaces using regularly spaced grids (DEM/DTM/DSM) and lines of equal elevation (contours). This is otherwise named as Triangulated Irregular Networks (TIN) surface.
A Triangulated Irregular Network (TIN) surface is a digital terrain model that is based on an irregular array of points which form a sheet of non-overlapping contiguous triangle facets. It is a vector model that supports the incorporation of point, line and area based features to capture and represent the surface morphology. An accurate, well-designed TIN maintains consistency with the variation in surface elevations of the terrain. If the terrain is very undulating and complex, the resolution of the TIN is increased accordingly by incorporating more data points in the TIN model. In special computations, such as spot height estimation, elevation values are to be interpolated for a given location based on the triangle in which it falls. Differential Global Positioning System (DGPS) survey has to be carried out in the study area along with the contours extracted from SOI toposheet, to construct TIN surfaces for the different sub surfaces.

The TIN module is used for surface modeling. With the known values of geo co ordinates and from VES data three dimensional parameters (XYZ points) will be known. TINs will be generated by connecting a set of XYZ points (scattered or gridded) with edges to form a network of triangles. Linear variation of surface is assumed across each triangle. The surface of a geologic unit is represented by TIN. The concept of TIN is presented in pictorial form in Fig. 2.6.

3D subsurface modeling helps in better understanding the structure, extent, thickness and distribution of subsurface materials especially in hydrogeology. With the known values of areal extent in the form of TIN surfaces and thickness of each subsurface formation from VES data, the corresponding 3D model of the subsurface can be generated using 3D analyst module in Arc GIS. Figure 2.7 shows a model 3D subsurface generated. However, at this stage it may be noted that ONLY volume of subsoil formation is computed and NOT the water holding capacity of the formation.
Now, using a suitable porosity model such as that proposed by Athy, wherein the porosity at a desired depth is expressed in terms of surface porosity and depth at which porosity is to be determined, porosity of the subsurface be determined. Thus, with the known values of volume of
subsurface formation and corresponding porosity, the water holding capacity of the subsurface can be estimated.

By conducting Vertical Electrical Soundings (VES) using four electrode Schlumberger configuration, the subsurface lithology is predicted. Triangulated Irregular Network (TIN) are generated from the interpreted resistivity data using ArcGIS – 3D Analyst module for different lithological surfaces starting with topographic surface up to hard rock surfaces to develop 3-Dimensional (3D) modeling. Results obtained from 3D modeling are useful in predicting the volume of each subsurface layer beneath the ground.

The disturbed soil samples collected from the field are to be tested in the laboratory for predicting its porosity. Using this estimated value of porosity at particular depth and multiplying the volume of each sub surface formation with the value of porosity gives the expected water holding capacity of the formation. Detailed procedure followed for evaluation of groundwater resources is presented in succeeding chapters.

2.6 Groundwater Quality

Water quality is a term used to describe physical, chemical and biological properties of water. Groundwater originates basically through infiltration of precipitation on the earth surface. Thus many activities on the earth surface adversely affect quality of groundwater. Also rapid growth of population and urbanization affects the quality of groundwater through over exploitation and improper waste disposal.

Groundwater has to be analysed for various physico-chemical parameters such as pH, Total Dissolved Solids (TDS), Alkalinity, Chlorides (Cl⁻), Fluorides (F⁻), Nitrates (NO₃⁻), Sulphates (SO₄²⁻), Calcium (Ca²⁺), Magnesium (Mg²⁺), Total Hardness (TH) and Electrical Conductivity (Ec) following APHA standard methods and Groundwater Quality Index (GWQI) can be computed with the results obtained. Horton in 1965 defined Water
Quality Index (WQI), as a reflection of composite influence of individual quality parameter on the overall quality of water. WQI assesses water quality trends for management purpose even though it is not meant for an absolute measure of the degree of pollution or the actual water quality. Application of WQI is a useful method in assessing the water quality of groundwater. For calculation of WQI, selection of parameters has great significance since number of parameters widens the WQI and their selection depends on the intended use.

Brown (1972) et al. developed a water quality index paying great rigor in selecting parameters, developing a common scale and assigning weights for which elaborate Delphic exercises were performed. This effort was supported by the National Sanitation Foundation (NSF) and also referred to as NSFWQI.

Some researchers used raster interpolation technique in GIS to delineate the distribution of various water quality parameters along with raster interpolation technique. Point layer data of sampling locations were imported duly assigning unique codes and integrated with standard permissible and excessive values of various water quality parameters in the study area which resulted in delineation of spatial distribution maps of water quality parameters and groundwater quality index (GWQI).

Detailed procedure for estimation of groundwater quality and Water Quality Index is presented in the subsequent chapters.

2.7 Concluding Remarks

Necessary aspects of Remote Sensing and GIS techniques, applications of Remote Sensing and GIS in water resources are discussed. Various aspects related to groundwater quantity and quality are also presented.