CHAPTER 2
LITERATURE REVIEW

2.1 Aquifer systems

Water resources of earth can be classified as surface water and ground water in which groundwater is the main source for the domestic, agricultural and industrial needs. Groundwater is an important part of the hydrologic cycle. Various components of a hydrological cycle are shown in Fig. 2.1

Fig. 2.1: The hydrological cycle (Source: From website water.com)

Precipitation, Infiltration, Evapotranspiration (Evaporation + Transpiration), Surface Runoff and Groundwater flow are the major components of a hydrological cycle (Todd and Mays, 2005; Viessman and Lewis, 2007). Once water from precipitation enters into the subsurface by infiltration it percolates down through different layers of soil material
or water bearing formation (also called as aquifers) to reach the rock material that is saturated with water. Water under the earth is stored in the void spaces between these rock particles in different layers. These voids or interstices act as conduits for water transmission and also as reservoirs to store water and are governed by the geological processes that decides the porosity of the rock material. Water under the earth can be broadly divided into two layers or zones, zone of aeration and saturation (Fig 2.2). The layer just below the surface is called zone of aeration or vadose zone or unsaturated zone where gaps (interstices) between soil particles are filled with both air and water. Below this layer is the zone of saturation, a huge storehouse of water where all the voids are filled with water. The boundary between these two layers is defined as water table or phreatic surface and marks upper surface of the zone of saturation.

Fig. 2.2: Divisions of subsurface water (Source: “Ground Water Resources in Time of Drought” October issue ROCKTALK, Colorado Geological Survey)

A belt of soil moisture exits within the zone of aeration from which plants draw their moisture (Leet and Judson, 1959; Todd and Mays, 2005). Water in this area is held by molecular attraction and water present in this soil-water zone depends predominantly on recent precipitation. During the periods of ground-water recharge water gets added to this zone in excess of the amount that can be held by molecular attraction, and the excess percolates downward to the water table through voids of the vadose zone. An
intermediate belt of vadose water (zone) lies between the soil moisture layer and the capillary fringe (Fig. 2.2). Water in this zone moves downward through the interstices of the rock material during groundwater replenishment to add to the water table. Thickness of this vadose zone may vary from a few centimeters (or even zero) to hundreds to metres depending upon the topography, geology and climate etc. In between the intermediate belt and the water table lies the capillary fringe (zone) in which water is held up from the zone of saturation by capillary force. The capillary fringe may be very thin (or even absent) in coarse grained materials, but it may be several metres thick in fine-grained materials (Todd and Mays, 2005). Water table is pseudo surface below which the pore spaces in soil are saturated with water. This is known as zone of saturation.

![Fig. 2.3: A cross-sectional view of unconfined and confined aquifer](Source: From website geocities)

Water entering the groundwater reservoirs either by natural recharge or by artificial means flows out due to gravity or when extracted by wells etc. These aquifers may be defined as unconfined or confined. In an unconfined aquifer water table varies depending upon the recharge and discharge (natural or by pumping) processes. Wells tapping the water from unconfined aquifers can be used to measure groundwater levels (depth to water table) and its variation with time and space. Such an aquifer is shown in Fig. 2.3. These are also sometimes called as water table or phreatic aquifers. Typically an
unconfined aquifer does not have any confining layer (of impermeable material) between it and the surface. On the other hand in a confined aquifer groundwater is confined by impermeable strata and is under pressure greater the atmospheric pressure. If a well is used to tap water from a confined aquifer, the water level rises above the confining bed (upto piezometric surface) and even flows out as shown by artesian well and a flowing well respectively (Fig. 2.3). Piezometric surface is an imaginary level that coincides with hydrostatic pressure of water in the confined aquifer. Water enters into confined aquifer from the area where the impermeable layer i.e. confining bed rises to the surface level as shown by recharge area in Fig. 2.3. Completely confined or unconfined aquifer rarely occurs (Todd and Mays, 2005). Semiconfined or leaky aquifers are very common where permeable layer is lies either above or below a semipervious aquitard or semiconfining layer.

2.2 Groundwater: Its exploitation and sustainability

Groundwater is an important part of the hydrologic cycle as it sustains life. Because of its several inherent qualities (e.g. consistent temperature, widespread and continuous availability, excellent natural quality, limited vulnerability, low development cost, drought reliability, etc.), it has become an immensely important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries (Todd and Mays, 2005). The principal source of groundwater recharge is the precipitation. Reservoirs, lakes, stream flows, return flow from irrigated fields and seepage from canals also contributes to groundwater recharge. Special water harvesting structures are installed to augment natural recharge in the region. Natural discharge occurs mostly as flow to the surface from springs and flow to surface water bodies such as streams, lakes and oceans. Groundwater present near the surface as soil moisture may also returns to surface by the process of evapotranspiration. However the major discharge of groundwater by artificial means is through pumping from wells to cater water requirement for domestic, agricultural and industrial usage.

Increased demand for water has stimulated development of groundwater supply. It has emerged as one of the principal source of water for irrigation over the past two
decades. Advent and rapid spread of highly energized pumping technologies has made it potentially accessible to far larger number of farmers (Moench, 1992; Scott and Shah, 2004). More than half of the world's population is dependent on groundwater for its survival. It is threatened by over-exploitation as its development has taken place without proper understanding of its occurrence in time and space (CGWB, 2005). Overexploitation of groundwater has been reported in many parts of the world. Water shortage is a serious problem today in 80 countries and 40% of the world population is suffering from water shortages. The water level of the main aquifer in Yemen has been receding. Las Vegas, Beijing, Bangkok and Manila are all suffering from severe water shortages because of the overexploitation of groundwater at different rates (World Water Day, 1998). In India as per the groundwater resource estimates of 2009, out of the 5842 assessed units (Blocks, Mandals, Talukas), 802 are over-exploited, 169 are critical and 523 are categorized as semi-critical units across the country by Central Groundwater Board (CGWB, 2011). Excessive extraction has resulted in gradual thinning of the fresh water zone and formation of regional depressions of potentiometric levels have been reported (Singh and Yadav, 1996; Biswas, 2003). In several parts of India (north Gujrat, southern Rajasthan, Saurashtra, Coimbatore and Madurai districts of Tamil Nadu, Kolar district of Karnataka, Rayalseema region of Andhra Pradesh and parts of Punjab, Haryana and Uttar Pradesh) declining water levels are in the order of 1-2 m/year (Singh and Singh, 2002). The levels may take months or years to get replenished once pumped for any use and is a matter of serious concern (Custodio, 2002).

2.3 Groundwater quality and its suitability

Quality of groundwater is equally important as its quantity and depends on its use i.e. domestic, agriculture or industrial usage. The quality of groundwater depends mainly on the chemical composition of groundwater which is related to the soluble products of rock weathering and decomposition with respect to time and space. Regions with high recharge volumes certainly affect the groundwater quality. Quality is defined by certain physical, chemical and biological characteristics. It is determined by the solutes and gases
dissolved in the water as well as the matter suspended in and floating on the water (Todd and Mays, 2005).

Investigations have reported that groundwater is highly susceptible to pollution from natural and anthropogenic factors (Appelo and Postma, 1996; Jain and Sharma, 2000). In India, overexploitation of groundwater and indiscriminate use of pesticides and chemicals in agriculture, percolating to ground in many parts of the country has resulted in deterioration of groundwater quality. Moreover untreated return from industrial and domestic sectors in the form of effluents and domestic sewage respectively have also polluted the groundwater (Palaniswami and Ramulu 1994; Mukherjee and Nelliyat, 2007). Therefore assessment of groundwater quality is necessary to determine its suitability for different uses. A review of the few studies is given below.

A study on groundwater evaluation of Ralegaon Sidhi watershed revealed that groundwater was slightly saline for irrigation usage (Durbude and Varadrajan, 2007). A comparative study conducted in Muktsar and Patiala (districts of Panjab) on suitability evaluation of groundwater for domestic and irrigation use revealed that groundwater quality of Patiala was better but it may deteriorate in future due the exiting irrigation practices( Kumar et al., 2007). Chemical analysis of water samples collected from Hisar City in Haryana revealed that concentrations of magnesium, sodium, sulphate and chloride were moderately higher than WHO recommendations for drinking water (Ravindra and Garg, 2007). The groundwater was found to vary between hard and very hard but under permissible limits of drinking in Sirsa city of Haryana (Mor et al., 2009). A study revealed that several villages in Chandrapur, Wardha and Yavatmal districts of Maharashtra have severe problems of fluoride contamination in groundwater. This will have far reaching impact on human health condition (Sinha et al., 2004). Suitability analysis was carried out by Goyal et al., 2010 in Kaithal district of Haryana. The study concluded that the local residents prefer the use of canal water over groundwater for domestic use as groundwater is found to be hard, alkiine and saline in the major portion of the district. Groundwater was found to be suitable for irrigation in 67% of the area, however high values of EC, SAR, SP and RSC values were obtained in the remaining part of the area. The main reason observed was the heavy application of fertilizers and their subsequent leaching to water table. Groundwater quality analysis for domestic and
irrigation use in district Yamuna Nagar revealed that groundwater was hard in general for domestic use but within the safe limits of drinking. Values obtained for EC, SAR, PS and RSC indicate that quality of groundwater was within the desirable limits to be used for irrigation. Groundwater recharge by monsoon was attributed to the improvement in the quality parameters in the post-monsoon period (Sethi et al., 2012).

### 2.4 Assessment of groundwater resources

For any water resource development and management program the analysis of water availability and demand in the area is the key issue (Kumar et al., 2002; Sinha et al., 2004). The assessment of water resources in India dates back to 1901 when first Irrigation Commission assessed the surface water resources of India as 144 million hectare metres (CGWB, 1995). The first systematic methodology to estimate the groundwater resource of India was developed by Groundwater Over-exploitation Committee in 1979. The committee suggested water level fluctuation method for the estimation of groundwater resource of an area. Based on the norms suggested by this committee, India’s gross groundwater recharge was assessed as 47 million hectare metre (CGWB, 1979). The methodology suggested had certain drawbacks like the non-inclusion of return recharge from irrigated fields while estimating the groundwater resource and computation of the stage of groundwater development. The methodology was then redefined by Groundwater Estimation Committee formed by government of India in 1982. The committee in association with central groundwater board (CGWB) submitted its recommendation in 1984, commonly known as GEC-84. The new methodology suggested that the estimation of rainfall recharge should be based on two approaches – rainfall infiltration factor (RIF) and water level fluctuation (WLF or WTF) method and the return flow from irrigated fields should be included in the total recharge. Further, the stage of groundwater development of an assessment unit was suggested to be determined solely in terms of its utilization in irrigation sector (CGWB, 1984). The total replenishable groundwater resource of India was estimated about 432 billion cubic metre. The methodology was again revised in 1997 incorporating the estimation of groundwater recharge from rainfall, seepage from canals, ponds, tanks and water conservation
structures and return flow from irrigated fields. Present status of groundwater development is now computed on the basis of the gross draft for irrigation, domestic and industrial sectors. Also long term trend of water level became one of the criteria for categorization of assessment units apart from the stage of groundwater development along with the level of groundwater utilization (CGWB, 1997). Based on the norms of this committee, dynamic groundwater resource of India was estimated as 433 bcm as on March 2011 (CGWB, 2014).

Writings of Vedas indicate the use of groundwater for irrigation since long back in 300B.C. (Raghunath, 2007). The importance of the groundwater resource in India can be realized by the fact that about 50% of the total irrigated area is dependent upon groundwater and about 60% of irrigated food production depends on irrigation from groundwater (Shah et al., 2000). The exponential increase in the number of tubewells during last four decades has resulted in overdraft of groundwater (Singh and Yadav, 1996). Groundwater resources in India are showing increasing indications of over development (Scott and Shah, 2004). Various investigations performed in India are reviewed below.

Dasgupta and Sikdar (1992) estimated groundwater resources in the upper catchment of the Sali River basin, Bankura district, West Bengal and found that stage of groundwater development varied between 13 to 17 percent and there was enough scope of groundwater extraction without disturbing the groundwater balance of the region.

Pawar et al., (1997) did assessment of groundwater resources of two blocks, Falakata and Madrihat, of Jalpaiguri district, West Bengal to assess groundwater potential using water balance equation. From the study it was revealed that the both the blocks had plentiful unutilized groundwater resources as the available groundwater extracting structures were being underutilized.

Sikdar and Bhattacharya (2000) worked on assessment and management of groundwater resources in Puruliya district of West Bengal. On the basis of groundwater assessment and long term trend analysis phased construction of water harvesting structure in the study area was suggested to combat expected fall in groundwater table in he coing ears and to manage the groundwater resources on a sustainable basis.
Gaur (2001) did the groundwater budgeting of a small watershed of Amba Bai village of Jhansi district in Uttar Pradesh by applying GEC, 1997 norms and found that exiting stage of groundwater development was 91.8% which needs to be preserved.

Kumar et al., (2002) conducted a study on the assessment of water resource potential, availability and demand of the IARI watershed, New Delhi, by estimating surface runoff and groundwater recharge using Curve Number (CN) method and EC-1997 guidelines. The study revealed that although there was no scarcity of water within the watershed however fresh water resources were inadequate to meet the water demand. Use of treated sewage water for irrigation was suggested.

Sharda et al., (2006) used water table fluctuation (WTF) and chloride mass balance (CMB) methods for the estimation of groundwater recharge from water storage structures in two micro watershed of Kheda district in Gujrat, India. The study revealed that a minimum of 104.3 mm cumulative rainfall was required to generate 1 mm of recharge from the water storage structures. An empirical linear relationship was found in the chloride concentration with the rise or fall of water table in the study area.

Sethi et al., (2008) did the trend analysis based on the present groundwater use and future requirements in Munijhara watershed of Orrisa. It was revealed from the study that if the preventive measures are not taken up to rationalize the rate of groundwater draft with groundwater recharge, this watershed will be depleted of the only source of irrigation i.e. groundwater in the near future.

Aggarwal et al., (2009 a & b) estimated the water requirement for crops on the basis of evapotranspiration in Jalandhar and Hoshiapur districts of Punjab. The study revealed that the existing cropping pattern was the major factor responsible for higher water demand leading to water deficit. The study emphasized on the needs to grow crops which have lesser water requirements and to adopt efficient irrigation methods and water conservation techniques.

Chatterji et al., (2009) evaluated the dynamic groundwater resources of national capital territory (NCT), Delhi using GEC, 1997 methodology. The study revealed that out of the nine districts seven districts were overexploited as the stage of groundwater development exceeded 100% and only two districts, North and Central were in the safe range of groundwater development. The study also suggested that rainwater harvesting
methods should be adopted in the hydrogeologically suitable areas to augment the depleting groundwater resources in the overexploited districts.

Singh and Sharma (2010) assessed availability and demand of water resources at block level during Kharif and Rabi seasons in Rewari district, Haryana. It was found that the available water was not adequate to meet the total crop water demand during Rabi season however during the Kharif season crops it was surplus. Scientific and rational conservation methods like design of suitable recharge structures to bridge the gap between water availability and demand were suggested.

Singhal et al., (2010) in Pathri Rao watershed of Haridwar district, Uttrakhand conducted a study and found decline in water table during both pre and post monsoon period. The study revealed that this may be due to over-exploitation of groundwater resources in the study area. Authors suggested suitable artificial recharge sites to accelerate the groundwater recharge and to arrest the further decline in groundwater levels.

Gontia and Patil (2012) conducted a remote sensing and GIS based assessment of groundwater recharge through rainfall and water harvesting structures in Jamka watershed of Saurashtra region, Gujarat. The analysis concluded that groundwater recharge by rainfall varies between 11 to 16 percent of annual rainfall and water harvesting structures contribute about 39 percent of the total recharge.

Ganguli (2012) did assessment of groundwater resources and their sustainability in municipal area of Chandernagore and Hoogly-Chinsurah, West Bengal using GEC-97 guidelines and revealed that area falls under semi critical zone and recommended the construction of water harvesting structures in the apartments.

2.5 Groundwater recharge

Imprudent exploitation of groundwater resources may often result in undesirable and irreversible consequences and thus demand better and simplified means of recharge predictions at micro level (Gaur, 2001). Although a huge quantity of surface water is available in India, the topography and other constraints has limited its beneficial use to only 50 percent (Jothiprakash et al., 2003; Das, 2011). Therefore in such situations
recharge by artificial means becomes more relevant where precipitation is seasonal. Also replenishment of aquifer by natural recharge is often inadequate to meet the increasing water demand of groundwater resources.

Harvesting of surface water is the most common practice being practiced in the country since ancient times of Harappan civilization. In southern peninsular region tanks and ponds constructed hundreds of years ago are still in use. However decline in the maintenance of these structures is being reported due administrative, technical and social reasons (Athavale, 2003). Also water from the basin drains out into rivers and is not available for use during non- monsoon period. Thus there is need to direct the surface runoff to aquifer by constructing suitable artificial recharge structures according to terrain conditions. Direct and indirect methods are the two broad categories for artificially augmenting the groundwater recharge. The necessity of artificial recharge in India was recognized more than four decades ago (Karanth, 1963). Systematic application of artificial recharge is still at an initial stage as evaluation of groundwater potentials by these augmenting structures have not been done scientifically. Artificial recharge studies in India have mainly concentrated on the mechanism of recharge but recently a number of studies also focused on site selection process using hydrogeological parameters and integrated approach of remote sensing and GIS techniques (Anbazhagan and Ramaswamy, 2002).

2.6 Remote Sensing and GIS in groundwater hydrology

Groundwater being a subsurface phenomenon, its assessment (occurrence and movement) is based on indirect analysis of some directly observable features like topography, lithology, geological structures, depth of weathering, extent of fractures, primary and secondary porosity, drainage pattern, geomorphology, slope, land use/land cover, and climate and their hydrological characteristics (Mukherjee, 1996; Jaiswal et al., 2003; Javed and Wani, 2009). In-situ hydrogeological experiments and surveys help in groundwater exploration, but are time consuming and costlier for spatial and temporal investigations. In recent, remote sensing has been increasingly employed to replace traditional on-site experimentation and exploration. The reason being that not only it
provides unparalleled synoptic view of the region as a whole for data observation but also saves time and money (Saraf and Choudhury, 1998; Murthy, 2000; Tweed et al., 2007). Advent of satellite remote sensing and geographic information system has added a new dimension in the field of groundwater investigations. e.g. the upper boundary of a shallow aquifer is strongly influenced by features at or near the surface, the information about which is provided by remote sensing (Meijerink, 1996). This is due to the fact that the surface features such as geology, landforms, soils, land use/land cover, surface water bodies, etc. which are the indicators of groundwater existence can be easily derived from a satellite imagery (Bobba et al., 1992; Das et al., 1997; Ravindran and Jeyaram 1997; Meijerink, 2000; Jha and Pieffer, 2006). The earth observing devices both on spacecraft as well as on aircraft provide most up-to-date, accurate and detailed spectral, spatial and temporal informations on the hydrogeological conditions of large and inaccessible areas within a short time. This advantage of remote sensing has made it a very handy and useful tool in exploration, evaluation and management of groundwater resources. Reviews presented on applications of remote sensing in groundwater hydrology by Farnsworth et al., (1984), Waters et al., (1990), Engman and Gurney (1991) and Meijerink (2000) indicate that remote sensing has been widely used as a tool, mostly to complement standard geophysical techniques. Aerial photographs, multispectral scanner images, radar images operating in different parts of the electromagnetic spectrum, airborne geophysical methods etc. are the various common techniques of remote sensing used in groundwater studies.

Applications of remote sensing in groundwater exploration using aerial photographs, visible and near-infrared satellite images dates back to 1960 with limited success (Engman and Gurney, 1991). With the advent of high resolution multi-spectral satellite sensors, the use of satellite imagery for targeting groundwater prospects increased manifolds in late 1980s (Waters et al., 1990; Engman and Gurney, 1991; Meijernik, 2000; Jackson, 2002). Generally, the satellite data (aerial photographs or satellite imagery) is analyzed prior to ground surveys and fieldwork, because it may eliminate areas of potentially low water-bearing strata and may also indicate promising areas for intensive field investigations, thus minimizing the field data collection (Revzon et al., 1983). Therefore it is an ideal tool for generating spatial information needs.
However, the use of remote sensing technology involves large amount of spatial
data management and requires an efficient system to handle such data. The Geographical
Information Systems (GIS) technology provides suitable alternatives for efficient
management of large and complex databases. It has emerged as an efficient tool for
manipulating and storing large volumes of data, integrating spatial and non-spatial
information within the same georeferencing scheme for analyzing and solving various
spatial problems (Moore et al., 1991; Goodchild, 1993; Meijerink et al., 1994). It has also
emerged as an effective tool for decision making in several areas including engineering
and environmental fields (Stafford, 1991; Goodchild, 1993). In early nineties and mid-
nineties the reviews presented on application of GIS in hydrology and water management
by authors such as Zhang et al., (1990), DeVantier and Feldman (1993), Ross and Tara
indicate that application were essentially in a modeling dominated context. It is reported
that use of geographic information systems in groundwater studies dates back to 1987,
but its use for surface-water modeling has been more prevalent because the available
standardized GIS coverages are primarily of the land surface and only a few standardized
coverages of hydrogeologic properties are available (Watkins et al., 1996). Watkins et al.,
(1996) presented an overview of GIS applications in groundwater flow modeling and on
the other hand, Pinder (2002) provided step-by-step procedures for groundwater flow and
transport modeling using GIS technology.

Remote sensing and GIS are now established tools for natural resources and
environmental studies. During the last few years, research has been going on to integrate
both the tools. As the demand for spatial information grows there is an ever increasing
synergy between remote sensing and geographical information systems where remote
sensing data can be used as data set in GIS. Integration of the two technologies has proved
to be an efficient tool in groundwater studies (Saraf and Jain, 1993; Krishnamurthy et al.,
1996; Punithavathi et al., 2011). An integrated approach of remote sensing and GIS
techniques is successfully used by several investigators to delineate groundwater
potential zones both in India and abroad (Saraf and Jain, 1993; Jankowski, 1995;
Chaudhary et al., 1996; Krishnamurty et al., 1996; Shahid et al., 2000; Senser et al., 2005;
Ravi Shankar and Mohan, 2006; Solomon and Quiel, 2006; Chowdhury et al., 2009).
These studies commonly made use of the thematic layers such as geology, geomorphology, soil, topographic slope, drainage pattern, lineament density etc. Some researchers integrated remote sensing, GIS and geoelectrical techniques to delineate groundwater potential zones (Murthy, 2000; Shahid and Nath, 2002; Srivastava and Bhattacharya, 2006). They conducted geoelectrical surveys to derive thematic layers of subsurface parameters such as aquifer resistivity, depth and thickness of aquifer, clay layers etc. Comprehensive literature survey on applications of RS and GIS techniques in groundwater studies is succinctly described in the following sections.

2.6.1 Hydrogeological indicators derived from remote sensing

Remote sensing data provide accurate spatial information and are cost-effective compared with conventional methods of hydrogeological surveys. Digital enhancement of satellite data improves maximum extraction of information useful for groundwater studies. The various hydrogeological clues that can be extracted from remote sensing are geology, geomorphology, structures (lineaments, fault zones etc.), vegetation, drainage (density and pattern), soil properties, land use, soil moisture, recharge and discharge areas etc. Detection of occurrence and movement of groundwater from remote sensing data depends upon the spectral properties of earth surface features. Electromagnetic radiation when incident on an object is either reflected, absorbed or transmitted, the proportion of the three being different for different objects as well as the sensors. The spectral properties of the materials depend on the physical and physiological nature. The most important are vegetation, soil and water properties.

The spectral reflectance properties of a leaf which is the major contributor to the reflected energy from a vegetation canopy in the visible and infrared region is a function of the leaf pigments, the leaf cell morphology, internal refractive index discontinuities and the water content (Raines and Canny, 1980). The reflectance from a leaf primarily depends on the pigments and proportion of chlorophyll, internal cell structure and the water content, any change in these due to any reason (e.g. change in species, disease, senescence etc.) can give a different spectral response to the incident radiations. A plant leaf typically has a low reflectance in the visible spectral region because of the strong
absorption by chlorophyll, a relatively high reflectance in the near-infrared because of the internal scattering and relatively low reflectance in the infrared beyond 1.3 µm because of strong absorption by water (Knipling, 1970). Pigments are the main determinants controlling the spectral responses of leaves in the visible wavelengths (Gaussman, 1977). Reduced concentrations of chlorophyll are indicative of plant stress (Curran et al., 1991). On the other hand, cellular structure and water content of leaves are the main determinants in the near and mid-infrared wavelengths as shown in Fig. 2.4. Similarly due to plant senescence, plant tissues break down and there is chlorophyll degradation, high reflectance is observed in the visible region. In general, lower the water content of a plant higher the reflectance in the middle infrared, with reflectance peak between moisture absorption band at around 1.6 µm and 2.2 µm (Belward, 1991).

Several researchers have extensively studied soil reflectance properties in the visible and IR region, both in field and laboratory (Bowers and Hanks, 1965; Cipra et al., 1971; Condit, 1972; Stoner and Baumgardner, 1981). Reflectance property of soil mainly

![Fig. 2.4: Typical reflectance sensitivities as controlled by leaf pigments, cell structure and water content (Adapted from Gaussman, 1977)]
depends upon the moisture, texture and structural arrangement and is very little affected by chemical composition (Mulders, 1987). With increase in soil moisture reflectance in the visible region decreases due to total internal reflection with in soil and soil appears darker. Effect of varying soil moisture on reflectance is shown in Fig. 2.5. The reflectance curve dips at 1.4 µm, 1.9 µm and 2.7 µm due to water absorption band and at 2.2 µm due to presence of hydroxyl absorption band. Also it was observed that soil reflectance increases with decrease in particle size (Bowers and Hanks, 1965). Further it has been observed that structure dominates over texture (Colwell et al., 1983). Rougher soil surface has lesser reflectance because of aggregation of reflectance.

The presence of suspended sediment, living organisms, dissolves organic matter and other particles can affect remotely sensed signal by changing the scattering and absorption properties of water. The reflectance of pure water generally decreases uniformly from visible to infrared with a peak at 0.55 µm. Adding sediment to water (turbid water) will increase its reflectance through the visible spectrum Fig. 2.6. This helps in detecting sediment load in water and monitoring water quality from remote sensing data.

Drainage is one of the simplest parameter, which can be extracted through remote sensing. It gives the most recent and accurate information and the seasonal changes can also be mapped using multi date data. Astaras (1985) used Landsat imagery for mapping of drainage features for quantitative analysis in the Olympus-Pieria mountain area. Astaras et al., (1990) performed a multi-sensor analysis using Landsat-3, RBV, TM images and SPOT PLA stereo pairs in Central Macedonia for drainage extraction. Drainage pattern and texture reflect the permeability of the underlying lithology and provide an important indication of groundwater condition (Charon, 1974; Salman, 1983; Mishra S., 2013). High drainage density is the result of impervious lithology at or near the surface indicating low percolation of water into groundwater and unfavourable recharge conditions (Anbazhagan et al., 2005; Ravi Shankar and Mohan, 2005; Chowdhury et al., 2010). Identification of hydrologically significant lineaments is another important application, especially in hard rock terrains where large amount of groundwater can be obtained from wells along fractures (Saraf and Choudhury, 1998).
Fig. 2.5: Silt loam reflectance spectra for various moisture contents (Adapted from Bowers and Hanks, 1965)

Fig. 2.6: Spectral curve of water with different concentrations of suspended sediment (Adapted from Farooq S., 2011)
2.6.2 Land use/land cover from remote sensing data

Land use information is essential for the comprehensive land-use planning and an integrated management of natural resources (Singh and Roy, 1989; Asselman and Middelkoop, 1995; Zhu, 1997) to ensure sustainability of land and to achieve social equity, economic efficiency and environmental sustainability. Also it is a desired input for many agricultural, geological, hydrological and ecological models. The study of any natural calamity such as landslide hazard zonation (Gupta et al., 1999; Saha et al., 2002) highly depends on the availability of accurate and up to date land cover information. The benefits of satellite-based remote sensing in land use/land cover mapping, monitoring and change detection as well as providing up to date information within short time at less cost and efforts were recognized long ago by several researchers. Many studies and surveys have used remote sensing techniques to acquire land use/land cover information during the past 40 years and this technique has become now the only most effective tool for land use/land cover data acquisition (Gautam and Channaich, 1985; Lillesand and Kiefer; 1994, Kelarestaghi et al., 2006). Synoptic view with repetitive coverage makes satellite remote sensing imagery a viable source of gathering quality land cover information from local to global scales (Csaplovics, 1998; Foody, 2002).

Remote sensing techniques have been valuable in mapping urban land use pattern as well as data sources which aid in the analysis and modeling of urban growth and land use change (Clarke et al., 2002). Land use/land cover changes are one of the main human induced activities altering the groundwater system (Calder, 1993) and are known to impact the hydrology of the catchment area (Bhaduri et al., 2000; Bronstert, 2004; Ott and Uhlenbrook, 2004; Tang et al., 2005).

Ming et al., (1993) used minimum distance to mean classifier, the maximum likelihood classifier and the box classification for land use classification of Nanjing, Eastern China, from Landsat MSS data. It was found that classification algorithms and threshold parametres have an important influence on classification results and should be selected carefully based on the training area.

Saha et al., (2005) did land cover classification of Himalaya region covering portions of Rudraprayag and Chamoli Districts of Uttaranchal State in India using multi-
source classification approach. Multispectral image from IRS-LISSIII was used as primary data to produce land cover classification, whereas the PAN image was used as reference data for creation of training and testing data sets and NDVI and DEM as the additional data layers to implement multi-source land cover classification using the maximum likelihood classifier (MLC). The study revealed that addition of ancillary data with remote sensing data substantially reduced the misclassifications incurred due to the effect of shadow in the image and also due to the similarity in spectral characteristics of some classes in high elevation areas. A remarkable increase in accuracy up to 90% was achieved on incorporation of DEM and NDVI data layers with IRS-LISS-III image.

Al-Ahmadi and Hames (2009) applied unsupervised (ISODATA) and supervised (Maximum likelihood, Mahalanobis Distance, and Minimum Distance) in three sub-catchments in Saudi Arabia for land use classification of the raw TM5 images. It was found that the maximum likelihood method gave the best results with an average accuracy of 80% and both Mahalanobis distance and Minimum distance methods overestimated agriculture land and suburban areas with an average accuracy of 74% and 67% respectively.

Mahdavi (2010) did image classification for land use/land cover mapping in Zagros region, Iran using supervised classification techniques of maximum likelihood and minimum distance classifier, utilizing original and synthetic bands resulted from diverse spectral transformation such as rationing, PCA and Tasseled Cap. Nine main classes, based on spectral values and textural characteristics, of land use / land cover such as rangeland, dense forest, semi-dense forest, sparse forest, very sparse forest, agriculture, gardens, settlements and bare lands were found with 83% overall accuracy and 0.78 kappa coefficient.

Kenneth and Gunter (2012) combined data from optical sensors (Landsat, Worldview-2) with Radar sensor data from Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) data for urban land-use mapping in Nakuru municipality of Kenya. The study used several classical and modern classifiers namely maximum likelihood (ML) for image classification and revealed that Landsat has sufficient spectral bands allowing for better delineation of urban green and impervious surface, Worldview-2 has a higher spatial resolution and facilitates urban
growth mapping while PALSAR has higher temporal resolution compared to other operational sensors.

Brar (2013) carried out study for land use change detection in Siwaliks of Punjab using 1989 and 2005 Landsat TM and IRS P6 satellite imageries respectively. Supervised classification coupled with field verification revealed that land under natural vegetation was decreasing at alarming rate and most of the land under closed forest in 1989 had changed to open forest in 2005. Similarly increase in area under water bodies, agricultural practices and settlements were also noticed.

2.6.3 Remote Sensing and GIS applications in artificial groundwater recharge

Generation of spatial data and information by remote sensing techniques and management of a large and complex data by GIS for artificial groundwater studies is reviewed in this section.

Anbazhagan et al., (1997) used IRS-IA LISS II satellite imagery to extract geological structures, lineaments and soil types for the analysis in selection of suitable sites for artificial recharge in hard rock terrain of central Tamilnadu, India. Rock soil contact map was prepared from the aerial photo interpretation to understand the regional view of soil covered area. Areas with water level deeper than the mean water level were considered suitable for artificial recharge. Further, these areas were integrated with pervious soil, synclinal structures and regions of higher lineament density to identify the areas having good permeability with adequate aquifer dimension to construct the recharge structures.

Saraf and Choudhury (1998) applied various standard digital image processing techniques to IRS-LISS-II data to enhance and extract information on geology, geomorphology, land use, structural features and vegetation cover for groundwater exploration and identification of suitable sites for artificial recharge in Sironj area of Madhya Pradesh. DEM, drainage and groundwater level data was used as supporting data in the analysis. Integration of thematic maps by weighted indexing overlay method revealed that geology, geomorphology, slope and lineaments were the main features in controlling the recharge pattern of the area. Moreover, the integrated analysis of these
features using GIS provided a further insight into the hydrogeological regime of the area for site selection for artificial recharge.

Elango and Arrikkat (1998) using remote sensing and GIS integrated and analyzed various thematic layers related to groundwater recharge for the identification of recharge sites in parts of Ongur sub-basin, south India. Seven thematic layers were prepared using both remotely sensed and conventional data. After being ranked and reclassified these thematic layers were overlayed in ArcInfo GIS. Based on the analysis, the study area was divided into four zones viz., ‘very good’, ‘good’, ‘poor’, and ‘very poor’ according to the potential for natural recharge. The unfavorable areas were further classified into four classes on the basis of potential for artificial recharge. The study concluded that remotely sensed data, conventional data, and GIS overlay analyses provide a powerful and practical approach to identify groundwater recharge areas in a basin.

Anbazhagan et al., (1999) used remote sensing and GIS for interpreting the various terrain characters and integrating them for identifying the problematic areas and favourable sites for artificial recharge in Kinzig basin, Germany. Large amount of extraction had resulted in water table depletion and created water scarcity in the study area. Aerial photographs and Landsat Thematic Mapper data were analyzed for interpreting the lineaments, land use/ land cover and geomorphology and were integrated in GIS environment to identify suitable areas for aquifer replenishment by artificial recharge. Areas of water table depletion, areas of groundwater demand and the socio economic data were integrated with geological, hydrogeological data bases by using ILWIS 2.1 GIS software. Subsurface dams at confluence of slope and injection wells along the fracture zones were suggested to arrest the further decline of groundwater table. Areas with shallow water table were recommended for induced recharge to accelerate further infiltration from the surrounding areas.

Ramalingam and Santhakumar (2002) carried out a study on artificial recharge using remote sensing and GIS in all the blocks of Tamil Nadu and found that the increased use of groundwater had resulted in fast decline of groundwater table. Various thematic maps such as drainage density, lineament density, land use, geomorphology, geology, soil, slope, runoff isolines, depth to weathered zone, depth to basement,
groundwater level fluctuations and water quality were used in the analysis. The above maps were prepared using IRS-1C LISS III satellite data and other collateral information collected from the field. After assigning different weights and ranks to different themes and their features respectively, these maps were overlaid using ARC/INFO GIS software and statistical analysis was made on the integrated map to classify it into four suitable zones. After the ground truthing percolation ponds, check dams, subsurface dykes, recharge pits, nalla bund, contour trench etc. recharge structures were proposed depending on the terrain condition and favorable zonation. The study concluded that the zonation created using GIS as well as the type and location of water-harvesting structures suggested were agreeable, and the success rate was more than 90%.

Vasanthakumaran et al., (2002) used remote sensing and GIS techniques for selecting suitable sites for artificial groundwater recharge in the rocky terrain of Southern India. Thematic maps of soil, lineament, and drainage density were prepared using toposheets and satellite data. ArcView and ArcInfo GIS softwares were used to integrate these developed themes after assigning appropriate weights to each theme, which resulted in the identification of suitable artificial recharge sites.

Jothiprakash et al., (2003) delineate artificial recharge zones in Agnior-Ambuliar-Southvelllar river basins in Tamilnadu. Thematic maps pertaining to geology, permeability, effective soil depth, drainage intensity, soil texture, water holding capacity and physiography were integrated in GIS environment to delineate the potential zones for artificial recharge. For this each theme was assigned a weightage depending upon its influence on groundwater recharge and each feature of the parameters used was assigned a knowledge based ranking from one to four depending on its significance in storage and transmittance of groundwater. Areas having rapid permeability with high water holding capacity in alluvium soil were found to be excellent zones for constructing artificial structures. Areas nearer to the coastal area and inland coastal area were highly suitable for artificial recharging of groundwater.

Rao et al., (2003) conducted Vertical Electrical Soundings (VES) to identify recharge zones on the basis of geo-electrical parameters longitudinal conductance, transverse resistance and coefficient of anisotropy along with water table information in Champavathi river basin of Andhra Pradesh. Soil thickness and permeability evaluated
from apparent resistivity along with water table data were taken into account to demarcate potential zone for groundwater recharge.

Saraf et al., (2004) did GIS based surface hydrological modeling in identification of groundwater recharge zones in Dwarkeshwar watershed, West Bengal and Kethan basin, Madhya Pradesh. In this study, comparative analysis of the drainage network derived from DEM and toposheets had been carried out and it was found the potential groundwater recharge zones at locations of clustering of drainage networks. It was also found from the groundwater recharge maps of the two study areas that the areas where groundwater recharge was high, the degree of mismatch between the surveyed and simulated drainage was also high. Such mismatch was suggested to delineate the groundwater recharge zones. The study conducted was found in good correlation with suitable recharge zones derived from remote sensing and GIS techniques.

Ravi Shankar and Mohan (2005) used a GIS based hydrogeomorphic approach for identification of site-specific artificial recharge techniques in the Bhatsa and Kalu river basins of Thane district, in western Deccan Volcanic Province (DVP). In the present study they attempted to identify zones favorable for the application and adaptation of site specific artificial recharge techniques for augmentation of groundwater. Hydrogeomorphological characteristics of both the basins extracted from the IRS-1C LISS-III data and supported by lineament density, depth to bedrock, soil cover and water table fluctuation of the area were used for the analysis. Suitable sites for the construction of artificial recharge structures were suggested. Percolation ponds, check dams and en echelon dams were recommended on the basis of drainage morphology of the study area. Sensitivity analysis revealed that a variation of ± 12% in the parameters did not affect the location of suggested sites indicating the procedure adopted for decision rules was robust.

Ghayoumian et al., (2007) applied Fuzzy Logic among GIS techniques to determine most suitable areas for artificial groundwater recharge in a coastal aquifer in Gavbandi Drainage Basin in southern part of Iran. Thematic layers such as slope, infiltration rate, depth to groundwater, quality of alluvial sediments and land use were prepared, classified, weighted and integrated in a GIS environment by the means of Boolean and Fuzzy logic. The study revealed that about 12% of the study area was appropriate and 8% moderately appropriate for artificial groundwater recharge. The
relationship between geomorphology and appropriate areas for groundwater recharge indicate that the majority of these areas were located on alluvial fans and pediment units.

Kumar et al., (2008) delineated the potential sites for water harvesting structures using remote sensing and GIS in the Bakhar watershed, Uttar Pradesh. Various criterion maps depicting the land use/land cover, geomorphology, roads, drainage and lineaments were prepared using geocoded photographs and digitally enhanced products of the IRS LISS-III sensor. Knowledge base ranking of 1 to 4 was assigned to each feature of the thematic map depending on its significance in storage and transmittance of groundwater and these values were multiplied with criteria weight to get final score of each feature. These weighted maps were integrated in GIS by weighted aggregation method and the study area was classified into four categories of suitability sites based on the total score of polygons formed in final integrated map. Water harvesting structures such as check dams, contour bunding, recharge pits, wells and contour trenching were suggested as per technical guidelines provided by the Integrated Mission for Sustainable Development (IMSD) and Indian National Committee on Hydrology (INCOH). The study revealed that out of 136 villages of Bakhar watershed 22 villages were found suitable for check dams, 14 for contour bunding, 5 for recharge pits and 12 for contour trenching and rest were found not suitable for any of these water harvesting structure.

Singh et al., (2009) in their study of Soankhand watershed in Punjab found that water harvesting structures were extremely important for conserving natural resources like soil and water. From the study it was found that huge amount of available runoff can be considerably reduced by constructing suitable water harvesting structures which in turn reduces floods, increases infiltration and helps in water conservation. Depending upon the parameters like location, slope, soil type, intensity of rainfall, land cover and settlement, suitable sites for the construction of check dams, gully plugging structures, percolation tanks and farm ponds were suggested. Nala bunding and farm ponds were not found suitable in the area due to steep slope, less soil thickness and high runoff velocity.

Ramakrishnan et al., (2009) carried out a study for identifying potential water harvesting sites in Kali watershed of Mahi River basin, Gujrat using SCS-CN and GIS based approach. The study found that high runoff potential, evapo-transpiration and poor infiltration has resulted in drought like situation from December to June almost every
year in this area. Thus the augmentation of water resources by construction of runoff harvesting structures at suitable sites was proposed. The study considered spatial parameters like runoff potential, slope, fracture pattern and integrated them in GIS environment to determine sites of different water harvesting structures. Land use maps were prepared from March and October 2004 Indian Remote Sensing Satellite (IRS-LISS-III) data and Shuttle Radar Topographic Mission (SRTM) DEM was used to derive the slope map. In this study, lineament map was prepared from the satellite data following the conventional edge enhancement techniques and field checks. Construction of runoff harvesting structures like check dam, percolation pond, farm pond, well and subsurface dyke was suggested and an accuracy of 80-100% was achieved on ground truthing.

Chenini et al., (2010) used the GIS based multi-criteria analysis technique to map groundwater recharge zone in the Maknassy basin (central Tunisia) where depletion of groundwater levels were taking place for the last decade and the problem further aggravated due to increased demand for agricultural and industrial needs and arid climatic conditions. Thematic maps of the factors (watershed limit, drainage, drainage density, lithology, fractured outcrops, lineament, permeability, and piezometry) influencing the groundwater recharge were prepared and integrated in GIS after assignment of weights. The resultant map was categorized as per the weight ranges obtained.

Chowdhury et al., (2010) proposed a methodology for delineating artificial recharge zones and identifying possible recharge sites in the West Medinipur district of West Bengal using remote sensing, GIS and MCDM techniques. Thematic maps of geomorphology, geology, drainage density, slopes and aquifer transmissivity, considered for the study were prepared using IRS-1D imagery and conventional data. Each thematic layer and its feature were assigned a weight with help of expert’s knowledge and the normalized weights were calculated by the analytical hierarchy process (AHP). The five layers were then combined by addition to get the final integrated layer. The resultant layer was then classified into three zones as suitable, moderately suitable and not suitable. The study revealed that only 46 percent of the total area was under suitable zone for artificial recharge and 43 percent was moderately suitable. Further 40 artificial
recharge sites were selected in suitable to moderately suitable zones at the intersection of lineaments with 2nd and 3rd order streams.

Sukumar and Sankar (2010) delineated the potential zones for artificial recharge using GIS in Theni district, Tamil Nadu. Three problems, deeper groundwater levels, over-exploitation and salinity related to groundwater were identified in the study area. Therefore the layers of permeability, soil depth, drainage intensity, water holding capacity, soil texture and geology were integrated in GIS environment to prioritize the area for the identification of suitable artificial recharge sites. Structures like check dam and percolation ponds were suggested to create new plans and models to implement the water resource development and action plan in the study area.

Babu and Kumar (2010) demarcated groundwater recharge potential zones for Tiruppur block of Tiruppur district, Tamil Nadu using geographical information system. This was done to combat the problem of water scarcity and declining water levels in the area due to overexploitation. Geology, geomorphology, hydrological soil groups, lineament and land use parameters (themes) were consisderd for identification of potential groundwater recharge zones. The demarcation process involved the assignment of weights to each parameter according to the influence of each theme on supporting groundwater recharge and appropriate ranks were given to each individual feature. Weighted index overlay method was used to integrate all the themes and integrated map was classified into three zones namely good, moderate and poor potential areas for artificial recharge. The study proved that methodology adopted in assigning weights and integrating different thematic maps in GIS proved to be more accurate than for delineation of potential groundwater recharge zones using any other conventional method.

Kumar and Kumar (2011) used Multidate IRS 1D/P6 LISS III data in conjunction with collateral data to generate thematic layers on geology, geomorphology, land use/land cover, lineaments for study area of Sanjai Watershed, Jharkhand. Geographic Information System (GIS) framework was used for integration of these layers and analyzed using a developed model based on logical conditions to derive groundwater recharge zones. Technical guidelines provided by the Integrated Mission for Sustainable Development (IMSD, 1985), National (Natural) Resources Information System (NRIS,
2000), Rajiv Gandhi National Drinking Water Mission (NRSC, 2007) were adopted for identifying the groundwater recharge zones and selecting sites for rainwater harvesting structures. Suitable structures for groundwater recharge/harvesting such as boulder bunds, check dam, percolation/disiltation tanks and recharge pits and wells and subsurface dykes were suggested accordingly.

Sharma and Kujur (2012) applied remote sensing and GIS techniques for the identification of suitable sites for artificial recharge structures in and around Gola block, Jharkhand. Thematic data pertaining to geology, geomorphology, land use/land cover, lineaments, drainage pattern, etc. were prepared by visual interpretation of the digitally enhanced satellite data IRS-P6 LISS-III, for study area of Gola block, Ramgarh district, Jharkhand, India. The study found that in a hard rock terrain intersection zone of lineaments provide potential for groundwater accumulation and recharge. The multi-layer integration viz. geomorphology, land use, geology, lineament density and drainage density data helped to identify suitable zones for artificial recharge. These zones were then compared with land use land cover map and ordering of drainage for adopting the suitable structure for rainwater harvesting like boulder bunds, check dams and recharge pits.

Kadam et al., (2012) used SCS-CN method for identifying rainwater harvesting sites in basaltic region of Western India. The runoff was derived using SCS-CN method with the help of land use land cover, slope, soil and drainage layers. The analysis found that water body and agricultural land had high runoff potential followed by settlement, open scrub, dense scrub and low runoff from open forest and dense forest areas. The SCS-CN method integrated with geographical information system was found to be an effective method for identifying suitable rainwater harvesting sites because the average accuracy of these sites when checked in the field was found to be 86.25 %. The study revealed that 84 % of study area was suitable for constructing rainwater harvesting structures like farm ponds, check dam, percolation tank and gully plugs to augment the groundwater resource of the study area.
2.7 Limitations of spatial multi-criteria modeling

As discussed studies have been carried out where multi criteria decision making (MCDM) is implemented in GIS for suitability analysis. Although the spatial modeling techniques are quite effective and found appropriate in site suitability problems, there are certain limitations of these methods. Firstly, inaccuracy, imprecision and ambiguity are the inherent properties of data input to GIS which leads to inaccurate results. Some efforts like sensitivity analysis and error propagation analysis were suggested to tackle this problem by Lodwick and Hevelink (Malczewski, 2004). Fuzzy logic can also be incorporated to solve this. Standardization of the non commensurate criteria is the other problem. Different standardization methods lead to different suitability patterns. Third difficulty is related to the choice of decision rule for a particular problem. This problem still remains largely unsolved in decision analysis as different decision rules lead to different suitability patterns. The solution to this problem is to integrate MCDM with artificial intelligence (AI) techniques like, fuzzy, artificial neural network (ANN), genetic programming etc. to develop the intelligent multi criteria decision support (Malczewski, 2004).

2.8 Advance technology in spatial modeling: Artificial Neural Networks

Neural networks have seen an explosion of interest over the last few years and are being successfully applied across an extraordinarily range of problem domains, in areas as diverse as finance, medicine engineering, geology, physics, biology and urban development etc. Artificial neural networks (ANNs) refer to computing systems whose central theme is borrowed from highly simplified mathematical models of biological neural networks. From a statistical perspective neural networks are interesting because of their potential use in prediction and classification problems (Rajanayaka et al., 2001). They may be viewed as non-linear extensions of conventional spatial statistical models and pattern recognition techniques (Fischer and Gopal 1994a). Besides providing the extremely valuable classes of data driven mathematical tools for a series of spatial analysis tasks, neural networks also provide an appropriate framework for reengineering
the well established spatial data analysis techniques to meet the new large scale data processing needs in GIS (Fischer, 1999). They are powerful tools for modeling especially when the underlying data relationship is unknown. They include the ability to learn and generalize from examples to produce meaningful solutions to problems even when input data contain errors or are incomplete, and to adapt solutions over time to compensate for changing circumstances and to process information rapidly (Jain et al., 2004). Neural nets consist of sets of nodes between which weighted connections are established (Zahedi, 1991). After training, ANN can be used to predict the outcome of new independent input data. The important feature of adaptive nature, where “learning by example” replaces “programming” makes such computational models very appealing in application domains where one has little or incomplete understanding of the problem to be solved but where training data is readily available. Thus they are ideally suited for the modeling of hydrological data which are known to be complex and often non-linear (Govindaraju et al., 2000). It has been successfully used in many hydrologic applications as rainfall forecasting (Hung et al., 2008), rainfall-runoff relationship (Cigizoglu, 2007; Junsawang et al., 2007), evaporation modeling (Sudheer et al., 2002) and improving air temperature prediction (Smith et al., 2006).

Out of about 30 different neural network models developed, characteristics of 10 most well-known neural network paradigms were briefly reviewed by Sui, 1994. The multi layer perceptron (MLP) used in the back-propagation (BP) learning algorithm is one of the most widely used neural network models in natural resource management (Rumelhart et al., 1986 a & b). A typical BP network contains one input layer, one output layer and one or more hidden layers. The whole operation of a neural network performs like a black box. Sui, 1992 utilized back propagation neural network to analyze the suitability of a number of land parcels for development in vector GIS and also compared neural net based approach to cartographic modeling based techniques. Wand, 1994 used neural net in land use suitability assessment for wetland rice, soyabean, sugarcane, pasture and acacia crops in the north coast of west Java, Indonesia. The advantage of this method is that it focuses on the problems rather on the details of the techniques, therefore it is best suited for tackling planning decision makings where there is little or incomplete understanding of the problem. The drawback of the neural net is that it is not clear what
constitute the actual structure of the network, secondly overtraining, where the network seems to perform well in training, but is just memorizing solutions specifically for the training data and will perform poorly on real data (Collins et al., 2001; Malczewski, 2004).

2.9 Summary

The literature reviewed shows that overexploitation of groundwater resources has resulted in decline of groundwater levels at alarming rates. Therefore there is an urgent need to replenish the depleting aquifers. This requires assessment of the available groundwater resources and their utilization. Integrated Remote Sensing and GIS techniques have proved to be an efficient tool in artificial groundwater recharge studies to target suitable areas for artificial recharge. For these different thematic layers (factors) are combined by overlaying in GIS environment using spatial multi criteria decision making techniques. In GIS, the overlay method is often called as suitability analysis from the planning point of view. Prior to overlaying, different factors and their features are assigned a weightage (importance) by experts, considering their contribution towards achieving the goal i.e. artificial groundwater recharge. The assignment of weights to different factors in spatial modeling methods is usually subjective. AHP is one of the most widely applied multiattribute decision making methods for calculating weights. The final output largely depends upon the weights and how the different layers are combined. Advanced technology like artificial neural networks are gaining popularity in applications to hydrology problems due to their power and potential in mapping nonlinear system data. Moreover artificial neural network techniques can be used to resolve the bottleneck of weight estimation for site suitability analysis in the absence of expert’s knowledge.