CHAPTER – I

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1.1 General statement:

Population growth and impacts of climate change on the hydrology of river basins could result in water scarcity by 2050 affecting 7 billion people in 60 countries (http://www.nature.com/nature/journal/v422/n6929/full/422243a.html). Globally, between 12.5 and 14 billion cubic meters of water is available for human use on an annual basis (http://www.infoforhealth.org/pr/ml4/ml4.pdf). In 1989 the per capita water availability was 9,000 cubic meters which had dropped to around 7,800 cubic meters in 2002. By 2025 the per capita water availability is expected to fall below 5,000 cubic meters as a result of growth in world's population from 6 billion to over 8 billion (UNESCO, 1996).

The demand for fresh water in the country has been rising over the years due to increased demand for food production and growing urbanization and industrialization. In 2007 total water use (including groundwater) was 634 BCM, of which 83% was for irrigation. The demand for water is projected to grow to 813 BCM by 2010, 1093 BCM by 2025 and 1447 BCM by 2050, against utilizable quantum of 1123 BCM (Anon, 2007). It is expected that by the year 2050 more than 50 percent of India’s population will be living in the urban areas, creating a huge stress on safe and fresh drinking water availability (Kumar et al., 2005). Central Ground Water Board (CGWB) has warned that the reservoir of groundwater will be completely depleted in as many as 15 states by 2025 if the water extraction and exploitation continues at the present rate (Anon, 2007). Due to improper planning of water conservation, India is ranked 122 out of 130 nations in terms of water quality and 132 out of 180 nations in terms of water availability (Tikoo, 2003).

India is a vast country having diversity in geological, climatological, and topographic set-up, giving rise to divergent groundwater situations in terms of its occurrence, distribution and movement. The climatic conditions of India vary widely across length and breadth of the country. The average annual rainfall in the country is 1170 mm, which corresponds to annual precipitation, including snowfall (Anon,
However less than twenty percent of it is utilized, the rest reaches the sea or evaporates. Variability of rainfall results in space and time in flooding of some regions and at the same time drought occurring in some other regions/states.

India has a highly seasonal pattern of rainfall, with 50% of precipitation falling in just 15 days and over 90% of river flows occurring in just four months. The topography and rainfall virtually control runoff and groundwater recharge. Major parts of the states of Andhra Pradesh, Chhattisgarh, Gujarat, Jharkhand, Karnataka, Maharashtra, Orissa, Tamil Nadu, Madhya Pradesh and Rajasthan are underlain by hard rocks and presence of groundwater is subject to availability of secondary porosity i.e., joints, fractures, fissures and weathered structures. In these rocks, groundwater occurs in shallow unconfined aquifers in the weathered material and under semi-confined conditions in deeper fractures and joints. Groundwater exploration in granitic/gneissic terrain has proved existence of water bearing fractures down to 300 m and more. Basaltic terrain covering nearly 40% of the hard rock areas has multilayer aquifer system due to multiple lava flows at many places.

The uncontrolled exploitation of groundwater resources has resulted in declining of water levels and deterioration in quality, which is clearly evident as base flow to the streams has decreased and large tracts of irrigated land has been converted into waste lands in many states. Under the influence of industrial effluents, and over usage of fertilizers, several groundwater basins have become unfit for drinking and irrigation. The rate of extraction of groundwater is increasing and in many blocks exceeds the rate of recharge, leading to declining water tables (Anon 2007).

In India out of 5723 assessment units (blocks/mandals/talukas/watersheds), 839 are categorized as “overexploited”, 226 blocks/watersheds are “critical” and 550 are semi-critical. The remaining, 4078 units are safe and 30 units are categorised as saline. The number of over-exploited critical blocks has grown from 4% in 1995 to 15% in 2004. 28% of blocks in India fall in semi-critical, critical and over-exploited category (Anon 2007).
In the light of these facts our country faces a stiff challenge in terms of water availability, hence water management practices are required at all levels. The present situation demands a focused approach on the management of the water resources, using latest scientific methods and technologies.

1.2 Rajasthan Scenario:

Rajasthan is one of the states where water scarcity has always been a regular feature. Since the state is underlain by hard rocks in the east and central parts and arid desert in the west, it has always been in news for water related issues. The increase in population and development activities has affected the water availability significantly in different parts of the state. In the recent past, the rainfall cycle has undergone significant changes, in variation, distribution, intensity and duration. The years 1998 to 2000 as well as 2002 have been rainfall-deficit years, adversely affecting the ground water recharge resulting in depleting ground water resources (Anon, 2004). In 2009 also the state has received deficient rainfall leading to drought.

The depth of water table varies widely throughout the state. To the east of Aravalli, the depth to water is comparatively shallower than in the west. It generally varies between 10 to 25 meters below ground level in the eastern part, whereas in the western part, it ranges between 20 to 80 meters below ground level (www.indiawaterportals.org/data/datastats/rj/rajasthan.pdf). Shallow water levels have been recorded in the canal command areas of Ganganagar, Banswara, Kota and Bundi districts whereas deeper water levels have been observed in western districts particularly in Jaisalmer, Bikaner and Jodhpur. On the basis of average depletion per year these districts have further been classified as most critical, critical, moderate and marginal (Table 1.1).
Table 1.1: Classification of Districts on the basis of Depletion of Groundwater

<table>
<thead>
<tr>
<th>Category</th>
<th>Average Depletion (m/year)</th>
<th>District</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most Critical</td>
<td>&gt;0.40</td>
<td>Alwar, Jaipur, Jalore, Jhunjhunu, Jodhpur, Nagaur and Pali</td>
</tr>
<tr>
<td>Critical</td>
<td>0.20-0.40</td>
<td>Ajmer, Bhilwara, Chittorgarh, Dausa, Dholpur, Karauli, Rajsamand, Sawai, Madhopur, Sikar, Sirohi and Tonk</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.10-0.20</td>
<td>Baran, Barmer, <strong>Bharatpur</strong>, Bundi, Dungarpur, Jhalawar, Kota and Udaipur</td>
</tr>
<tr>
<td>Marginal</td>
<td>&lt;0.10</td>
<td>Banswara and Churu</td>
</tr>
</tbody>
</table>

(Source: Department of Ground Water Resources, GOR, Jaipur, 2004)

Rajasthan has 14 river valley catchments, the Chambal catchment being the largest one which has got maximum runoff water, followed by Mahi, Banas, Luni, etc. The total surface water potential in the state has been estimated as 19.56 BCM (http://www.planning.rajasthan.gov.in/Tenth%20Plan/Chapter/PDF/chapl3-irri.pdf). To make use of surplus runoff water of the adjoining states, inter-state agreements have been signed, as a result of which water is available in Indira Gandhi Nahar Project and Chambal Irrigation project. There are many inter-state water agreements such as Ravi and Beas between Punjab, Haryana and Rajasthan, Narmada agreement between Madhya Pradesh, Maharashtra, Gujarat and Rajasthan, Mahi river agreement between Rajasthan and Gujarat, Parbati-Kalisindh-Chambal project between Rajasthan and Madhya Pradesh and Ken-Betwa linking project between Madhya Pradesh and Uttar Pradesh. Many more such agreements and understanding are expected in the light of the proposed mega project inter-linking of rivers of Government of India (GOI).

1.3 Stage of Groundwater Development:

The state has been divided into 595 water potential zones. Out of these 327 zones fall in the 'White' category where ground water development is less than 65 per cent, 62 zones fall in the 'Grey' category, having 65 per cent to 85 per cent stage of development. The remaining 206 zones have been categorised as 'Dark', where the
stage of ground water development is more than 85 per cent. Whereas 189 zones are over-exploited, representing a stage of development more than 100 per cent.

Depletion of ground water has been very significant in the State during the pre-monsoon period in 1984 to pre monsoon period in 2002. Out of the total 237 blocks, 220 blocks show a depleting trend of ground water level. Thus, 81.76% area of the State has come under water level depletion zone during this period. Depletion of water level is seen in 28 districts of the State, including Bharatpur District. Ground water assessment reveals that out of 237 blocks in the State, 49 blocks come under safe category, 21 fall in semi critical, 80 in critical and the remaining 86 in the over-exploited category (one block of Churu district is entirely saline) (Table 1.2).

Table 1.2: Groundwater Assessment of Blocks in Rajasthan

<table>
<thead>
<tr>
<th>Category</th>
<th>No. Of blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe</td>
<td>49</td>
</tr>
<tr>
<td>Semi Critical</td>
<td>21</td>
</tr>
<tr>
<td>Critical</td>
<td>80</td>
</tr>
<tr>
<td>Over Exploited</td>
<td>86</td>
</tr>
<tr>
<td>Saline</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>237</strong></td>
</tr>
</tbody>
</table>

(Source: Department of Ground Water Resources, GOR, Jaipur, 2004)

1.4 Watershed Concept:

The term ‘watershed’ is defined as a naturally occurring geo-hydrological unit draining to a common point by a system of natural stream/drains. A Watershed comprises of a catchment area (recharge zone), a command area (transition zone) and a delta area (discharge zone). Therefore watershed is the area encompassing the catchment, command and delta area of a stream. The topmost portion of the watershed is known as the “ridge” and a line joining the ridge portions along the boundary of the watershed is called a “ridgeline”. A watershed is thus a logical unit for planning optimal development of its soil, water and biomass resources. Management of a watershed to conserve soil and water requires land to be “used within its capabilities and treated according to its needs” (Chow, 1964).
The terms such as basin, catchment, watershed etc are widely used to denote hydrological units. Size of a watershed is governed by the size of the stream occupied by it, which is of practical importance in watershed development programmes. For example, size of irrigation cum hydel project has its watershed size several thousands of square kilometers but for a farm pond the size may be few hectares only. In deserts and flat terrains with little incipient drainage, it may be difficult to delineate small sized watersheds whereas in undulating and hilly terrains smaller sized watersheds could be easily delineated. Hence the areal extent of watersheds vary widely depending upon the topography, climate, structure, slope, relief, landforms etc.

Watersheds could be classified on various factors such as size, drainage, shape and land use pattern. The categorization could also be based on the size of the stream or river, the point of interception of the stream or the river and the drainage density and its distribution. All India Soil and Land Use Survey (AIS&LUS, 1990) has developed a system for watershed delineation like water resource region, basin, catchment, sub-catchment, and watershed. The usually accepted five levels of watershed delineation based on geographical area of the watershed are given in Table 1.3. National Remote Sensing Agency (1995) has further classified watershed into sub-watershed (30 – 50 km²), mini-watershed (10 – 30 km²) and micro-watershed (5 – 10 km²).

Table 1.3: Types of watershed on the basis of geographical area

<table>
<thead>
<tr>
<th>Watershed Level</th>
<th>Geographical Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro-watershed</td>
<td>&gt; 500 km²</td>
</tr>
<tr>
<td>Sub-watershed</td>
<td>100 to 500 km²</td>
</tr>
<tr>
<td>Milli-watershed</td>
<td>10 to 100 km²</td>
</tr>
<tr>
<td>Micro-watershed</td>
<td>1 to 10 km²</td>
</tr>
<tr>
<td>Mini-watershed</td>
<td>0.01-1 km²</td>
</tr>
</tbody>
</table>

Source: (AIS&LUS, 1990)

A watershed could be described as fan shaped (near circular) or fen shaped (elongated). Hydrologically the shape of the watershed is important because it controls the time taken for the runoff to concentrate at the outlet. Watersheds may
also be categorized as hill or flat watersheds, humid or arid watersheds, red soil watershed or black soil watershed based on criteria like physiography, climate. Depending on the land use pattern watershed could again be classified as highland watersheds, tribal settlements and watersheds in areas of settled cultivation.

A watershed is considered to be the most appropriate spatial arrangement and functional unit for managing complex environmental problems. Managing issues of bio-complexity in the environment on a watershed basis offers the potential benefit of balancing the competing demands placed on natural and human systems. Because of the highly complex nature of human and natural systems, the ability to understand them and project future conditions using a watershed approach has increasingly taken a geographic dimension (Tim and Mallavaram, 2003).

1.5 Watershed Management:

Watershed management is a holistic approach which defines inter-relationships between land use, soil and water. Soil and water conservation are the key issues in watershed management which has been dealt by various workers in terms of management of land and water resources (Moore et al., 1994; Tideman. 1996; Honore, 1999; Khan, 1999; Peter, 2004).

Watershed management has acquired immense importance in the recent past and involves development and conservation of natural resources with active participation of the local people. It has emerged as a new paradigm for planning, development and management of land, water and biomass resources with a focus on social and environmental aspects following a participatory approach. Watershed management could perhaps be more accurately defined as resource management with watershed as the basic organizing unit. It involves judicious use of natural resource with active participation of institutions, organizations and local people in harmony with the ecosystem. Landowners, land use agencies, storm water management experts, environmental specialists, water use surveyors and communities all play an integral part in the management of a watershed.

Watershed management is the process of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the
plant, animal, and human communities within a watershed boundary. Its aim is to sustain and enhance watershed functions that provide the goods, services and values desired by the community affected by conditions within a watershed boundary.

1.5.1 Watershed development in India:

The process of watershed development consists of soil and water conservations interventions, regenerating the environment, increasing green/vegetation cover and adopting suitable land practices in the watershed. In India, watershed management programme was initiated more than four decades ago but the activities became more significant since 1990s, covering different agro-ecological regions of the country. The nature and scope of these programmes were continuously modified to bring about uniformity in their formulation, execution and implementation by various government departments and agencies. Integrated watershed management programmes have successfully shown the potential of doubling the productivity of rain-fed areas (Wani et al., 2003). However, one of the major gaps in watershed development programme has been the inadequate database for planning, methodology and its implementation (Dhruvnarayana et al., 1990, Vaidyanathan, 1991, Sarkar and Singh, 1997).

The Guidelines for Watershed Development in India were formulated in 1995, to assess Drought Prone Area programme (DPAP) and Desert Development Programme (DDP) being executed by government agencies in some states, however, the Ministry of Rural Development (MoRD) revised the 1994 guidelines in 2001 and yet again in 2003 under the nomenclature “Hariyali Guidelines”. To further simplify procedures and involve the local community in planning, implementation and management of economic development activities of a region, these new guidelines called “Hariyali Guidelines” were issued in April 2003. These identify a critical role of the Panchayat Raj institutions in implementation of watershed development programmes (Wani et al. 2002; Wani et al, 2003).

The government of India formed National Rainfed Area Authority (NRAA) in November 2006, to give a special thrust to rainfed regions of the country. NRAA has framed “Common Guidelines for Watershed Development Projects” in order to
overcome the problems faced by previous committees/agencies, and are applicable to all watershed development projects executed by the Government of India (GOI). These Guidelines broadly indicate a fresh framework for the next generation watershed programmes. The new guidelines would provide an enabling framework for the planning, design, management and implementation of all watershed development projects in the country. The common guidelines for Watershed development projects are based on the following principles: Equity and Gender Sensitivity, Decentralization, Centrality of Community Participation, Capacity Building and Technology Inputs, Monitoring, Evaluation and Learning, and Organizational Restructuring.

Managing a watershed involves not only individual plots, but also common property resources like forests, springs, roads, footpaths and vegetation along streams and rivers (Swallow et al., 2001). Participatory watershed management should involve all stake holders to jointly discuss their interests, prioritize their needs, evaluate potential alternatives and implement, monitor and evaluate the project outcomes (Mirghani and Savenije, 1995).

The new guidelines also suggest that remote sensing data would be utilized for finalizing contour maps for assessment of run-off and for identifying structures best suited for location of projects. Thus, the endeavor would be to build in strong technology inputs into the new vision of watershed programmes. The NRAA also emphasised establishing core GIS facilities, with spatial and non-spatial data, would be established and augmented with satellite imagery data received from NRSA, ISRO and Survey of India at state and national level.

1.6 Tools for Watershed Management:

Visual interpretation of satellite data, with emphasis on terrain analysis is being used widely for selection of sites suitable for recharge augmentation. Aspects, which are given special attention for the study, usually carried out with satellite imagery or False Colour Composite (FCC) on 1: 50,000 scale include stream course delineation, land form analysis, outcrop pattern analysis, fracture pattern analysis and
land use analysis. These studies can provide valuable information on drainage density and lineament intensity, which helps in identification of suitable sites for recharge.

Various thematic layers generated using remote sensing data such as lithology, structure, geomorphology, land use/land cover, lineaments etc. can be integrated with slope, drainage density and other collateral data in a Geographic Information System (GIS) framework and analysed using a model developed with logical conditions to arrive at suitable sites for artificial recharge.

Information obtained from characterization and assessment studies, primarily in the form of charts and maps can be combined with other data sets to improve understanding of the complex relationships between natural and human systems as they relate to land and resource use within watersheds. GIS provides a common framework – spatial location – for watershed management data obtained from a variety of sources. Because watershed data and watershed biophysical processes have spatial dimensions, GIS can be a powerful tool for understanding these processes and for managing potential impacts of human activities. The modelling and visualization capabilities of modern GIS, coupled with the explosive growth of the Internet and the World Wide Web, offer fundamentally new tools to understand the processes and dynamics that shape the physical, biological and chemical environment of watersheds. The linkage between GIS, the Internet, and environmental databases is especially helpful in planning studies where information exchange and feedback on a timely basis is very crucial and more so when there are several different agencies and stakeholders involved.

In addition, several GIS-based simulation models have been developed for natural resources management and are used in watershed management (Sample, 1994). Geographic Information Systems (GIS) technology has played critical roles in all aspects of watershed management (Tim and Mallavaram, 2003). Water management, both in its conservation and control aspects, has significantly benefited from satellite remote sensing inputs that has become an effective tool for a number of applications related to water resources development and management (http://wgbis.ces.iisc.ernet.in/energy/paper/gis/gis.htm). Remotely sensed data (e.g., aerial photographs and satellite imagery) can be used to obtain information on soils.
land use, vegetation, slope gradient, runoff, erosion, etc. However, recent developments in multispectral scanner, radar system, and a multitude of quantitative techniques for analyzing and processing such data provide opportunities for data acquisition through Remote Sensing and array of techniques for data analyses (Shanwal and Singh, 2006). Rapid advances in Remote Sensing and GIS technologies can bring about quantum leap in watershed management (Shanwal and Singh, 2006).

1.7 Remote sensing and GIS studies in watershed management:

Remote sensing and Geographic Information System (GIS) has been widely used in watershed management, which involves mapping of varied land forms, soil, drainage, linear features, structural elements, and terrain characteristics (Bhattacharya et al., 1979; Bakilwal and Ramasamy, 1987; Haris, 1991; Kumar and Shirivastava, 1991; Venkatachalam et al., 1991; Kulkami, 1992; Rengers, 1992; Jain and Ahmad 1993; Mangrulkar, 1993; Mishra et al., 1994; Mohanty 1994; Chatterjee and Bhattacharya, 1995; Krishnamurthy et al., 1996; Pahari, 1996; Ravindran et al., 1996; Saini and Nathawat, 1996; Menris 1997; Chaudhary and Sharma, 1998; Thomas et al., 1999; Datta et al., 2003; Srivastava et al., 2004; Srivastava and Saxena, 2004; Suresh. 2004; Nag, 2005; Raju and Kumar 2006; Srivastava and Bhattacharya, 2006; Bhatt et al., 2007, Martin et al., 2007; Chowdary et al., 2009; Martin and Saha, 2009). The last decade of the 20th century witnessed rapid advances and a significant increase in the operational use of Remote Sensing and GIS in watershed management (Murai, 1996).


1.8 Review of Literature:

The basic framework of the stratigraphy of Rajasthan in general and Gambhir basin in particular was developed by pioneer geologists like Heron (1917,1922), Fermer (1930) etc. Some of the detailed and significant work has been carried out by Banerjee and Singh (1977a), Singh (1985, 1991 and 1995), Banerjee and Singh (1977b) and Alam and Ahmad (2000) on stratigraphy, palaeogeography, sedimentological studies and petrofacies analysis of elastics of Bayana basin. Banerjee and Singh, (1981) described sedimentary tectonics of Bayana sub basin, whereas Singh (1982) gave stratigraphy of the Delhi supergroup in Bayana sub-basin. Various other studies related to tectonic significance of syn-sedimentary volcanism, petrofacies and diagenetic aspects of Bharatpur district, have been carried out by Ahmad et al., (2004; 2005) Alam et al., (2006).
Land use change analysis of Bharatpur district using GIS was carried out by Dhinwa et al. (1992). Detailed study on geomorphological features, drainage morphometric analysis and landscape evolution of Bharatpur district Rajasthan was carried out by Iqbaluddin et al. (1997). Chemical characteristics of groundwater samples in parts of Ghambir river basin, Bharatpur district, was done by Umar and Absar (2003).

using remote sensing and GIS. Golmehr (2009) carried out land use mapping in parts of Kolhapur District, India using application of remote sensing techniques. Hadeel et al., (2009) used remote sensing and GIS to study the land use/cover change and urbanization in Barsah Province of Southern Iraq.

Drainage basin morphometry has been carried out by Horton, (1932, 1945); Miller, (1953); Smith, (1954); Strahler, (1964) and others. However some of the recent studies on morphometry have been carried out by Chakraborti (1991), Srivastava, (1997) in coalfield (Bihar) using remote sensing technology. Morphometric analysis using remote sensing technique has been carried out by Mishra et al. (1994) of lower Sind basin, marginal plains of Madhya Pradesh and Uttar Pradesh, Nautiyal (1994) in Khairkuli drainage basin of Dehradun, and by Ravindran et al. (1996) in Zuvari basin, South Goa. Nag (1998) carried out morphometric analysis of Chaka sub-basin of Purulia district of West Bengal. Khan et al. (2001) used remote sensing and GIS techniques for watershed prioritization in the Guhiya basin, India. Nag and Chakraborti (2003) deciphered the influence of rock types and structures in the development of drainage network in hard rock area. The other significant recent studies include Chaudhary and Sharma, (1998); Biswas et al., (1999); Shrimali et al., (2001); Reddy et al. (2002b); Nooka Ratnam et al., (2005) for prioritisation of watersheds and conservation strategies for landscape management. Reddy et al. (2004) demonstrated prioritization of river sub-basins using morphometric and universal soil loss equation (USLE) parameters aided by remote sensing and GIS. Vittala et al. (2004) used remote sensing and GIS techniques in morphometric analysis of sub-watersheds in Pavagada area of Tumkur district of Karnataka state. Chopra et al. (2005) have carried out morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using remote sensing and GIS techniques. Singh (2006) has recently carried out morphometric analysis in Vidarbha region. Thakkar and Dhiman (2007) carried out morphometric analysis and prioritization of mini-watersheds in Mohr watershed, Gujarat using remote sensing and GIS techniques. Morphometric analysis of a Wailapalli watershed Andhra Pradesh of south India using SRTM data and GIS was carried out by Sreedevi et al., (2009). Khanday, (2009) carried out characterisation and prioritisation of watersheds in parts of Guna, district Madhya Pradesh, using remote sensing and GIS techniques.
Remote sensing and GIS techniques have been used by a host of workers in hydrogeomorphological mapping (Bhattacharya et al., 1979; Jones, 1986; Kumar and Tomar, 1998; Tomar et al., 1999; Pratap et al., 2000; Subba Rao et al., 2001; Reddy et al., 2002a; Sankar, 2002;). Roy and Raina, (1973) described the hydrogeomorphological units coupled with geological parameters in Kotipally catchment area of Hyderabad. Remotely sensed data was used for hydrogeomorphological mapping in Keonjar district, Orissa, for ground exploration by Das et al. (1997). Hydrogeomorphological mapping, assessing ground water using remote sensing in Sangrur district, Punjab, was carried out by Thomas et al., (1999). Mapping of hydrogeomorphological features in Varaha river basin using remote sensing data was carried out by Murthy and Rao (1999). Some other studies on hydrogeomorphological mapping have been carried out by Srinivasan, (1988); Behra (1989); Kar (1990). Sharma and Jurgan (1992); Tiwari and Rai (1996); Das et al. (1997); and Sankar et al. (1996). Aslam et al. (2003) have carried out hydrogeomorphological mapping using remote sensing techniques for water resource management around palaeochannels in Cauvery basin, around Manchanahalli, Karnataka state. Mufid al-hadithi (2006) carried out hydrogeomorphological mapping in the Piedmont zone of Himalaya. Mondal et al. (2008) carried out hydrogeomorphological mapping using high resolution satellite images in Uttarakhand. Paul et al. (2008) carried out hydrogeomorphological mapping in Khurda Sadar block of Khurda district, Orissa. Matsunaga et al., (2009) analyzed simple DEM-based methods to delineate channel networks for hydrogeomorphological mapping in loess plateau, China.

GIS and remote sensing applications have been used by numerous workers in delineation of groundwater potential zones (Haridas et al 1998; Venkatachalam et al., 1991; Ghose, 1993; Krishnamurthy et al., 1996; Pradeep, 1998; Saraf and Choudhary, 1998; Muralidhar et al., 2000; Reddy et al., 2000; Srivastava and Battacharya, 2000; Khan and Moharana, 2002; Murthy et al., 2003., Lokesha et al., 2005; Vittala et al., 2005; Rao and Jurgan, 2003; Biswajeet 2009; Thomas et al., 2009; Singhal at al., 2010). Pal et al. (1997) used remote sensing and GIS application demarcating groundwater potential zones in parts of Yamunanagar and Sirmaur districts. Rokade et al. (2004) carried a study on Water resource development action plan for Sasti watershed, Chandrapur district, Maharashtra using remote sensing and GIS. Nag

1.9 Present Study:

Kakund watershed lies in the semi-arid tract of the state and forms part of Bharatpur district. The watershed is characterised by varying topography which includes alluvial plains, plateau and hills/ridges. The agriculture is mainly rained but in some parts well irrigation is also reported. The area faces acute water shortages especially in summer. The study has been carried out using IRS LISS III satellite data of 2001 and 2005. The satellite data has been visually interpreted to derive thematic maps on drainage, land use/land cover, hydrogeomorphology, soil, geology, etc. GIS has been used for data input, editing and analysis spatial, and non-spatial data has been analysed in GIS by integrating various thematic layers. The data from secondary sources has been analysed and incorporated wherever required. The climate data (rainfall and temperature) have been analysed to assess the trend in rainfall and temperature for the period of 1971 – 2006 and 1974 – 2006 respectively. The watershed has been suitably demarcated into small units i.e. sub-watersheds for micro-level watershed management measures. The work has been suitably divided into chapters on introduction, study area, data sources and methodology, morphometric, land use/land cover, hydrogeomorphic analysis and watershed management. An attempt has been made to integrate the results obtained through the morphometric, land use/land cover and hydrogeomorphic analysis to select sub-watersheds which require immediate intervention for land and water conservation. Suitable measures have been suggested for each sub-watershed for watershed planning and management.