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Remote Sensing Applications
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Groundwater

8.1. Introduction

The distribution of groundwater is not uniform throughout the country. The spatio-temporal variations in rainfall and regional/local differences in geology and geomorphology have led to uneven distribution of groundwater in different regions across the country. Unplanned and haphazard development of groundwater in some areas has further compounded the problem and has led to a sharp decline in groundwater levels. As a result, a large number of shallow wells have gone dry, resulting in a huge loss and shortage of drinking water in 20 to 25% of the habitation in the country. Similarly, along the coastal zones also the delicate balance between sea water and the groundwater has been disturbed leading to sea water intrusion into the fresh water aquifers causing irreparable damage and environmental degradation. Systematic estimation and budgeting of groundwater resource based on its spatio-temporal distribution, its allocation for meeting the competing demands for irrigation, industrial and domestic usage, and conjunctive use of surface and a groundwater resource are, therefore, pre-requisite for optimal utilization of available groundwater on a sustained basis.

Groundwater study of an area requires the knowledge of the nature of lithological units occurring in the area, their structural disposition, geomorphic set up, surface water conditions and climate. These had been studied by the conventional method of extensive field work till recent past. With the development of remote sensing sensors accompanied with improvement of interpretation techniques of the remotely sensed data, focus has turned to this technique. World wide professional organizations involved with groundwater investigation in an area commence their work with analysis of remotely sensed data. Although remote sensing data can't directly detect subsurface resources, its importance lies in providing indirect but reliable inferences about the groundwater potentiality of the region. Analysis and interpretation of remote sensing data followed by selective ground check is important to obtain an idea about the probable groundwater potential areas. This should be substantiated through surface and subsurface geophysical methods best suited for groundwater exploration.

8.2. Background

Timely and reliable information on the occurrence and movement of groundwater is a prerequisite for meeting its growing demand for drinking, domestic and industrial sector. Being a sub-surface feature, the detection of groundwater relies heavily on the controlling factors, namely lithology, geomorphology, structures and precipitation, run-off, surface water and the extent of irrigated lands that control its occurrence and movement. Spaceborne spectral measurements hold a great promise in providing such information in timely, reliable and cost-effective manner. In India, initially the coarse resolution data from Indian Remote Sensing Satellite (IRS-1A/-1B LISS-II) & Landsat-TM have been operationally used by the Department of Space Govt. of India mainly for identifying and mapping groundwater potential zones for entire country (447 districts) on 1:250,000 scale under National Drinking Water Technology Mission. Mapping of the groundwater prospects on 1:50,000 scale using IRS-1C/-ID LISS-III data for entire country under Rajiv Gandhi Drinking Water Technology Mission is in progress and till now ten states have been completed successfully.

Conventional surveys are tedious, time consuming apart from being impractical in the inaccessible and inhospitable terrain. Moreover, many features of regional nature could not be mapped precisely owing to lack of regional perspective. Earlier, the aerial photographs have been used for deriving information on lithology, geomorphology and structures. By virtue of providing synoptic view of the terrain at regular intervals, space borne multi-spectral measurements offer immense potential in generating the information on parameters required for groundwater exploration, exploitation and development.

8.2.1. Factors Controlling Groundwater Regime

The groundwater regime is a dynamic system wherein water is absorbed at the surface of the earth and eventually recycled back to the surface through the geological strata. In this process, various elements like relief, slope, ruggedness, depth and nature of weathering, thickness and nature of deposited material, distribution of surface water bodies, river / stream network, precipitation, canal command areas, groundwater, irrigated areas, etc., also influence the groundwater regime, besides the geologic framework. Thus, the framework in which the groundwater occurs is as varied as that of rock types, as intricate as their structural deformation and geomorphic history, and as complex as that of the balance among the lithologic, structural, geomorphic and hydrologic parameters (Jasrotia *et al.*, 2007; Chowdhury *et al.*, 2009). The possible combinations of variety and intricacy are virtually infinite leading to the unavoidable conclusion that the groundwater conditions at a given site are unique and not completely amenable to scientific understanding. Some of the conditions are often obscured and not readily apparent even from the field observations. However, factor-wise analysis, systematic mapping, data integration and interpretation based on conceptual understanding will help in overcoming this problem to some extent.

Though, there are a large number of variables that are important in understanding the groundwater conditions of an area, it is not possible to separately map and study all the variables individually during the course of the investigation. Rarely is it possible for an investigator to complete all the examinations to eliminate uncertainties and provide quantitative information about the type, thickness and depth of aquifer, its yield potential, success rate, etc with complete confidence. Varying degrees of uncertainty and inconsistency are inherent in the present methodology (conventional hydrogeological mapping). Hence, the entire procedure of mapping has to be made more systematic and simpler with well defined units based on which better inferences can be made. For this purpose, all the variables that control the groundwater regime have been grouped into the following 4 factors -

- Geology / Lithology
- Geological Structures
- Geomorphology / Landforms
- Recharge conditions

Once, information on these 4 factors is precisely known, it is possible to understand the groundwater regime better by visualizing the gross aquifer characteristics of each unit. Systematic visual interpretation of satellite imagery in conjunction with existing geological / hydrogeological / geomorphological maps and data supported by limited field checks / observations provide the information related to these 4 factors. By integrating the lithological, structural, landform and hydrological information, the groundwater prospects map can be prepared which provide better understanding of groundwater regime as compared to the conventional hydrogeological map.

8.3. Role of Space Technology in Groundwater Studies

The launch of Earth Resources Technology Satellite (ERTS-1), later renamed as Landsat-1 with the Multispectral Scanner System in 1972 ushered in a new era in mapping and updating of geological, geomorphological and structural features using the optical sensors data. Subsequently, Landsat-Thematic Mapper and the India Remote Sensing Satellite (IRS-1A LISS-II) sensors have been operationally used in India to generate groundwater potential maps at 1:250,000 scale. Remote sensing data have been widely used in groundwater prospecting (Sreedevi *et al.*, 2005; Dinesh *et al.*, 2007; Chandra *et al.*, 2006; Per Sander, 2007). The LISS-III multispectral data from IRS-1C and 1D satellites have been used later for preparing groundwater potential maps at 1:50,000 scale.

In addition to optical sensors data, microwave data have also been used at experimental level for deriving information on lithology, landforms and structures (Ghoneim and El-Baz, 2007). Microwave (Synthetic Aperture Radar) data have a very limited capability for direct measurement of groundwater because the depth of penetration is limited to a few centimeters except in extremely dry sand covered areas. Imaging radar data has proven to be very useful in discrimination of surface lithology buried palaeo-channels, dykes, sand-covered bed rock to a depth ranging from 1.5 to 6.0 m (Drury 1990; Jensen 1995; Sabins 1987; Shankar *et al.*, 2001).

Apart from optical and microwave data thermal infrared sensor data have also been used for identification of groundwater potential zones under certain conditions. Heilman et al (1982) found a correlation between Heat Capacity Mapping Mission-derived radiometric temperatures and groundwater depth when the effect of vegetation on the surface thermal region was considered. Similarly, a correlation between predawn radiometric temperature and thickness of aquifer was also observed (Moore, 1982). In-spite of encouraging results, insufficient ground spatial resolution and lack of repetitive global calibrated thermal data precludes the usage of thermal infrared data for groundwater studies. Thus, the satellite data provide supporting information for recharge estimation, draft estimation, mapping of prospective zones, identification of over exploited and under developed/undeveloped areas and prioritization of areas for recharge structures which conjunctively facilitate systematic planning, development and management of groundwater resources on a sustainable basis.

Geophysical measurements, namely geo-electrical, seismic refraction and electromagnetic systems, have also been commonly used for groundwater exploration. Besides, Ground Penetrating Radar (GPR) operating in low frequency (100 to 500MHZ), nuclear magnetic resonance, magnetic and gamma ray spectrometric techniques have been tried out at experimental level for detection of shallow groundwater table, phreatic surface, crustal structures and bedrock profile (Bahuguna *et al.*, 2003; Gupta, 1991).

8.4. Groundwater Prospects Mapping

Groundwater targeting and prospects mapping is one of the thrust areas in groundwater studies since it forms the base for groundwater exploration and development. It involves identification and mapping of prospective zones for groundwater exploitation. The methodology for preparing groundwater maps using satellite imagery has undergone rapid changes during the last two decades. Initially, the remote sensing data, namely aerial photographs and satellite images were used mainly to update and refine the conventional hydrogeological maps prepared from ground surveys. Subsequently, many organizations in the country including National Remote Sensing Centre (NRSC) /Department of Space (DOS), Central Ground Water Board (CGWB), Groundwater Departments of different states, research laboratories and academic institutions have also started preparing the groundwater maps through a systematic visual interpretation of satellite data with limited field checks. These maps, with different titles, vary greatly in their quality and information content. The operational utilization of satellite data for groundwater studies in India has taken a firm footing in the year 1985 when the Department of Space prepared the groundwater potential zone maps at 1:250,000 scale for two states, namely Maharashtra and Karnataka during the period 1985 –1986 followed by a nation-wide mapping of groundwater potential zone at 1:250,000 scale using the Landsat-TM and the Indian Remote Sensing Satellite - IRS-1A Linear Imaging Self-scanning Sensor (LISS-II) data under National Drinking Water Technology Mission during the period 1987 to 1992 using a common legend (Baldev *et al.*, 1991).

These maps formed the regional database for groundwater exploration for entire country. Subsequently, the Department of Space in collaboration with the State Remote Sensing Centres and concerned State Departments has prepared, apart from other thematic maps, the hydrogeomorphological maps on 1:50,000 scale for 84.0 million hectares covering 175 districts under major national level project Integrated Mission for Sustainable Development (IMSD) project.

For providing safe drinking water to 4.4 lakhs villages in the country a nation-wide project titled “Rajiv Gandhi National Drinking Water Mission (RGNDWM): has been taken up by NRSC/DOS to prepare groundwater prospects maps on 1:50,000 scale through visual interpretation of IRS-1C/-1D LISS-III geo-coded images in conjunction with the existing geological, hydrogeological and hydrological information with the limited field checks. In order to achieve the objective of the project, a new methodology has been developed and the manual has been brought out. In this approach, the information on lithology, landform, geological structure and hydrology are generated and by integrating them subsequently the groundwater prospects map is prepared. Thus, by taking input parameters, namely lithology, landform, geological structures, recharge conditions, depth to water table, and yield information, the groundwater prospects are evaluated and defined in terms of following output parameters i) Aquifer material (ii) Type of wells suitable (iii) Depth range of wells (iv) Yield factor (v) Heterogeneity of the aquifer/the failure rate of wells (vi) priority for planning recharge structure and the type of recharge structures suitable and (vii) Quality/ problems/limitation. In the first phase, Rajasthan, Madhya Pradesh, Andhra Pradesh, Karnataka and Kerala States have been taken up. These maps are generated as digital outputs in GIS environment (Burrough 1986) containing information on several layers covering different parameters. Thus, these maps provide much more information as compared to the conventional hydrogeological maps and are quite useful in narrowing down the target zones for detailed geophysical/ground hydrogeological studies (Bhattacharya and Patra 1968) for selection of sites for drilling as well as for planning recharge structures.

8.4.1. Lithology

The synoptic view and multispectral nature of the satellite imagery help in discrimination and mapping of different lithologic units. Geological mapping is carried out mainly based on visual interpretation of satellite images (Figure 8.1) adopting deductive approach by studying image characteristics and terrain information in conjunction with a prior knowledge of general geological setting of the area. The tone (colour) and landform characteristics combined with relative erodibility, drainage, soil type, land use/ land cover and other contextual information observable on the satellite image are useful in differentiating different rock groups / types.

The direct clue for interpretation of rock type / lithologic unit comes from the tone (colour) of the image. For example, the acidic and arenaceous rocks appear in lighter tone as compared to the basic / argillaceous rocks. Similarly, coarse grained rocks having higher porosity and permeability appear brighter on the image as compared to fine-grained rocks having higher moisture retaining capacity. The highly resistant rock formations occur as

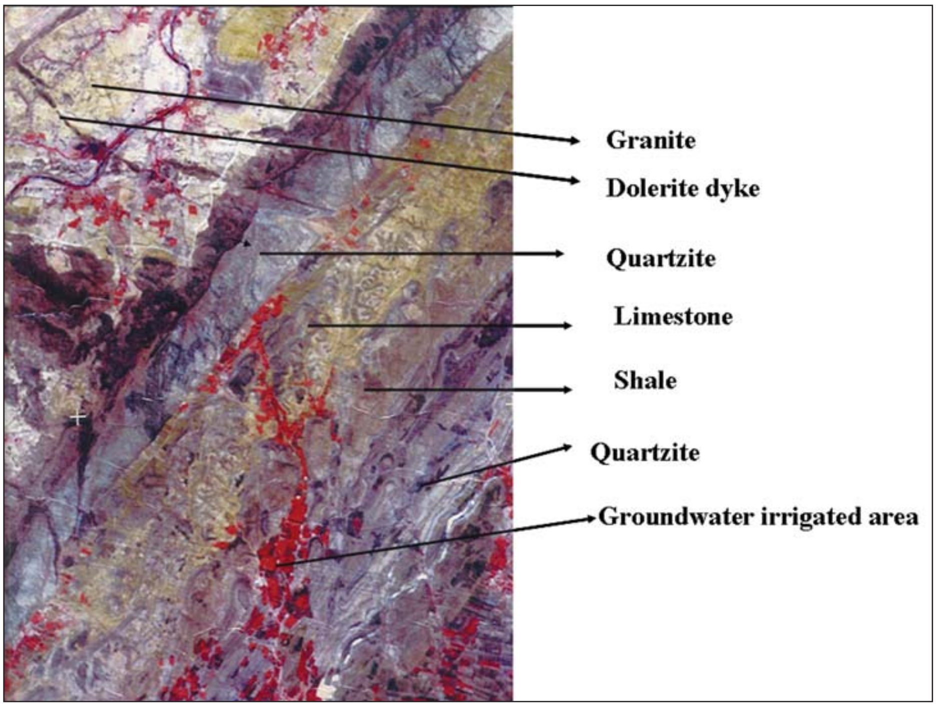

Figure 8.1: Interpretation of Lithology from satellite imagery

different types of hills depending upon their texture and internal structure; whereas, the easily erodible rocks occur as different types of plains and valleys. While dendritic drainage indicates homogeneous rocks, the trellis, rectangular and parallel drainage patterns indicate structural and lithological controls. The coarse drainage texture indicates highly porous and permeable rock formations; whereas, fine drainage texture is more common in less pervious formations. The coarse textured and light coloured soils indicate the acidic / arenaceous rocks rich in quartz and felspars; whereas, the fine textured and dark coloured soils indicate basic / argillaceous rocks. Thus, by combining all these evidences, it is possible to interpret different rock groups / formations. Though, one or two recognition elements, mentioned above, may be diagnostic for the identification of a particular rock type, the convergence of evidences must be considered by studying all the recognition elements conjunctively (figure 8.1). However, limited field checks are a must to identify the rock types and to make necessary corrections in the interpreted map based on field evidences. Once, the rock types are identified, the contacts can be extended over large areas with minimum ground control. The identification, correlation and extrapolation of rock types are possible based on similar spectral and morphological characters.

For preparation of lithological map overlay (Figure 8.2'b'), information from the following sources is required:

- Consultation of existing geological / hydrogeological maps or literature
- Interpretation of satellite imagery (figure 8.2 'a')
- Field visits / surveys

8.4.2. Geological Structure

Various workers have emphasized the utility of satellite imagery for mapping the geological structures. The synoptic coverage provided by the satellite imagery enable mapping regional structures which is difficult in conventional

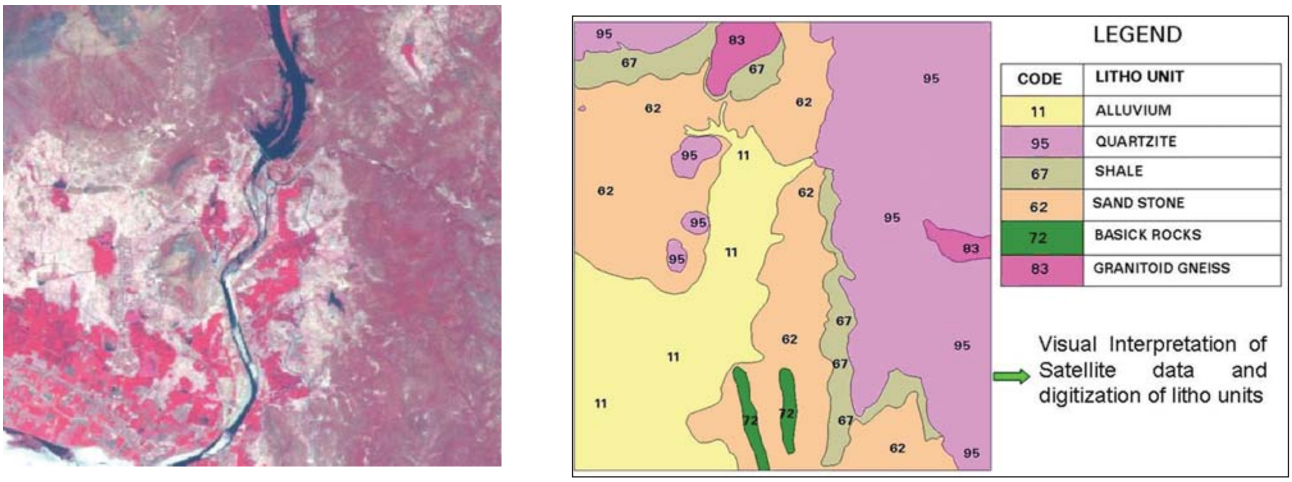

Figure 8.2: (a) Satellite imagery of the study area and (b) Preparation of lithological map

ground surveys due to scanty rock exposures, soil cover, lack of continuous observations, etc. The different types of primary and secondary geological structures (attitude of beds, schistosity / foliation, folds, lineaments etc.) can be interpreted from satellite imagery by studying the landforms, slope asymmetry, outcrop pattern, drainage pattern, individual stream / river courses, etc.

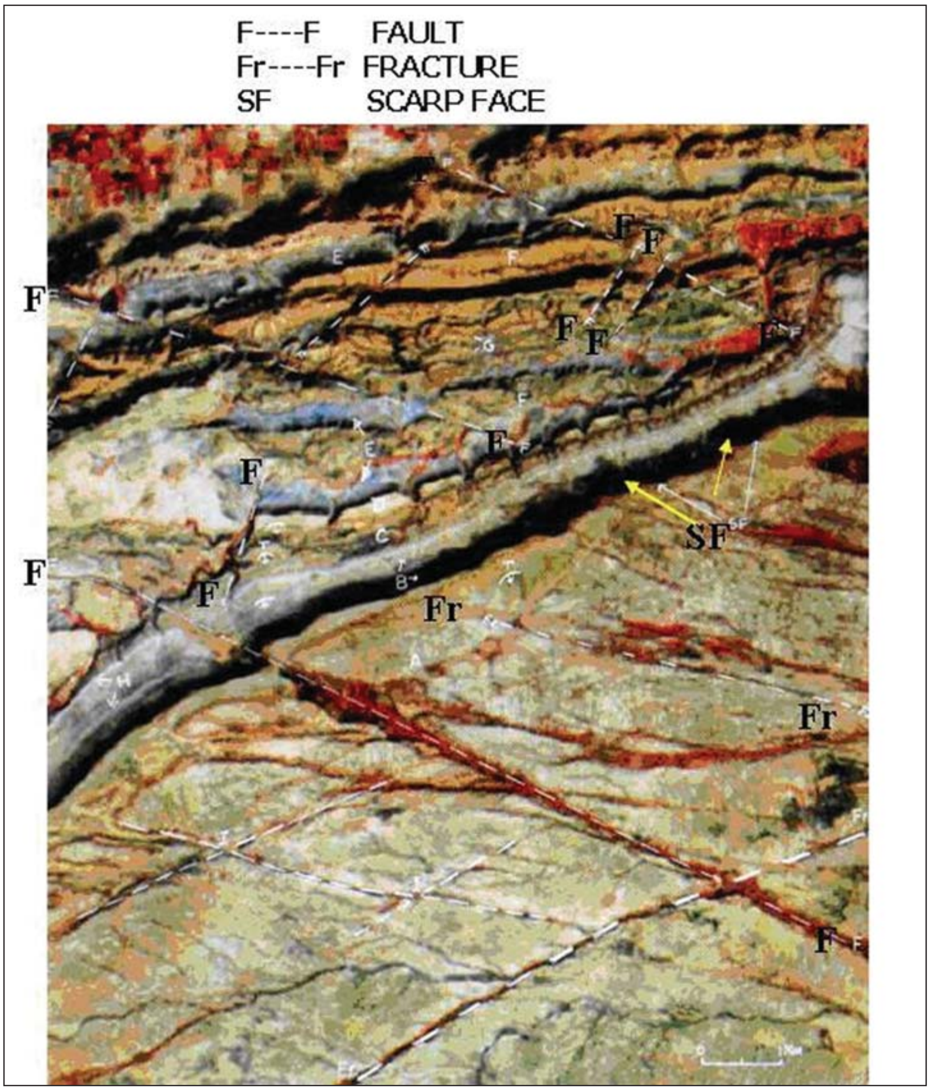

Figure 8.3: Interpretation of structural features from satellite imagery

Lineaments representing the faults, fractures, shear zones, etc., are the most obvious structural features interpretable on the satellite imagery (Figure 8.3). They control the occurrence and movement of groundwater in hard rock terrain and their significance in groundwater exploration has been proved beyond doubt. They occur in parallel sets in different directions indicating different tectonic events. They appear as linear to curvilinear lines on the satellite imagery and are often marked by the presence of moisture, alignment of vegetation, straight stream / river courses, alignment of tanks / ponds, etc. These lineaments can be further subdivided into faults, fractures and shear based on their image characters and geological evidences.

The attitude of beds (strike and dip) can be estimated broadly by studying the slope asymmetry, landform, drainage characteristics, etc. For example, horizontal to sub-horizontal beds show mesa / butte type of landform, dendritic drainage pattern and tonal / colour banding parallel to the contour lines. Inclined beds show triangular dip facets, cuestas, homoclines and hogbacks. The schistosity / foliation of the rocks are depicted on the satellite imagery by numerous thin, wavy and discontinuous lines. Folds can be identified on the satellite imagery by mapping the marker horizons. Further classification into anticline or syncline can be made on the basis of dip direction of beds.

For preparation of structural overlay, information from the following sources is required:

- Existing geological / hydrogeological maps and literature
- Interpretation of satellite imagery
- Field visits / surveys

8.4.3. Geomorphology

The synoptic view of satellite imagery facilitates better appreciation of geomorphology and helps in mapping of different landforms and their assemblage. The photo-interpretation criteria, such as tone, texture, shape, size,

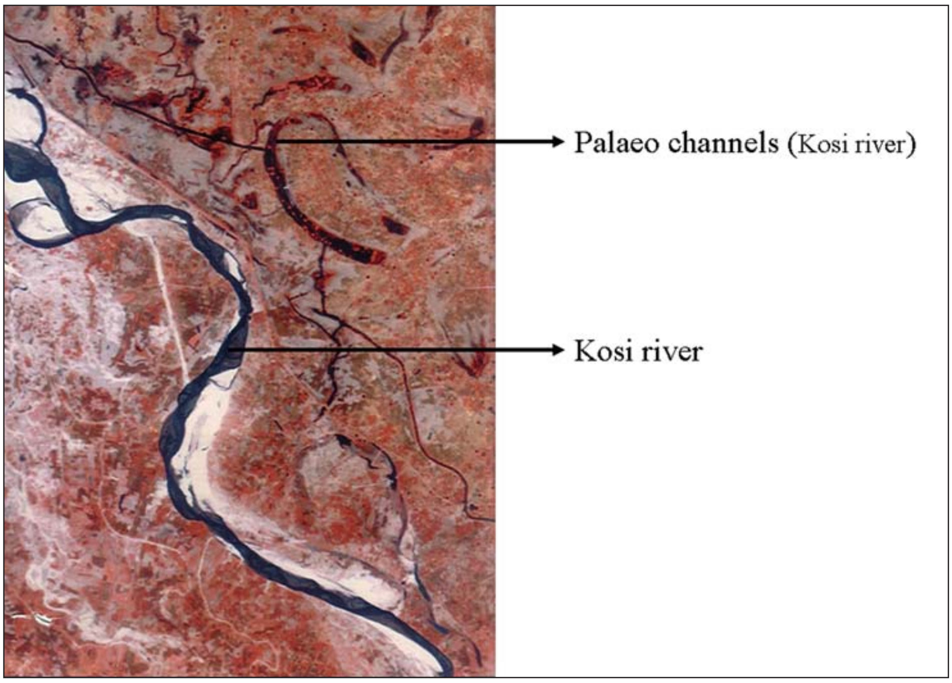

Figure 8.4: Interpretation of Lithology from satellite imagery

location, association, physiography, genesis of the landforms, nature of rocks / sediments, associated geological structures, etc., are to be used for identification of different landforms / geomorphic units (Figure 8.4). Initially, the entire image has to be classified into 3 major zones, i.e. Hills & Plateaus, Piedmont Zones, and Plains considering the physiography and relief as the criteria. Then, within each zone, different geomorphic units have to be mapped based on the landform characteristics, their aerial extent, depth of weathering, thickness of deposition etc., as discussed earlier. Subsequently, within the alluvial, deltaic, coastal, eolian and flood plains, individual landforms have to be mapped and represented on the map using the standard alphabetic codes.

These geomorphic units / landforms interpreted from the satellite imagery have to be verified on the ground during the field visit to collect the information on the depth of weathering, nature of weathered material, thickness of deposition and nature of deposited material, etc. For this purpose, nala / stream cuttings, existing wells, lithologs of the wells drilled have to be examined. By incorporating these details in the pre-field interpretation map, the final geomorphic map overlay has to be prepared.

For preparation of geomorphic map overlay, information from the following sources is required:

- Lithological map overlays
- Interpretation of satellite imagery
- Field visits / surveys

If previous maps / literature are available, the job becomes easier; even otherwise also, a good geomorphological map showing assemblage of different landforms can be prepared based on the above sources of information (Figure 8.5). The satellite image along with the interpreted lithological map overlay should be kept on the light table. A fresh transparent overlay should be kept on the top and each rock type should be classified into different geomorphic units / landforms as per the

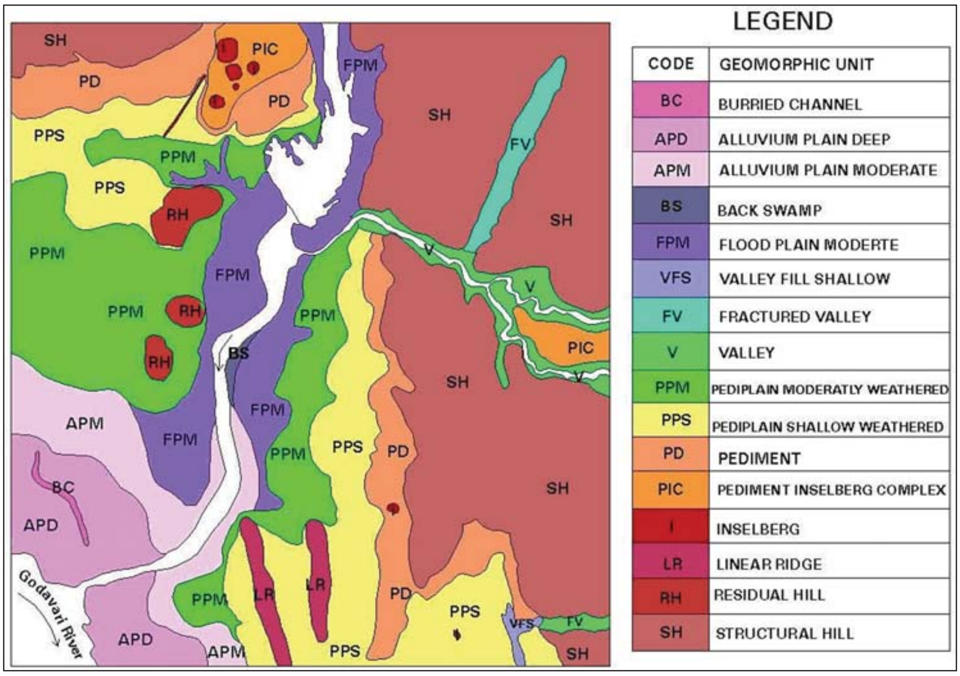

Figure 8.5: Preparation of Geomorphological map from satellite imagery

classification system suggested. Sometimes one lithologic unit may be classified into 2 or more geomorphic units / landforms and vice versa. This is to note that wherever the lithologic/ geomorphic boundaries are common, they should be made co-terminus. All the geomorphic units / landforms should be labeled with alphabetic annotation as RH, PPS, VFD, etc.

8.4.4. Hydrological Mapping

Satellite imagery provide excellent information on hydrologic aspects like stream/river courses, canals, major reservoirs, lakes, tanks, springs / seepages, canal commands, groundwater irrigated areas, etc. Based on visual interpretation of satellite data, all the above information can be derived and mapped.

The hydrologic information, derived from satellite imagery in conjunction with collateral data has to be shown on a separate map overlay in a classified manner with appropriate symbols. Further, the observation wells of State and Central Groundwater Departments and the wells inventoried during field visit have to be marked on this map overlay in a classified manner with appropriate symbols.

For preparation of hydrological map overlay, the following sources of information are required -

- Interpretation of satellite imagery
- Field visits / surveys
- Observation well data and
- Meteorological data

The following details are shown in the hydrological map overlay (Figure 8.6) -

- Canal / tank commands
- Groundwater irrigated areas
- Well observation data collected in the field and Govt. Depts
- Rain gauge stations indicating average annual rainfall. In case of absence of rain gauge station in a Toposheet, average annual rainfall in mm shall be given in the legend. Source of rainfall data shall be either IMD or District Gazetteer.

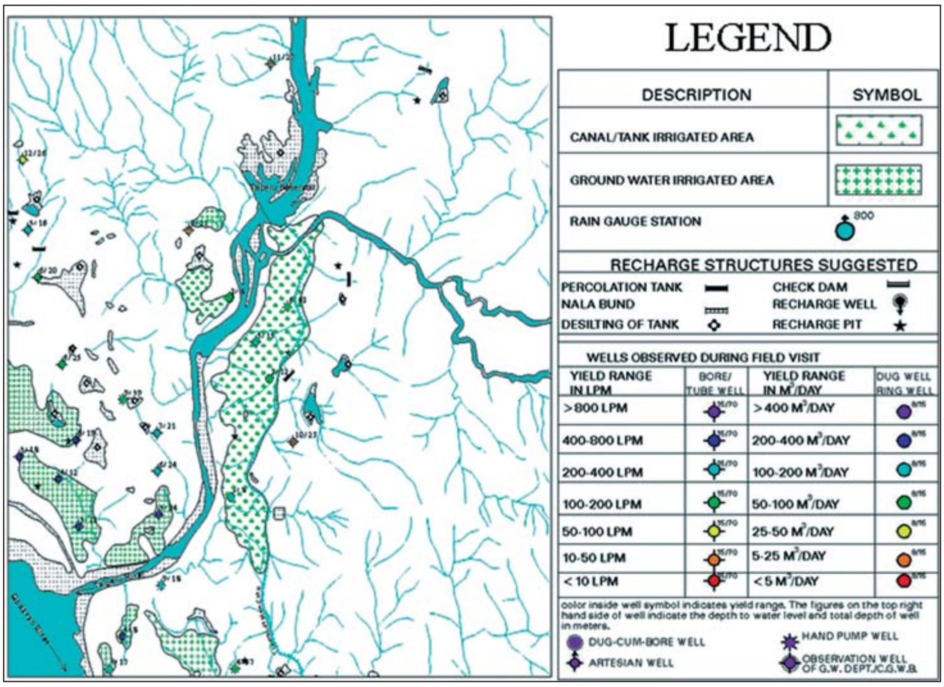

Figure 8.6: Preparation of Hydrological map from satellite imagery

8.4.5. Groundwater Prospects

For preparing the groundwater prospects map first integrate manually the lithological, structural, geomorphological and hydrological map overlays in the following manner:

Integrate lithologic-geomorphic units by superimposing the lithological and geomorphological map overlays. These integrated lithologic-geomorphic units are the 'hydrogeomorphic units' and have to be annotated with alphanumeric codes, e.g. PPS-71, PPD-81, UPM-32, etc. wherein the alphabetic code represents the geomorphic unit and the numeric code represents the lithologic unit. Transfer the geological structures from the structural map overlay on to the integrated lithologic-landform map. The geological structures, which act as conduits and barriers for groundwater movement, should be drawn.

Transfer the hydrological information including all the drainages and water bodies from the hydrological map overlay on to the integrated lithologic-landform -structure map. In addition to above, some of the rivers/streams, major water bodies and metalled roads (including NH & SH) have also to be transferred on the integrated map for control. To avoid the confusion in identification of features, rivers/stream/water bodies have to be drawn in cyan colour and roads in brown colour.

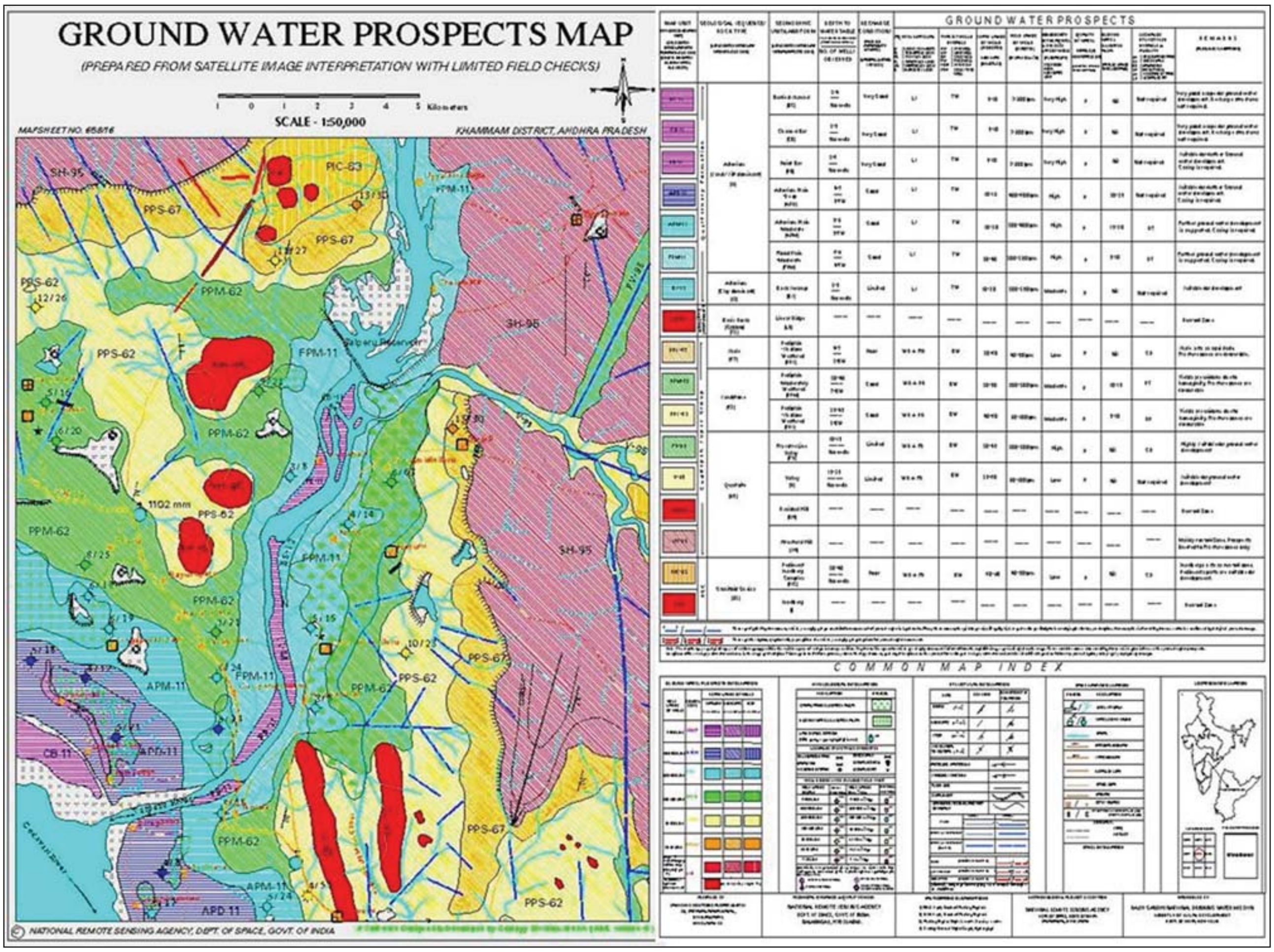

Figure 8.7: Preparation of Groundwater prospects map

All the hydrogeomorphic units occurring in the area have to be listed in the legend following the geological sequence. Then, the groundwater prospects of each hydrogeomorphic unit have to be evaluated by considering the lithological, structural, geomorphological and hydrological information (Figure 8.7). The details of the columns are mentioned in Figure 8.8.

Map Unit	Column- 1	Geological sequence/rock type
	Column- 2	Geomorphic unit/Landform
	Column- 3	Depth of water table/No. of wells observed
	Column- 4	Recharge conditions (rainfall &other sources)
	Column- 5	Nature of aquifer material
	Column- 6	Type of wells suitable
	Column- 7	Depth range of wells (suggested)
	Column- 8	Yield range of wells (expected)
	Column- 9	Aquifer homogeneity & success rate of wells
	Column-10	Quality of water (potable/non-potable)
	Column-11	Ground water irrig. Area (exploration status)
	Column-12	Recharge structures suitability & priority
	Column-13	Remarks (problems/limitations)

Figure 8.8: Details of the columns as listed in Figure 8.7

8.4.6. Groundwater Quality Mapping

There are many dissolved minerals and organic constituents present in groundwater in various concentrations. Among them the most common dissolved mineral substances are sodium,calcium, magnesium, potassium, chloride, bicarbonate, and sulphate. In water chemistry, these substances are called common constituents. They are not harmful if they are within permissible limits. Few elements are highly toxic and hazardous to health of both human and animals. Groundwater is less susceptible to bacterial pollution than surface water because the soil and rocks through which groundwater flows screen out most of the bacteria. Bacteria, however, occasionally find their way into groundwater, sometimes in dangerous concentrations. But the bacterial pollution is not considered for the present study.

Water typically is not considered desirable for drinking if the quantity of dissolved minerals exceeds 500 mg/l (milligrams per liter). Water with > 500 mg/l of dissolved minerals is classed as slightly saline, but it is sometimes used in areas where less-mineralized water is not available. Water from some wells and springs contains very large concentrations of dissolved minerals and cannot be consumed by humans and other animals or plants. Many parts of the nation are underlain at depth by highly saline groundwater that has only very limited uses. Water that contains a lot of calcium and magnesium is said to be hard. The hardness of water is expressed in terms of the amount of calcium carbonate-the principal constituent of limestone or equivalent minerals that would be formed if the water is evaporated. Groundwater, especially if it is acidic, in many places contains excessive amounts of Iron. Iron causes reddish stains on plumbing fixtures and clothing. Like hardness, excessive iron content can be reduced by treatment. A test of the acidity of water is pH, which is a measure of the hydrogen-ion concentration. The pH scale ranges from 0 to 14. A pH of 7 indicates neutral water; greater than 7, the water is basic; less than 7, it is acidic.

The important toxic elements like fluoride and arsenic are creating more hazardous in many parts of the country. Fluoride is a major, naturally occurring contaminant in drinking water in many regions. At low levels, say 1 mg/l, it is found to be beneficial and high levels can cause structural tooth damage and at a high enough level can cause skeletal damage. The arsenic contamination invariably arises from natural geological and environmental conditions. Arsenic arises in many ores and minerals and is frequently present in combination with iron and manganese oxides; under various natural conditions it can be rendered soluble and released into the groundwater. The problem is especially acute in the Ganges delta region, where the arsenic is believed to be associated with the iron and manganese oxides in the alluvial sediments.

8.5. Groundwater Recharge Estimation

Since the groundwater is a replenishable resource, the quantity of water recharged every year from rainfall and other sources to a particular aquifer/basin/area is an important element in planning various developmental activities. The groundwater recharge estimation in the country is carried out using one of the following methods as recommended by Groundwater Resource Estimation Committee (GEC,1997) constituted by the Government of India.

8.5.1. Water Level Fluctuation Method

In this method, the gross groundwater recharge is worked out by multiplying the aquifer thickness (T) with specific yield (S) of the formation and the area (A) occupied by the unit. The thickness of aquifer (T) is determined based on water table fluctuations recorded from the observation wells. The specific yield (S) of each aquifer/formation is calculated by conducting pump tests. The Groundwater Estimation Committee (GEC, 1997) has suggested certain (S) values for different rock formations but recommended to use the actual (S) values calculated from the pumping tests in the concerned areas. In hard rock areas, variations in specific yield values are so common within the same rock formation, which lead to either over-estimation or under-estimation of the resource. The studies carried out at NRSC have proved that the satellite imagery by way of providing additional information on landforms, weathering and fracturing of the rocks which account for variations in specific yield values within the same rock formation, could help in more realistic estimation of the recharge. The individual rock formation could be sub-divided into more homogeneous hydrogeomorphic units taking into account the lithology, landform, fracturing and weathering characteristics derived from satellite data which further minimizes the error of averaging the aquifer parameters over large areas leading to more realistic and accurate estimation of the groundwater recharge.

Even for estimation of rechargeable area (A), satellite data provide the information on certain landforms like different types of hills, inselbergs, pediments, pediment-inselberg complexes and other rocky areas which are note favourable for groundwater recharge. Thus, it leads to more precise estimation of groundwater resource.

8.5.2. Rainfall Infiltration Method

The method involves the estimation of groundwater recharge by taking certain percentage of the rainfall as infiltration to groundwater depending upon the type of rock formation. By multiplying the average annual rainfall with the rainfall infiltration factor (RF) and the rechargeable area (A), the gross groundwater resource is estimated. The GEC (1997) has recommended different rainfall infiltration factors for different rock types. But in reality, the rainfall infiltration values are not constant for a given rock type and vary significantly with the variation in geomorphology, fracturing, weathering, type of soil, land use/land cover, etc., within the same rock type. Thus, the satellite data provide information on all the above mentioned factors which help in determining the rainfall infiltration values more accurately leading thereby to improved estimation of groundwater resource.

Further, like in the previous method, here also the satellite imagery enables identifying the landforms unfavourable for groundwater recharge. Satellite images also help driving precise estimation of the spatial extent of surface water bodies in different zones during different seasons which helps in the precise estimation of seepage to groundwater. Another important input that could be derived from satellite imagery is the spatial extent of irrigated croplands based on which the return flow of water from the irrigated fields could be worked out more precisely.

8.5.3. Groundwater Draft Estimation

Groundwater draft refers to the quantity of water that is being withdrawn from the aquifer. It is a key input in estimating groundwater balance available in a given area/basin which in turn governs all its developmental activities. Over-estimation of groundwater balance has resulted in a significant loss to the industrial and agricultural activities in many parts of the country and the under-estimation has restricted the planning of developmental activities in some parts. Hence, precise estimation of groundwater draft assumes greater significance.

Conventionally, the groundwater draft is estimated by unit draft method using mainly well census data. The number of wells of different types available in the area are multiplied with the unit draft fixed for each type of well to estimate the groundwater draft. But, upto-date well census and average withdrawal for each type of well are not precisely known. In some parts of the country, the groundwater draft is estimated based on the electricity consumed by the agricultural pump sets multiplied with the quantity of water discharged per unit power approximately gives the quantity of groundwater withdrawn. However, the power consumed by pump sets is not always proportional to the groundwater withdrawal and it depends mainly on the depth of the water table and efficiently of the pump sets. Further, misuse of power for other agricultural purposes and the groundwater draft from non-energized wells is also not taken into account in this method. Thus, by and large, the scientific community involved in groundwater budgeting in the country has been looking for a more realistic and appropriate method for groundwater draft estimation.

Satellite data provide reliable information of the extent of groundwater irrigated crops and their spatial distribution which helps in estimating the groundwater draft. Due to the presence of chlorophyll, the irrigated crops have maximum absorption in 0.63-0.69 micrometer region and high reflection in the infrared (0.77 to 0.86 micrometer) region of the electromagnetic (EM) spectrum. Because of characteristic absorption and reflection in different spectral bands, irrigated areas can be easily mapped by digital analysis of satellite data. From the total irrigated area, the area irrigated by major and minor irrigation sources can be excluded based on the association of such areas with surface water bodies and canal systems. Using multi-temporal satellite data and crop calendar supported by limited ground truth, the spatial extent of different crops irrigated by groundwater could be mapped. By multiplying the acreage of different crop types obtained from satellite data with the crop water requirement with respect to crop, the groundwater draft could be estimated more accurately.

This approach has been successfully demonstrated by NRSC, through an R&D study in Moinabad mandal of Ranga Reddy district, Andhra Pradesh. In this study, 100% well inventory was conducted for entire mandal in terms of total number of wells of different type, number of hours of pumping for each well and the number of days of pumping, acreage and crops cultivated, etc., under each well during the same period. Spatial distribution of groundwater irrigated areas within the mandal was derived from satellite data. The potential of remote sensing data for groundwater draft estimation and identification of over-exploited zones has been presented to the Groundwater Resources Estimation Committee (CGWB, 1991). Based on the suggestion made by GEC (1996), a pilot study was taken up in Rolla mandal of Ananthapur district A.P. in collaboration with the State Groundwater Department, Govt. of A. P. and the potential of remote sensing for groundwater draft estimation has been established.

8.5.4. Groundwater Balance and Stage of Development

The concept of groundwater balance was introduced by the World Bank for clearance of minor irrigation schemes under ARDC phase-III programme. The groundwater balance refers to the net groundwater resource available for development in a given basin/area which is estimated by subtracting the net groundwater draft from the new recoverable recharge. Based on the balance, the stage of development is assessed and the areas are categorized into white, gray and dark zones. Thus, the groundwater balance and the stage of development are the two important factors governing the development of groundwater in a given area.

The inputs for realitistic estimation of groundwater resource and the draft derived from satellite data, as mentioned earlier, enable estimation of its balance more accurately which ultimately helps in the assessment of the stage of development. The demonstrative studies carried out at NRSC have shown that some of the areas which were categorized earlier as white through conventional approach have been re-categorized into gray or dark areas when refinements were made in the recharge and draft estimation based on inputs derived from satellite data. In many cases in the conventional approach it has been observed that the recharge is over estimated and draft is under estimated. Use of satellite image –derived inputs can rectify such anomalies and help in proper categorization of the areas in terms of development.

8.5.5. Identification and Mapping of Over-exploited Areas

In many parts of the country, the groundwater levels have started declining and in some cases even the existing wells have dried up due to lowering of water table. Rough estimates made so far put the loss due to drying up of old wells so far in the country at around Rupees 1000 crores. Studies conducted at NRSA have proved that satellite data by providing the information on distribution of groundwater irrigated areas, helps in mapping of groundwater over-exploited zones. On satellite image, the over exploited zones appear as large clusters of groundwater irrigated crops in different shades of red colour. Multitemporal satellite images are useful in continuous monitoring of groundwater utilisation in gray and dark areas.

8.6. Systematic Planning and Development

Systematic planning and development involves a scientific rationale for planning and development of groundwater. As mentioned earlier, using inputs derived from remote sensing data, it is possible to know more precisely where and how much of groundwater is available, how much of it is already utilized along with its spatial distribution, the net balance available for planning and prioritization of the areas based on the prospects, the demand and above all the rational development. Thus, the satellite data facilitate in the systematic planning and development of groundwater resource.

Augmentation of the Resource:

The demand for groundwater in our country is more than the resource available. Wherever the demand is higher than its availability augmentation of the resource by way constructing the percolation tanks, check dams and other water harvesting structures is required. The watershed management programme also helps improving the groundwater recharge resulting thereby in its augmentation.

Though the augmentation of the resource is possible everywhere, except in a few hydrogeologically unfavourable zones, covering entire country at a time during a given period with the available resources may not be feasible. Hence, the prioritization of zones is essential. In this endeavor too, the satellite data is useful in selection of areas based on the purpose for which water is required and the suitability of the site conditions. The problem villages having shortage of drinking water get first priority followed by and over exploited zones where crops are suffering from water or industrial production is affected due to shortage of water. Besides, satellite data help in the selection of suitable sites for construction of water harvesting structures. In our country, the IRS-1A/1B LISS-II data have been operationally used for identifying sites for construction of water harvesting structures apart from other soil and water conservation measures under a major nation wide project titled “Integrated Mission for Sustainable Development (IMSD) “covering 84 million ha and spread over in 175 districts.

Identification of Problem Areas for Conservation of Resource:

In spite of employing all the resource augmentation measures, in some parts, there may be a large gap between the demand and the resource that can be realized. Satellite data help in identifying and mapping of such hydrogeologically unfavourable zones/problem areas where conservation of the resource need to be taken up on a priority. Besides, satellite data are useful in suggesting the necessary changes in land use, cropping pattern and irrigation practices, etc., for conservation of the resource.

Conjunctive Use of Surface and Groundwater:

By providing information on surface and groundwater, the satellite data help in planning conjunctive use of surface and groundwater. Satellite data, as pointed out earlier, enable mapping of surface water bodies like minor, medium and major irrigation tanks/reservoirs; prospective groundwater zones, and canal and groundwater irrigated areas; and planning of new reservoirs/tanks. By suing such information, conjunctive use and management of surface and groundwater resources can be planned and implemented.

Optimum utilization and Management of Groundwater:

In the areas where resource potential is less than the demand and there is no scope for its augmentation optimal use of water for most beneficial purpose is the only solution. To avoid indiscriminate use of the scarce resource in such critical zones, certain regulations/ restrictions are essential. In this context, high spatial resolution IRS-1C LISS-III data have been found useful in demarcation of critical zones where groundwater resource is limited/scarce requiring regulated use, identification of alternative surface and groundwater sources around the problem areas and potential and prospective zones for establishing groundwater sanctuaries, and continuous monitoring to detect the unauthorized/indiscriminate use of groundwater for irrigation in the prohibited and restricted zones.

Monitoring Groundwater Development and Utilization:

The development of groundwater resource and its utilization is a dynamic phenomenon which requires frequent monitoring. Multi-temporal satellite images help in periodic monitoring of groundwater development which in turn helps in controlling the overexploitation and indiscriminate use of groundwater in some pockets leading thereby to scarcity of water for drinking and other essential uses. Proper monitoring of groundwater for projecting the drinking water sources assumes greater significance for a semi-arid country like India with competing demands for water. Due to continuous pumping of water for irrigation, the drinking water sources may get dried up. Some of the state Governments have already brought legislation to protect the drinking water sources. In this endeavor too, satellite data form a very valuable tool in monitoring the groundwater utilization for irrigation closer to the drinking water sources and also in the over-exploited zones.

8.7. Conclusions and Future Perspective

Satellite data provide information on rock types, landforms, geological structures, namely faults, folds, fractures, dykes, weathering, soil types, erosion, land use/land cover and surface water bodies (lakes, tanks, and reservoirs), distribution of groundwater irrigated areas and their acreage. Such information when integrated in a Geographic Information System (GIS) environment enable groundwater recharge estimation, draft estimation, calculating the balance, categorization of areas into highly developed, under developed and undeveloped, identification and mapping of prospective groundwater zones, systematic planning and development of groundwater, identification of over-exploited zones, prioritization of areas for resource augmentation, conservation and optimal use of water, conjunctive use of surface and groundwater, and continuous monitoring of groundwater development and its utilization. Polarimetric SAR, radar interferometry, Ground Penetrating Radar (GPR) and nuclear magnetic resonance techniques along with the stereoscopic measurements in the optical region may help further refinement in the level of information generated on groundwater using remote sensing data. The development of Groundwater Information System based on information derived from in situ, and air and space borne observation help in judicious planning, effective management and sustainable development of groundwater resource in the country.

Lot of progress is being made in groundwater prospects mapping, however full potential of total groundwater balance and its quality is yet to be realized. National Remote Sensing Centre (NRSC) has started work on preparation of groundwater quality layer in collaboration with states remote sensing centres under RGNDWM project. Detailed hydrogeological units have been extracted from remote sensing data from interpolating point locations (wells) of groundwater samples to prepare groundwater quality layer.

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