CHAPTER 2
REVIEW OF LITERATURE

In this chapter, the research works carried-out in the field of watershed management using satellite remote sensing and GIS techniques have been reviewed and discussed covering the history of watershed development, prioritization of watersheds, generation of thematic and developmental action plans and monitoring and evaluation of watersheds.

A watershed can be defined as the drainage or catchment area of a particular stream or river. It refers to the area from where the water to a particular drainage system (nala or stream or river) comes from and drains out through a single outlet. The size of the watershed may vary from a few hectares to several thousand hectares. The watershed may cover part of one village or few villages. It may contain both arable and nonarable lands, various sizes of land holdings and categories of farmers. The watershed development refers to the overall development leading to conservation, regeneration, and judicious use of human and natural resources within a particular watershed. Soil, water and vegetation are among the important gifts of nature and the three are so interdependent that one cannot be managed effectively without the other two. Rainwater, being the climatic parameter, needs to be disciplined once it comes in contact with vegetation and soil.

There is a close relationship between the environment and the human community living within the region or watershed. Community depends on the environment for its livelihood. When there is deterioration of economic and social condition of the community, it leads to over-exploitation and degradation of natural resources. Hence, environmental regeneration is possible only when community understands the reasons for degradation and adopts appropriate resources mobilization, management and conservation. The major components of the watershed management and development are soil and land management, rainwater management, afforestation, pasture development, agriculture & horticulture development, live-stock management, rural energy management, human resources and community development, empowerment of women through self help groups (SHGs), creation of income generation activities for economically weaker groups and employment generation. The term watershed development
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encompasses additional dimensions like equity, sustainability, gender and peoples participation. It has become a trusted tool for the overall development of the village and people living within a watershed area.

Watershed development refers to the conservation, regeneration and the judicious use of all the resources – natural (like land, water plants, animals) and human – within the watershed area. Watershed management tries to bring about the best possible balance in the environment between natural resources on the one side and man and animals on the other. Since, it is the man who is primarily responsible for degradation of environment, regeneration and conservation can only be possible by promoting awakening and participation among the people who inhabit the watersheds.

2.1 HISTORY OF WATERSHEDS

2.1.1 India: The work on soil and water conservation by Ministry of Agriculture begun in the early 1960’s. After Independence, India relied on multi-purpose reservoirs for providing irrigation and generating hydro-electricity. In 1962-63, a centrally sponsored scheme of ‘soil conservation work in the River Valley Projects (RVP)’ was started to stabilize the catchment areas of the reservoirs and control the siltation. Later the Ministry of Agriculture has begun a scheme of integrated watershed management in the catchments of the flood prone rivers (FPR) in 1980-81.

The Ministry of Agriculture launched a programme on water harvesting or conservation in 19 identified watersheds in dry land regions of the country in 1982-83. In October 1984, Ministry of Rural Development (MoRD), adopted this approach in 22 other location in rainfed areas. In these model watersheds Indian Council of Agriculture Research (ICAR) was also involved to provide research and technology support. The purpose of these operation research projects was to develop model watersheds in different agro-climatic zones of the country.

With experience gained from all these, the concept of integrated watershed development was first institutionalized with the launching of the National Watershed Development Programme of Rainfed Areas (NWDPRA) in 1990, covering 99 districts in 16 states. Meanwhile, conservation work was ongoing in the Drought Prone Areas Programme (DPAP) launched by MoRD in 1972-73.
The objective of this programme was to tackle the special problems of areas constantly affected by severe drought conditions. In 1977-78, the MoRD started a special programme for hot desert areas of Rajasthan, Gujarat and Haryana and cold desert areas of Jammu & Kashmir and Himachal Pradesh (which were earlier under DPAP) called Desert Development Programme (DDP). In 1994, the Prof. C.H. Hanumantha Rao technical committee recommended suitable institutional mechanism for bringing about coordination between different approaches at the state and central levels with a view of ensuring uniformity of approach in implementing similar programmes for the conservation of land and water resources.

The MoA launched programmes include National Watershed Development Projects for Rainfed Areas (NWDPRA), River Valley Project (RVP) and Flood Prone Rivers (FPR), Watershed Development Project in Shifting Cultivation Areas (WSDSCA), Alkali Soils and Externally Aided projects (EAP). Till March 2005, MoA has treated an area of 17.24 Mha with an investment of 9368.03 crores. Department of Land Records under MoRD initiated programmes include Drought Prone Areas Programme (DPAP), Desert Development Programme (DDP), Integrated Watershed Development Programme (IWDP) and Externally Aided projects (EAP). Till March 2005, MoRD has treated an area of 27.52 Mha with an investment of 6855.66 crores. The Ministry of Environment and Forests also treated an area of 0.82 Mha with an investment of 813.73 crores under Integrated Afforestation & Eco-Development Projects Scheme (IAEPS). So far (March 2005), a total of 45.58 Mha has been treated through various programmes with an investment of Rs 17,037 crores. Average expenditure per annum during the tenth five-year programme is around 2300 crores.

2.1.2 Karnataka: Out of the total geographical area of 190.50 lakh hectares in the state, the total available land for treatment is 116.90 lakh hectares. An area of 35.42 lakh hectares (18.6%) is already treated and the balance area of 81.48 lakh hectares (42.77%) is to be treated under various schemes. The area under on-going watershed treatment schemes is about 16.75 lakh hectares.

The land resources of Karnataka especially its dry drought prone lands, which comprises more than 79% of the total arable area, have been poorly managed by the resource poor farmers of the state. Soil loss due to erosion coupled with
reduced water resources has led to a situation of rapid soil fertility deterioration, declining or stagnating crop yields, depletion of ground water sources, deforestation, denudation, destruction of natural pasture and diminishing biomass production. Exploring the full potential of rainfed agriculture to meet the food, fodder and fuel requirement of the state population, is the only alternative. However, this will require investing in suitable soil and water conservation technologies, crop breeding targeted to rain-fed environments, agricultural extension services and access to markets, credit and input supplies in rainfed areas.

The potential for increasing the irrigable area and enhancing productivity from irrigated lands has its limitations. The total irrigation potential from all sources, including inter basin transfers, is estimated at around 50% of the total cropped area of 104.89 lakh hectares by the Karnataka state land use board. The remaining land has to depend on rainfed farming forever. Therefore, if the state has to conserve and develop natural resources in rainfed areas to improve their production and productivity, their development on watershed basis is inevitable. Development of rainfed areas is important because more than 44% of its agricultural production comes from dry lands. Karnataka has the highest proportion (79%) of drought prone area among all major states in the country and in absolute terms, it has the second largest area of dry land in the country after Rajasthan. In addition, Karnataka also has the second lowest (154.2 M ha m/yr) replenishable ground water resources among major states after Rajasthan.

After Independence, Karnataka continued with the traditional techniques of soil conservation and water retention treatments with a host of programmes being implemented by the Agriculture Department. In 1983, a World Bank assisted comprehensive watershed development project was taken-up in Kabbala Nala watershed.

In order to capitalize on the gains of the Kabbala Nala watershed project in 1984, Government of Karnataka created four Dry Land Development Boards under four revenue Divisional Commissioners with a jurisdiction over 19 districts. Each district had a multi-disciplinary team comprising of line departments. The main objectives included 1) Conserve basic resources such as soil, rainwater, and vegetation, 2) Achieve higher biomass production both in arable and non-arable
areas and impart stability to crop yields through proper rainwater management, crop patterns and land use, 3) Enhance the income of individuals through adoption of alternative enterprises and 4) To restore and sustain ecological balance.

The success of these watersheds encouraged GOI to follow the strategy of watersheds in principle and launched a massive NWDP in 7th five-year plan and extended to 693 watersheds located in 99 districts of the country with a total outlay of Rs. 239 crores in 15 states, including Karnataka. This project was renamed as NWDPRA during 8th five-year plan and was operated in 85 watersheds in Karnataka ranging from 5,000 to 10,000 ha.

During the two decades of watershed program implementation in Karnataka, the various partners for these projects included Ministry of Agriculture, Ministry of Rural Development, Government of India, World Bank, DANIDA (Royal Danish Govt. assistance), DFID (British Govt. assistance), German Development Bank (KFW) and SDC (Swiss Govt. assistance). State plan funds were also used for the over all development of watersheds.

The watershed development approach, as implemented in Karnataka, consists of the basic components viz., Human resource development (community development), soil and land management, water management, afforestation, pasture / fodder development, livestock management, rural energy management and farm and non-farm value addition activities. This system has led to overall development of the human resource and environment in the watershed.

Benefits derived from watershed methodology includes: 1) the crop yield has increased by 25-40% in dry land farming, 2) the soil loss due to erosion was brought down by 30%, 3) large extents of barren hill slopes were covered by vegetation, 4) large tracts of marginal lands brought under dry land horticulture, 5) development of agro-horticulture and agro-forestry systems, 6) water resources were harvested through nala bunds, farm ponds, gully embankments, 7) Regeneration of grasslands for more fodder and grass and 8) the income of farmers increased considerably.
2.2 WATERSHED DEVELOPMENT PROGRAMMES

Some of the Programmes implemented in Karnataka are National Watershed Development Programme for Rain-fed Areas (NWDPRA), River Valley Project (RVP); Reclamation of Saline, Alkaline & Water logged areas; Drought Prone Area Development Programme (DPAP); Integrated Wasteland Development Programme (IWDP); Desert Development Programme (DDP); Western Ghat Development Programme (WGDP); Special Component Plan (SCP); Tribal Sub Plan (TSP); Karnataka Watershed Development Project (DANIDA) – II\textsuperscript{nd} Phase (KWDP) and World Bank Assisted Sujala Watershed Project.

2.2.1 River Valley Project (RVP): The Objectives of the program includes preventing & checking premature siltation of reservoirs, increase production & productivity of the catchment area and prevention of land degradation by adoption of multi-disciplinary integrated approach of soil conservation & watershed management in the catchment areas. In order to preserve the wealth of the surface land, natural resources like soil & water and to prevent premature siltation of reservoirs CSS of the River Valley Project scheme was initiated in Karnataka during the 3\textsuperscript{rd} five-year plan in the catchments of Tungabhadra, Nijamsagar & Nagarjunasagar. The scheme was started during 1963-64 and in operation in 101 selected watersheds.

2.2.2 Drought Prone Area Development Programme (DPAP): The Objectives of the program are a) to minimize the adverse effects of drought on the production of crops, livestock and productivity of land, water and human resources with drought proofing techniques, b) to promote the overall economic development and improve the socio-economic conditions of vulnerable groups. The programme was first launched by GOI during 1973-74, to address special problems of drought prone areas. Based on the recommendations of Hanumantha Rao committee (1994) the programme has been under implementation on watershed basis since 1995. The allocation for the programme is shared in the ratio of 75:25 between the centre and state.

2.2.3 Desert Development Programme (DDP): The Objectives of the program are a) to mitigate the adverse effects of desertification and adverse climatic conditions on crops, human and livestock population and combating
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desertification, b) to restore ecological balance by harnessing, conserving and developing natural resources i.e. land, water, vegetative cover and rising land productivity and c) to implement developmental works through the watershed approach, for land development, water resource development and afforestation / pasture development. Over the years, the increase in human and livestock population in drought prone and desert areas has placed the natural resources of certain very arid areas under relatively greater stress. The major problems are continuous depletion of vegetative cover, increase in soil erosion and fall in ground water table. On the recommendations of the National Commission on Agriculture, in its Interim Report (1974), and the Final Report (1976), the Desert Development Programme (DDP) was started in the year 1977-78. The programme is being implemented through watershed approach under the Guidelines for Watershed development with effect from 1995.

2.2.4 NWDPRA Project: The broad objectives of NWDPRA are

i. Conservation, development & sustainable management of natural resources including their use.

ii. Enhancement of agricultural productivity & production in a sustainable manner.

iii. Restoration of ecological balance in the degraded and fragile rainfed eco- systems by greening these areas through appropriate mix of trees, shrubs and grasses.

iv. Reduction in regional disparity between irrigated & rainfed areas and

v. Creation of sustained employment opportunities for the rural community including the landless.

Centrally sponsored scheme (CSS) of NWDPRA has been in operation in the state since 8th plan period. This has been modified and restructured initially during 1992 and then later during 2002 by GOI. The 2002 restructured Jana saha - bhagithva, NWDPRA allow a much greater degree of flexibility in choice of technology, decentralization of procedures, provision for sustainability and ensures active participation of watershed community in the planning and execution for their watershed development programme.
2.2.5 Integrated Watershed Development Programme: The broad objectives of Integrated Watershed Development Program are a) an integrated wastelands development to enhance their productivity and b) aims at rural employment besides enhancing the contents of people's participation in the wastelands development programmes at all stages. This programme is implemented for improving the productivity of waste & degraded lands keeping in view the poverty, backwardness, gender & equity. Development of wastelands mainly in non-forest areas aimed at checking land degradation, putting such wastelands of the country to sustainable use & increasing biomass availability especially that of fuel wood, fodder, fruits, fiber & small timber. This scheme is under implementation since 1989-90. The development of non-forest wastelands is taken up under this scheme. The scheme provides for the development of an entire micro watershed in a holistic manner rather than piecemeal treatment in sporadic patches. The thrust of the scheme continues to be on development of wastelands. The IWDP is in operation since 1989-90 aiming at checking land degradation, putting wastelands to sustainable use and increasing the biomass availability, especially fuel, wood & fodder.

2.2.6 Western Ghat Development Programme (WGDP): The broad objectives of WGDP are a) to prevent floods and to protect the villages and lands from disastrous rains and b) development of Western Ghats regions in harmony with the environment & conservation of its fragile eco-system. The approach adopted includes implementation on an integrated watershed basis to improve the management of land & water involving various departments like Agriculture, Horticulture, Forest and Animal Husbandry. A separate Western Ghats Development Programme (WGDP) was launched in 1974-75 as a part of the programme for the development of hill areas of the country. The one-man committee headed by Dr. M.S. Swaminathan, the then Member-Incharge of the Hill Areas in the Planning Commission, settled the delineation of the Western Ghats region for inclusion in the Programme in 1981. The programme is being implemented in 159 talukas comprising of the Western Ghats in five States viz. Maharashtra (62 talukas), Karnataka (40 talukas), Kerala (29 talukas), Tamil Nadu (25 talukas) and Goa (3 talukas).

The objective of the WGDP during the 5th five-year plan, when the programme was introduced, laid emphasis on the economic well being of the population in hill
areas and exploitation of the resources of the hilly region. The 6th five-year plan stressed the need for a balance between beneficiary oriented and infrastructural development schemes, keeping in view the vital importance of ecological restoration and conservation. The financing pattern of Special Central Assistance (SCA) earmarked to WGDP is allocated among five states on the basis of 75% weightage to the area and 25% weightage to the population (except Goa in which case adhoc allocation of 5% of the total SCA is made, as Goa's share works out to be negligible by adopting the same criteria of weightage of area and population).

2.2.7 Karnataka Watershed Development Programme: The second phase of DANIDA funded Karnataka Watershed Development Project (KWDP) has been in operation in the state since June 1997, in three districts namely Bijapur, Bagalakote and Gulbarga. The project was designed for a period of seven years from 1997 and this was closed on 31st May 2004.

The project covered an area of about 28,000 ha in northern dry and north eastern dry zones of Karnataka spread over in 46 villages of 12 watersheds viz., Bijapur, Indi, Muddebihal, Sindagi taluks of Bijapur district, Hungund taluk of Bagalakote district and Chittapur, Chincholi, Afzalput, Aland, Jevargi, Shahapur, Surpur taluks of Gulbarga district.

2.2.8 NABARD Assisted Watershed Development Project: The objective of the funding is to spread the message of participatory watershed development & to replicate and consolidate the isolated successful initiatives under different programmes in the government, semi-government & NGO sectors. Watershed community, central and state government departments, banks, agricultural research institutions, NGOs & NABARD will act in concert to make a breakthrough in participatory watershed development. The union budget for 1999-2000 announced the creation of watershed development fund in NABARD. In pursuance thereof, the Board of Directors of NABARD approved the proposal of creation of WDF with Rs.100 crores contribution from NABARD and a matching upfront contribution of Rs. 100 crores from the Government of India raising the size of the fund to Rs. 200 crores. The actual allocation to the state is Rs 60 crores. NABARD – RIDF with the objectives of rejuvenation of drinking water bore well sources in drinking water problematic villages has been
sanctioned by NABARD under RIDF – 10 assistance with a project cost of Rs. 3124 lakhs to implement the project in 1286 villages covering 109 taluks in 21 districts. During 2005-06, it was planned to establish 10750 water harvesting / conservation structures with an outlay of Rs 3061.02 lakhs, against which 3435 structures has been established by incurring Rs 978.05 lakhs.

The purposes of the implementation of watershed programmes in Karnataka include improving agriculture productivity; improving vegetative cover; increasing milk and horticulture production; increasing fodder and fuel availability; reducing soil erosion; runoff and nutrient loss; improve water availability at surface and ground water; increasing household income; enhancing quality of life among local communities; local institutional development through community based organizations; ensuring institutional support by Watershed Development and Department as facilitator and by NGOs for community organization and strengthening.

Some of the lessons learnt from the past experience are weak institutional collaboration and co-ordination among various agencies, inadequate beneficiary and stake holders involvement in planning and implementation of programme with a tendency towards top-down approach resulting in lack of sustainability of project activities, weak linkage with PRIs, poor cost recovery in many programmes and inadequately defined benefit and cost-sharing arrangements, lack of appropriate and technical recommendations and norms suitable for rainfed agriculture in different agro-climatic zones, inadequate emphasis on equity aspects of watershed development, inadequate monitoring & evaluation of physical, financial performance and quality indicators.

The lessons learnt from the earlier experiences were thoroughly diagnosed and integrated into the present ongoing projects by adopting an integrated participatory approach for watershed development, using appropriate technologies along with building up of appropriate institutions to ensure peoples participation in watershed development and management, there by improving the livelihoods with equal participation of women and vulnerable groups.
2.3 WATERSHED PRIORITIZATION

Kudrat (1993) has quantified the sediment yield of the Song watershed of Doon valley spread over an area of 935 km² using RS & GIS. Indian Remote Sensing Satellite LISS II data is used in conjunction with SOI reference maps and conventional data. Sediment yield was assessed using sediment yield predictive equation (SYPE) as suggested by Flaxman (1971). Out of the 23 sub-watersheds, six are very high priority class, characterized by denuded hills devoid of forest cover. One high priority category, four moderate category and fifteen are low to very low priority category having good vegetation and gentle slope.

Watershed prioritization has also been done by Ravishankar et al. (1994) using IRS LISS I and Landsat TM data for Sitla Rao watershed of Dehra Dun district covering an area of 10,812 ha. They have also used USLE method for calculation of soil loss. Prioritization of sub-watersheds was carried-out based upon area weighted average soil loss of each micro-watershed. Erosional soil data are integrated in to digital soil physiographic map to obtain soil erosion assessment for different hazard classes. Appropriate soil conservation practices have been suggested like better forest management, check dams, improved terracing and bunding for top priority watersheds. Medium category needs improved agronomy practices based upon the land productivity classes apart from afforestation.

Priority rating based on soil loss for the sub-watersheds of Jainti watershed of Bihar is done by Kudrat (1996) using RS and GIS and modeled through USLE using Landsat TM data. The categories assigned are very high (> 50 t/ha/yr), high (40-50 t/ha/yr), medium (25-40 t/ha/yr) and low (<25 t/ha/yr) and ranked according to soil loss. Based upon severity class and loss, various conservation measures have been suggested.

Bhanu Masthan et al. (1994) have estimated annual soil loss following the method suggested by Wischmeier and Smith (1978). Input maps used for this study are contour, drainage, soil and land capability. Various derived layers viz., rainfall erosivity factor, soil erodibility factor, slope length, vegetation cover and conservation practice factors are generated for GIS overlay. Annual soil loss is computed to generate erosion susceptibility map and classified into five classes. When this map was draped over the terrain model, it gives better visualization of
erosion prone areas and subsequent location for soil conservation that is useful for land use planning.

Ravikumar (1994) has also used USLE method of soil loss assessment for optimal land use planning for Bevi Bikkenahalli Doddahalla watershed in Kolar District, spread over an area of 580 km². Various resources maps, viz., hydro-geomorphology, soil, slope and land use are integrated and alternate land use suggested.

Pathak (2001) studied the characteristics and flow accumulation of Machan river catchment for their drainage characteristics, degree of dissection, and basin shape using soil hydrology, land use, vegetation vigor and slope. The information generated is used for deriving curve numbers (CN) and runoff calculation along with flow accumulation. The catchment is divided into sub-catchments, the area of which varies from 71.85 km² to 176.34 km². Based on these computations the sub-watersheds were prioritized.

A study to map and suggest developmental measures for combating land degradation was taken up in the Sagwada tehsil of Dungtapur district (Rajasthan) by Garima Arun et al. (1994). Two season satellite data was analysed through visual interpretation technique to map various land use / land cover classes on 1:50,000 scale. The area was categorized into different priority classes based on level of data sets, developmental measures have been suggested.

Sujata Biswas et al. (1999) prioritized nine sub-watershed of Nayagram block in Midnapore district of West Bengal based on morphometric analysis of drainage basin. It was observed that sub-watershed eight had the highest priority because of high erosion intensity that was also confirmed through SYI model. Thus, morphometric analysis could be used for prioritization of sub-watersheds even without the availability of reliable soil maps of the area.

Ramesh et al. (2001) generated information on natural resources using IRS 1C LISS III data in Dakshina Kannada district. They prioritized the micro-watersheds using an elimination technique and considering the factors like current vegetation covers, wastelands, soil type, erosion status, scope for development, etc., Each of these factors were given weightings in spatial domain using Arc-Info GIS to arrive at very low, low, medium, high and very high priority micro- watersheds.
A study was conducted for the Nagwan watershed of the Damodar valley of Bihar state using contour map, soil map, GIS and satellite images of IRS 1B-LISS II to compute runoff Curve Number. The results indicated that the weighted average SCS runoff curve number of the watershed was estimated to be 61.7 and the developed empirical model, which predicts the runoff for the available events for a small agricultural watershed satisfactorily (Tripathi et al. 2002).

The SCS runoff curve number of the Hemavathi reservoir catchment area located in Hassan district of Karnataka was calculated by integrating the hydrological soil group map, land use/land cover map prepared by using IRS 1B LISS II. Antecedent Moisture Condition (AMC) and the runoff was validated with the observed runoff, which was computed from the hydrograph for a particular storm after the base flow separation. The results reveals that the calculated runoff found is $3.75 \times 10^8$ cubic meters and the observed runoff is $4.06 \times 10^8$ cubic meters (Aavudai Anandhi, 1995).

Bhat. C.M. et al. (2007) demonstrated the utility of remote sensing in delineating structural, drainage features and quantification of morphometric parameters in Anandpur Sahib Area, Punjab (India) in GIS environment. They found strong evidences like drainage basin symmetry, elongation nature of the sub-watersheds, straight to curvilinear mountain fronts and narrow incised valley floor further substantiate the role of active tectonics in the area with a strong structural control on the fluvial features.

Amee K. Thakkar et al. (2007) demonstrated the usefulness of GIS for morphometric analysis and prioritization of the mini-watersheds of Mohr watershed of Gujarat. The results of the study indicated that mini watersheds 5F2B5b2 and 5F2B5c2 which have high erosion can be given high priority for taking-up suitable soil erosion control measure thereby preserving the land from further erosion.

### 2.4 HYDRO-GEOMORPHOLOGY AND GROUND WATER PROSPECTS

In Gainmukh watershed of Bhandra district of Maharashtra integrated remote sensing and GIS based analysis had revealed that excellent ground water potential zones were associated with deep valley fill with thick alluvium, very good zone with shallow valley fills and deeply weathered pediplains, good
potential zone with moderately weathered pediplains in geological formation of Tiridi gneisses Sausar group, poor and very poor in structural hills, inselberg and linear ridges. The ground verification confirmed the above study (Obi Reddy et al., 2001).

The integrated study conducted by Raviprakash et al. (2001) in hard rock terrain of Barkha watershed of Sonebhadra district, Uttar Pradesh the authors proved the use of remote sensing and GIS for locating suitable sites for ground water exploration. Hydro-geomorphology map was prepared showing ground water prospects such as valley fills (excellent to good), buried pediplain and pediment on plateau (good to moderate), dissected plateau, pediment inselberg complex and buried pediplain shallow (moderate to poor) and denudational hills (poor).

Shah (2001) in Mirzapur district of UP used IRS 1A LISS II geocoded FCC to delineate various geomorphic units, structure features and associated landforms. Geophysical investigations carried out based on information obtained from hydro-geomorphological maps prepared on 1:50,000 scales had indicated that the ground water prospect zones identified were perfectly matching with the field investigations data.

Varzir Mahamood and Durga Rao (2001) proved that the use of remote sensing and GIS provides an excellent facility for the integration of thematic maps such as soil, land use / land cover, hydro-geomorphology, drainage and slope maps coupled with meteorological data for a fast and economical detection of ground water potential zones.

Regular receipt of feedback from over 2,00,000 case studies, have confirmed that use of remote sensing imagery followed by conventional geophysical methods has increased the success rate of locating underground aquifers to 93 percent as against less than 45 percent achieved using conventional method alone (Rao, 1991).

In Punjab utilizing the available information about lithology, land and textural contrasts in satellite imagery, geomorphic units were identified; mapped and later ground water potential assessment was made (Rajiv Chopra and Sharma, 1992).
A combination of conventional methods of survey, data collection and remote sensing techniques were used by Ravindran et al. (1992) and identified valley fills, buried pediments and coastal alluvial plains as highly prospective zones for ground water exploration.

The integrated units information on geology, structure, geomorphology, soil, land use / land cover etc derived from satellite data was used by Reddy et al. (1995) to evolve hydrologic units which were highly essential for planned exploration, development and usage of ground water resources.

Various geological and geomorphologic factors play a major role at different levels in the occurrence and movement of ground water in any terrain. Krishnamurthy and Srinivas (1995) observed that by integrating details on lithology, structure landforms along with morphometric parameters derived from the drainage map, ground water conditions in three drainage basins of Karnataka were assessed.

Various hydro-geomorphology features such as lineaments, abandoned channels, buried channels, water bodies, vegetation and flood plains were mapped at 1:25,000 scale and area with good ground water potential were identified in Saurashtra. The results from exploratory drilling showed that the remote sensing approach reduces time, expenditure and risk factor involved in conventional ground water exploration in hard-rock areas (Baldev Sahai et al., 1985).

It was known from the finding of Bassappa Reddy and Gaikwad (1985) that the use of remote sensing technique facilitates to demarcate good ground water potential zones like the moist weathered zones, stream channels and linements for further exploration and exploitation, which reduces the time and cost per unit quantity of water produced.

Using geology, geomorphology and hydrology of Nagpur, a hydro-geomorphological map was prepared by Jeyaram et al. (1990), showing five distinct hydro-geomorphological zones such as upland fractured terrain, dissected plateau, pediment zone, pediplain and alluvium. The results showed that pediplain and alluvium were having good and remaining poor to moderately good ground water prospects.
Rajiv Chopra and Tandon (1990) reported that conventional method of mapping was expensive, laborious, time consuming and require long-term hydro-geomorphological database when compared to remote sensing technique, as it provides quick, reliable and significant information for delineation of target areas for ground water exploration.

Bagepalli area of Karnataka was demarcated into four geomorphic units in a study conducted by Appanna et al. (1991) to map ground water prospects. Depending on the probability of the availability of ground water, valley fills and fractures within the pediments, pediments on granite, pediments on gneissic terrain, and residual hills and dykes were identified as good to moderate, moderate to low and poor to no yielding units, respectively.

In order to demarcate the ground water potential zones of Marudaiyar basin in Tamil Nadu, different thematic maps such as lithology, landforms, lineaments, surface water bodies, drainage density, slope and soil maps were integrated and a ground water potential zones map was prepared which was in agreement with the bore well yield data collected in the field (Krishnamurthy et al. 1996).

Hydro-geomorphological studies were conducted by Srinivasa Rao et al. (1997) in Niva river basin Chittoor district of AP using Landsat FCC. The basin was classified into different zones covered by denudational hills, residual hills, inselbergs, pediments, pediplains with moderate and shallow weathered zones and valley fills. The ground water prospects ranges from poor to very good in hills to fractured zones and valley fills.

Identification of fractures, lineaments and hydro-geomorphic units is a prerequisite for understanding ground water exploration and development in any terrain. The study conducted by Das et al. (1998) had revealed the significance of different hydro-geomorphic units and lineaments in controlling ground water potential of Keonjhar district of Orissa.

According to Reddy et al. (1998) the high-resolution data (IRS 1C) of PAN coupled with multi-spectral LISS III data provide spatial information for irrigation in different areas, helps in ground water budgeting, delineation of over-exploited areas, helps in identification of problem village to facilitate systematic planning and development of ground water.
In a study conducted by Ravindran and Jeyaram (1998) various geomorphic units and landform features were delineated and evaluated for their ground water potential on the basis of underlying lithology, structural features, topography and available data on aquifer characteristics. The study had shown that in western part of Shahbad, Rajasthan, the Vindhyan sandstones and fracture zones have vast potential for ground water development.

Hydro-geomorphological studies were carried out by Venkateshwara Rao (1998) in Vizianagaram district of Andhra Pradesh. The hydro-geomorphological, lineament, drainage, slope map and other collateral data like well yields and geophysical data had been analysed to evaluate the ground water prospective units. The result showed that shallow buried weathered pediplains and valley plains were the two best ground water prospect landforms among the seven landforms identified in the basin.

A Geomorphological analysis of degraded lands was conducted in Vena river basin of basaltic terrain located in western part of Nagpur district using IRS-1D LISS III. The integrated analysis of slope, geomorphology and degraded land layers in GIS reveals that the pediplains, rolling plains and subdued plateau are associated with very severe land degradation and accounts for 6.05%, 3.85% and 3.47% of total area respectively. The analysis of percentage of degraded lands at geomorphic sub-unit level indicates that severe land degradation process is dominant in dissected ridges, isolated moulds, escarpments and plateau spurs (Obi Reddy et al., 2002).

Vijeth (2007) demonstrated the capability of a remote sensing data and GIS technique for demarcation of ground water potential zones in hard rock terrain of the Western Ghats, Kottayam district, Kerala. The vital integrated information was used effectively for identification of suitable locations for extraction of potable water for rural population. The approach adopted was holistic in nature and will minimize the cost and time especially for identifying ground water potential zones and suitable recharge structures on a regional as well as local scale enabling quick decision making for water management.

The integrated studies of geology, geomorphology, lineament analysis, drainage density, well inventory data by Lokesh et al. (2007) indicated that lineaments,
fractures, joints and lithology controlling the drainage system in the Kallambella watershed area. They also observed that the valley regions with lineaments and intersection of lineaments are the potential zones of ground water.

2.5 SOIL RESOURCES INVENTORY

Soil mapping was carried out under IMSD on 1:50,000 scale using IRS data for many districts of Karnataka and soils were classified up to association of series. These maps were utilized for preparation of action plans for sustainable land use development (Anonymous, 1995).

Geocoded PAN merged LISS III data of IRS 1C was visually interpreted in Junewani village of Nagpur district in Maharashtra by Rajeev Srivastava et al. (2001). Based on physiography & soil relationship, seven soil series were classified as Typic Ustorthents, Typic Haplustents. They were grouped under different land capability and land suitability classes for their optimum utilization and better management.

The soil resource mapping of Rajkot district in Gujarat was carried out on 1:250,000 scale using a three tier approach viz. image interpretation, field surveys and lab investigation, and cartography. Soils were characterized and evaluated for its suitability for pearl millet, sorghum, groundnut and cotton that showed that not all the soils were equally suitable for all crops. Based on the assessed soil-site suitability, field observations and experiences, a suggested land use plan had been worked out (Sharma et al. 2001).

Soil and land use mapping of Balachaur watershed in Hoshiarpur district, Punjab was carried out by Charanjit Singh et al. (1994) using aerial photographs, IRS-1A data, cadastral maps and SOI top sheets. Six soil series were tentatively identified which were mapped as phases of soil series in plain area and as association of soil series in the hills. Village wise soil maps were prepared on the inherent soil characteristics and external land features; land capability maps for the individual villages and for the watershed were also prepared.

A field survey of red and lateritic soil under mango (Mangifera indica L.) in Karnataka was conducted by Naidu et al. (1994). They reported that soil depth,
coarse fragments, erosion and surface runoff as the major soil related constraints for crop production.

Using satellite data and topographical maps, it is possible to derive information related to physiography and vegetation with minimum fieldwork. Based on soil physiography coupled with soil sample analysis, soil map could be prepared which gives a broad understanding of various soil types present in an area (Prabhakar et al., 1996).

Soil inventory study was conducted using digital analysis of Landsat data along with conventional methods in central Spain by Labrandero and Palou (1978). The classification results differentiated soil surface features into nine bare soil classes and five classes of soil covered with vegetation under Alfisols, Entisols and Inceptisols.

The visual interpretation technique makes it possible to recognize the soil and map the soil from the spectrum of soil properties like texture, colour, moisture, structure, etc., and soil forming conditions consisting of landform, drainage, parent material, vegetation, hydrogeology, etc., reflected on the imagery (Lin Pie, 1981).

A multistage approach involving visual interpretation of landsat imagery in conjunction with geological and topographical information supported by limited field check was followed to prepare physiographic soil map in Tamil Nadu by Kanda Kumar et al. (1983). They have identified different physiographic units and soils were classified up to soil series association level.

Karale et al. (1984) studied soil mapping of Mahaboobnagar area using remote sensing techniques. The study revealed that both airborne and space borne data afford greater accuracy, economy and efficiency than conventional method at reconnaissance level of mapping.

Visual and digital remote sensing techniques were followed for generating soil and land use maps in Chitradurga district by Karale et al. (1985). They reported that digital data analysis helped better discrimination of soil and land cover classes. Soil was classified up to subgroup level.
In a study based on visual interpretation, six main landforms and further subdivisions were made in Punjab by Sehagal et al. (1985). After detailed field study, soils were classified up to association of sub-groups or great-groups of soil taxonomy. The study concluded that based on the problems of soil, suitable management practices could be suggested to increase productivity and help in macro-level land use planning.

Goyal et al. (1988) identified six major physiographic units namely, bars, levee complexes, flood plains, relict channel, river course and alluvial plains using Landsat FCC in Haryana. Physiographic soil and land use relationship was established. Based on auguring, minipits and profile studies dominant soils - Typic Ustipsamments, Typic Ustifluvents, Typic Ustochrepts and Udic Ustochrepts were classified.

It was concluded in the study conducted by Ravishankar et al. (1988) using IRS 1A data in parts of Bijapur and Belgaum that subgroup level association map could be prepared using LISS I data at 1:250,000 scale, where as mapping could be carried up to the family or their association using LISS II data at 1:50,000 scale.

Study conducted by Jayaraman et al. (1990) revealed that more accurate maps in terms of boundary delineation and composition of soil mapping units could be prepared by visual interpretation of satellite data. They also stated that the method could thus be used in revising and improving the existing reconnaissance soil maps prepared by conventional methods.

Goyal et al. (1999) utilizing remote sensing data, aerial photographs and SOI topo-sheets, geomorphic units like aeo-fluvial plains, recent sahibi flood plain and Aravally hills, rock-out crops and pediments were identified and mapped. Representative profiles were studied and soils were classified as Typic Ustipsamments, Typic Ustochrepts and Typic Ustorthents in Rewari district of Haryana.

Prasad et al. (2001) used IRS 1C PAN and LISS III data along with field observations and lab analysis, and identified nine soil series. The salt affected soils of parts of Krishna western Delta in Prakasam district of Andra Pradesh were classified into saline, sodic, saline-sodic soils developed on old tidal flats,
swale plains and beach ridges / sands. The soils were classified into Typic Ustochrepts, Fluventic Ustochrepts and Typic Ustipsamments.

Based on reflectance values, twenty-six classification codes were applied to delineate feature classes on IRS imagery in Kanpur district of Uttar Pradesh by Madhurama Seth et al. (2001). Five final classes showing very severe (pH 10.2) to moderate severity (pH 8.6) in sodicity have been classified. The soils had appreciable amounts of carbonates and bicarbonates besides chloride and sulphate. The clay complex was saturated with sodium that renders the soil barren with poor physical properties associated with water transmission characteristics. Taxonomically soils were classified into Typic Natrustalfs, Typic Natraqualfs, Typic Halaquepts and Aerie Halaquepts.

Khadse et al. (2001) based on the landscape variability and image characteristics, eighteen soil series had been identified and mapped as soil series association. The soils of the study area were grouped as per land capability classification and suitability for crops was assessed based on the number and degree of limitations. The results indicated that soils were highly, moderately, marginally and potentially suitable, or unsuitable for the cultivation of sorghum, pearl millet and pigeon pea with different degrees and intensities of limitations.

Martin et al. (2007) demonstrated the utility of remote sensing and GIS in soil inventory, prioritization of sub-watersheds using USLE model and land evaluation studies using land productivity index. The GIS analysis helped quickly to derive action plans to utilize the natural resources judiciously in the Ason river watershed, Doon valley, Dehradun district, Uttarakhand.

### 2.6 LAND EVALUATION STUDIES

Soil and land resources map was prepared using Landsat imagery supplemented by field investigations in parts of Northern Karnataka by Shivaprasad et al. (1990). Using this map, they prepared land capability and land irrigability map and areas suitable for agriculture, horticulture, forestry, pasture and other uses was suggested.
Mishra et al. (1994) conducted land evaluation studies in Balighat watershed using remote sensing and soil information system. They concluded that the physical land evaluation carried out for land use planning with the aid of remote sensing and soil information system could be used by planners for sustainable development of the watershed without disturbing the ecosystem.

Khadse et al. (2001) based on the landscape variability and image characteristics, eighteen soil series had been identified and mapped as soil series association. The soils of the study area were grouped as per land capability classification and suitability for crops was assessed based on the number and degree of limitations. The results indicated that soil were highly, moderately, marginally and potentially suitable, or unsuitable for the cultivation of sorghum, pearl millet and pigeon pea with different degrees and intensities of limitations.

Reconnaissance soil survey of Tumkur district was conducted by Harindranath et al. (2001) to obtain information on nature, extent and distribution of different soils in the district. The data was interpreted to generate various thematic maps such as land capability, land irrigability, problems, potentials, suggested land use and the suitability of soils for growing ragi, paddy, groundnut and coconut. They concluded that for agricultural development of the district the nature of the soils is known to farmers, administrators and planners before embarking on the management of land.

The soils of Rohtak district in Haryana were classified and evaluated using FAO system of land evaluation by Sangwan et al. (1994). Based on the suitability of land for different purposes and the present land use, the land resources regions were identified and suitable recommendations like growing pulses, commercial crops, agro-forestry, etc. were made in the suggested plan.

In a study conducted by Nagaraju et al. (2001) in Podili Mandal, Prakasam District, Andra Pradesh three major physiographic units were identified and soils were classified as per USDA soil taxonomy. Suitability evaluation for sunflower, tobacco, cotton and groundnut showed that pediment were marginally to not suitable for sunflower, tobacco and groundnut due to shallow depth and severe soil erosion. Deep soils occurring on weathered pediplains were moderately
suitable for sunflower, tobacco and groundnut whereas, moderate to severe limitation were observed for growing cotton.

A study was conducted by Prasuna Rani et al. (2001) using IRS 1A LISS I data for mapping black soils of Guntur district of Andra Pradesh. Ten physiographic units were identified and the soils were classified up to family level as per USDA soil taxonomy. The soils were evaluated for their suitability to soybean using Automated Land Evaluation System (ALES) into moderately suitable and marginally suitable classes.

The information generated using remote sensing data for the soil resource mapping of Ambad Block of Jalna district, Maharastra was utilized to assess the extent of irrigable land by Rajankar et al. (2001). The entire area was categorized into class 2, 3, 4 and 6 lands with moderate and severe limitations for sustained use under irrigation and presently and potentially unsuitable for use under irrigation in current condition respectively.

A soil survey and agricultural land evaluation study was conducted by Dharmesh Verma et al. (1995) using IRS 1A LISS II data. The soils were classified and evaluation studies placed the soil mapping units in II, IIw and IIIw land capability classes and 2d, 2t and 3d land irrigability classes.

The different land-mapping units derived using aerial photographs with intensive ground check were utilized for land capability classification and land irrigability classifications. Based on the land evaluation system Shanwal et al. (1988) grouped the land-mapping units into various classes and suitable land use pattern was suggested.

Mani et al. (1999) prepared a soil map showing 13 soil series and the soils were evaluated for their suitability for sustainable agriculture and irrigation by employing land capability and irrigability classification system. The results showed that the Vellar watershed was classified into three land capability classes namely II, III and IV and three land irrigability classes namely 2, 3 and 4.

In Lower Palar Manimuthar watershed, Tamil Nadu a study was conducted by Arun Kumar et al. (1999) using remote sensing technique for soil resource inventory and land evaluation. Ten soil series recognized in the study area were
classified as Entisols, Inceptisols and Alfisols. The soils were evaluated for the suitability for growing rice, sugarcane, cotton, groundnut and pulses by matching land qualities against the requirements for each crop. They concluded that the suitability classes have to be confirmed by conducting field experiments under different levels of management.

2.7 LAND USE / LAND COVER CLASSIFICATION

Singh et al. (1988) used both visual and digital techniques to delineate land use pattern. Seven land use classes including vegetation, grasslands, sand bars, riverbed, cultivated land, etc., were identified. They found that regional land use classification could easily be done with the help of remote sensing technique.

Using visual interpretation techniques, various land use patterns like vineyards, non-irrigation winter crops, bare land, woodland, etc., were identified by Toulios et al. (1990). The confusion patterns were rectified with the help of local observations, controls and the use of specified thematic maps.

Land use / land cover map of Haryana state consisting of six main categories and twelve sub categories including plantation, degraded and deciduous forest, forest blank, crop in forest, water logged area, salt affected land, etc. was prepared using IRS 1A data by Hooda et al. (1992). They suggested suitable measures to increase area under cropping.

Krishna Mohan and Narasimha Rao (1992) attempted to utilize IRS 1A, LISS II data for land use / land cover classification consisting of ten categories such as cropland, settlements, sand, coastal water, etc. Due to lack of precise ground truth, the increase in classification accuracy was not quantified.

Krishnamurthy et al. (1992) generated land use / land cover map of Ranganadi catchment on 1:50,000 scale showing built up land, agriculture, shifting cultivation, waterbodies and different types of forests including their state of degradation.

Kharif and rabi combined land use / land cover map using land use / land covers classification system with 24 categories (up to level II) under six main categories including mining and water bodies was generated on 1:250,000 scale. Pal et al.
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(1992) reported that information on land use / land cover in the form of maps and statistical data is vital for spatial planning, management and utilization of land for agriculture, forestry, pasture, economic production, etc.

Raghavaswamy et al. (1992) observed that level I classes like agriculture, forest were better defined with LISS I data, similarly level II classes like crop land, gullied land were better defined using LISS II data.

The satellite data helps in preparation of land use / land cover maps which in turn provide better understanding of land utilization aspects on cropping pattern, fallow land, forest covers and condition, waste land, surface water bodies, etc., which are vital for developmental planning (Shreedhara et al., 1992).

Srivastava and Rao Toleti (1992) prepared land use / land cover map of Jharia coalfield using IRS 1A LISS II data consisting of nine land use categories such as settlements, mining area agriculture, open scrub, etc.,. They concluded that using remote sensing techniques, basic data on land use could be obtained easily to asses the changes in an area.

Land use / land cover categories at level I and II were identified and mapped using kharif and rabi season IRS 1A LISS I data in conjunction with ground truth in Jodhpur district of Rajasthan by Surendar Singh et al. (1993). They suggested suitable cropping patterns, plant species and soil and water conservation measures for the national land use planning of different land use / land cover categories of the district.

Based on the detection, identification and classification of individual analytic element, Hussein and Loulou (1994) in Syria classified six land use / land cover categories comprising of intensive agriculture, extensive agriculture, forest, rangeland, barren land and water bodies. They reported that such classification would help in land use planning, agricultural development, forest management and natural resource conservation.

Waqar Ahmad (1994) in his study on land use / land cover mapping in North Australia, classified twenty one distinct land cover classes mainly consisting of different types of woodlands, pasture or agricultural land, grass land, cleared
land, urban area and waterbodies. He opined that remote sensing techniques help in effective management of present resources for the future.

In the study to compare visual and digital land cover classification Mas and Ramirez (1996) in Mexico, visually classified a composite image and accuracy was estimated by comparing each classification with ground information. The overall accuracy obtained by only spectral data classification was quite poor (67%) where as GIS procedures produced an overall improvement of 4 to 9 per cent. Finally, they concluded that the visual classification, presented an overall accuracy of 10% higher than that of the best digital classification, because of its capacity to integrate complex characteristics such as texture, size, pattern and association of objects, as well as the interpreter's knowledge.

The wasteland mapping on 1:50,000 scale for the entire country was carried out by National Remote Sensing Agency, Hyderabad using satellite remote sensing techniques. Thirteen types of wasteland were identified and mapped covering an area of more than eighty per cent of the total geographical area of the country. The wasteland in Tumkur district consists of 26.14 per cent of total geographical area of the district (Anonymous, 2000)

Land use and land cover exerts considerable influence on the various hydrologic phenomenons such as interception, infiltration, evaporation and surface flow. Various aspects of hydrological problems could be studied if information on land use / land cover was available for a catchment. Sreenivasulu and Vijay Kumar (2001) in a study used IRS 1B and IRS 1C data and prepared land use / land cover map showing mixed forest, agriculture with sparse habitation, open scrubs with scattered trees and water bodies. The results revealed a large change in the area of different land use categories during the period from 1958 to 1998.

A study of land use mapping of Kandi Belt of Jammu Region using IRS LISS III helped in delineating various land use categories like forest, agriculture, riverbed, urban, fallow, wasteland and water. The study also helped in suggesting various alternate land use practices. (Vijay Kumar et al., 2004).

A study on land use / land cover changes and urban expansion of Nairobi city using Landsat MSS (Multi-spectral scanner), Thematic mapper and enhanced thematic mapper plus images and GIS reveals that the urban / built areas
covered 15 km² in 1976 increased to 41 km² in 1998 and these areas further increased to 62 km² in the year 2000. Forest on the other hand has decreased substantially from 100 km² in 1996 to a mere 23 km² in the year 2000. The agricultural fields occupied 49 km² in 1976 increased to 57 km² in 1998 and further increased to 88 km² in 2000 and the expansion of the built-up areas has assumed an accretive as well as linear growth along the major roads. The urban expansion has been accompanied by the loss of forests and urban sprawl (Mundia et al., 2005).

A study was undertaken to assess erosion activity in Majuli, the world’s largest river island using IRS LISS I and LISS III comprising eight scenes of 1990, 1997, 2000 and 2002 are used. The results indicated that erosion in the river island of Majuli is due to uneven deposition, faulty land use, large-scale deforestation and frequent earthquakes of various magnitudes. Satellite images of 1990 and 2002 also revealed that the area of the Majuli Island has decreased by 39.30 km² over a period of 12 years (Sharma, 2005).

A study undertaken by Joshi et al. (2005) had a prime focus on mapping different land use / land cover classes in the cold deserts in the Nubra valley in Ladakh, India using RS & GIS. The mapping helped in identifying the important areas for biodiversity conservation, pasture development, plantation and predicting the distribution of valuable and rare medicinal herbs, which may have great potential for bio prospecting.

2.8 SOILS AND WATER RESOURCES DEVELOPMENT

Remote sensing technique could be used to obtain information on land use and its monitoring, surface water bodies, sources of ground water, suggesting sites for rainwater harvesting structures, delineation of boundaries etc., for the planning and operation of infrastructure for watershed management (Baldev Sahai and Dadhwal, 1989).

Satellite remote sensing provides data for identification of watershed characteristics such as drainage, stream network, landforms, etc. which could be used for proper management of watershed (Gawande, 1990)
Basappa Reddy (1991) reported that integration of different thematic maps like soil, slopes, drainage, hydro-geomorphology, land use / land covers along with collateral data such as rainfall, ground water level, evapo-transpiration and socio-economic data helps in providing various alternative cropping patterns and efficient packages for land / water resources management, which helps in mitigation of drought on short and long-term basis.

Information on current land use / land covers, landforms, drainage, geomorphic and morphometric characteristics, broad physiographic soil information in collation with topographic and other collateral data was used to prepare related thematic maps facilitate in planning of different soil and water conservation measures like laying water harvesting structures in the watershed.

The study was carried out for discrimination of natural salt affected soils on the FCC images of IRS 1-B in conjunction with SOI topographic maps and the satellite imagery was visually interpreted and classified into five darkness categories. The results reveals that the darkness category 1 represent fewer plant community with high salinity and gravelly surface, categories 2 and 3 were characterized by grass cover and moderate salt affected soils, whereas category 4 was dominated by thicket of *p.juliflora* with high salinity / alkalinity and category 5 represents dried waterbodies (Joshi *et al.*, 2002).

A detailed micro level catchment area treatment package for Sardar Sarovar catchment was evolved by Kimothi *et al.* (1994) using remote sensing data. The recommendation in terms of treatment plan was made to preserve forest and biodiversity in the catchment area along with development of tribal community by way of massive afforestation programmes coupled with soil and water conservation.

A National survey of potential and actual area under sericulture was completed employing remote sensing technique for Karnataka state using IRS-1A/1B and American Landsat satellite data. Study indicated that a total area of 5, 24,797 ha falling in the entire Karnataka come out as the best-suited (S1) soils to exploit immediately for sericulture programme. In addition, the actual area under mulberry 1, 20,119 ha which includes best suited as well as the other areas which are not that much best suited (S2 & S3) (Anonymous, 2001).
Thematic maps on geomorphology, geology, soil, land use / land cover, forest, drainage and slope were integrated by Krishnamurthy et al. (1994) to suggest suitable land and water resources development plan. The water resources development plan depicting the zones of exploitation through tube wells, dug wells, development and conservation through rainwater harvesting structure and land resources development plan depicting the alternate land use practices through double cropping, horticulture etc., was suggested for proper development of the area.

Decisions regarding the use of land and water resource of a backward region depend mostly on their productive potential and local priorities. As integrated approach requires information about the topographic and terrain parameters, geomorphic process, water availability, land capability and socio-economic condition of the inhabitants, a database of Chandragiri watershed, Koraput district was generated by Mohanty et al. (1994). In the action plan alternate land use practice and sites for water harvesting structures, dug wells and tube wells were suggested.

Remote sensing technique was used by Minakshi et al. (1995) in Saroa block to identify various categories of land use like wasteland, forestland, etc. They noticed that proper identification and evaluation of different categories of land use helps in delineating the areas suitable for various developmental activities, and soil and water management practices which in turn helps in formulating developmental programmes for sustainable development of the area.

Land use / land cover, soil, hydro-geomorphology, drainage, slope and transportation network maps were integrated spatially by Uday Raj et al. (1995) to arrive at composite mapping units, which were unique combination of various resources. Using this action plan comprising of alternate land use practices and comprehensive plan for soil conservation and water harvesting structures like check dams, nala bunds, etc., was suggested to improve the productivity of Hirehalla watershed in Bijapur district.

Visual analysis of IRS data was carried out by Hegde et al. (1996) in consultation with necessary collateral and ground data to generate thematic maps of land use / land cover, hydro-geomorphology, soil and land capability, drainage and slope.
The above information was integrated and suggestions for land and ground water development has been arrived based on developmental priorities and management needs.

The spatial distribution of terrestrial attributes such as land use / land cover, soil-physiographic and drainage characteristics derived through remote sensing and ground based information along with other collateral data were found to be significant towards evaluating the management priorities for development of agriculture, soil conservation, afforestation, and rainwater harvesting structures (Krishna, 1996).

Lingaraju et al. (1996) reported that integration of different thematic maps like land use / land cover, hydro-geomorphology, soil, surface water bodies generated by interpretation of remote sensing data, slope and drainage information from topomaps coupled with the socio-economic and meteorological data enable to generate development plan for land and water resources for its sustainable development.

An action plan for sustainable development of land and water resources was generated by Dwivedi et al. (1999) upon integration of landforms, soil, land use / land cover, slope with socio-economic and meteorological data, peoples aspirations, etc., in a GIS environment.

Using high-resolution IRS 1C PAN and LISS III satellite data, natural resources inventory was carried out on 1:25,000 scales. By integrating the thematic information, site-specific recommendation were given in the form of an action plan which aims at conservation, up-gradation and optimal utilization of natural resources to attain sustainable agriculture production (Bhagavan and Raghu, 2001).

Mohamed Ghouse et al. (2001) created shape file for Kangeyam, Kundadam, Mulanur and Chennimalai panchayat unions in Erode district of TN on themes such as land use, micro-watershed and village boundaries in Arc-View 3.2 GIS software. The geo-processing module in this package was used to fuse the layers and attribute tables. It was observed that the various analyses such as sediment yield estimation, soil erosion, priority of watershed based on land use, micro watershed boundaries, etc., could be done with ease.
Thematic information on soil, slope and land use was generated from remotely sensed data, topo-sheets and field survey by Patel et al. (2001) in a part of Solani watershed, Uttaranchal and Uttar Pradesh. The spatial information was integrated using GIS techniques along with the suitable criteria to prepare land use adjustment plan for appropriate soil conservation needs and proper land utilization.

The different thematic maps prepared using satellite data (IRS 1A, IRS 1B and LANDSAT - 5 TM) and topo-sheets were integrated along with collateral data to identify the potential and problematic regions. Based on resource potentials, limitations, local needs and meteorological conditions, locale-specific action plans for water and agricultural resources development through water harvesting structures, desiltation of tanks, use of efficient irrigation systems, to increase ground water recharge and conserve runoff and alternate land practices such as afforestation, raising of fodder and fuel wood and agricultural plantations were suggested for optimum utilization of resources in Bethamangala watershed (Sathish and Badrinath, 2001).

Vijay and Pradeep Kumar (2001) in a study conducted at Beguruhalla watershed utilized remote sensing data for preparing thematic maps. Upon integrating different thematic maps with the demographic and socio-economic parameters of the area, they suggested suitable strategies to achieve overall development of wastelands, checking the land degradation, soil and water conservation measures and overall improvement of socio-economic status of people.

2.9 WATER RESOURCE DEVELOPMENT

A study conducted by Prabhakar et al. (1995) in Vengasandra micro-watershed, Kolar district showed that integration of thematic maps like land use / land cover, soil type, slope and drainage would help in suggesting a sustainable action plan for drinking water supply.

Remote sensing based information coupled with ground observations enabled Panigrahi et al. (1999) in studying the geomorphic features, land use / land cover pattern, surface drainage, slope and hydrologic characteristics of the watershed. These themes were integrated and water resource management plan was suggested showing sites for digging bore wells, tube wells and water harvesting.
structures for storage of water and to increase the ground water potential of the Bajupur watershed in Orissa.

An action plan for the development of water resources was prepared by Rajiva Mohan et al. (1999) using information obtained form remote sensing and other collateral sources on slope, land cover, terrain characteristics, and hydro-geomorphology and drainage characteristics. Surface water harvesting structure such as check dam with diversion channels or gates, spring storage tank, roof top rainwater-harvesting structures were recommended.

Singh (1998) in his study identified eleven landforms, which control the development and distribution of different aquifers by using remote sensing techniques in conjunction with ground truth. He found that morphological characteristics of these aquifers led to the delineation of the recharge (donor) and recharged (receptor) zone for proper management of ground water.

In a study to suggest rainwater-harvesting structures in Gujarat, Sahai (1989) reported that use of remote sensing would provide extremely important information on multiple aspects of terrain like geomorphology, geology, physiographic, vegetation cover, etc., for locating appropriate site for rainwater harvesting structure in a given area.

The sites for ground water recharging through water-harvesting structures could be suggested based on hydrologic response parameters and hydrologic soil groups (Karale et al. 1990).

Tikekar et al. (1995) followed integration approach using geology, geomorphology, land use / land cover, soil characteristics, surface water system for systematic optimum use of water resources. They concluded that upgrading of socio-economic situation of the region (Maharashtra) could be possible if the developmental programmes were planned, considering mapped geomorphic units, surface water resources and exploitation of locked up ground water potential zones particularly in riverine sediments.

Integrated approach of remote sensing and GIS provides further insight into the hydro-geological regime of the area, which could be utilized for site selection for
artificial recharge and facilitates in decision making for efficient planning of ground water management (Saraf and Choudhury, 1998).

Chakravorty et al. (2001) in Ballowal - Sounkhri village in Hoshiarpur district of Punjab in a study conveyed an approach to water resources management through water harvesting structures. The study inferred that if the excess rainwater stored in the catchment were to be conveyed through small channels to the field as per the agriculture requirement in different seasons of the year, it would not only help in attaining self sufficiency in agriculture production, but would also reduce soil loss, recharge aquifers as well as increase agriculture production in the area.

Field experiments were conducted at ARS, Bhilwara, Rajasthan to evaluate the efficiency of recycling of harvested rainwater for rainfed crops. Jain and Kothari (2001) revealed that maximum water use efficiency of harvested water could be obtained by applying it in post monsoon period as partial irrigation to long duration crops in an intercropping system for improving crop production in dry land areas of Rajasthan.

An evaluation study was taken in Chevella watershed in the southwest part of Ranga Reddy district using remote sensing technique. Venkataramana (2001) observed that water levels had risen in the watershed due to the runoff water retained by various soil and water conservation structures with in the watershed boundary, in the long run helping the recharge of ground water and improving the level of ground water in the watershed.

A study was conducted in Bethamangala watershed, Kolar district by Sathish et al. (2001) to map ground water prospects and manage water resources using IRS 1B and Landsat data. Ground water prospects vary from poor in pediments to good in deep buried pediplains. Water resources development plan showing water-harvesting structures, soil and moisture conservation measures were suggested. Desilting programme in silted tanks was also recommended in a phased manner.

A site suitability analysis for soil and water conservation structures was conducted by Durbude (2004) in Hire watershed of Koppal district in Karnataka state, India. An integrated approach of remote sensing and GIS technique was
used to identify runoff potential zones and further suitable sites for soil and water conservation structures such as contour bunding / land leveling, farm ponds, gully plugging, percolation tanks / nala bunds etc.

2.10 AGRICULTURAL RESOURCES DEVELOPMENT

Rao (1991) was of the view that remote sensing has provided a unique opportunity to reshape our thinking for achieving the objectives of sustainable development and also provide food security to the increasing population with limited land resources even under drought and flood conditions.

Sustainable development of natural resources is based on maintaining a fragile balance between productivity functions and conservation practices through monitoring and identification of problem areas that require application of alternate agricultural practices (Anonymous, 1994).

It was known from the finding of Shreedhara et al. (1996) that the integration of land use/land cover, hydro-geomorphology, drainage, slope and transportation along with information on rainfall and socio-economic data indicated the local specific problems to come out with long and short-term solutions for sustainable development of Lingsagur taluk, Raichur district.

Geographical information system could be used to digitize spatial data into digital format. Maji et al. (1998) were of the opinion that land information generated through soil resource mapping could be used to prepare thematic maps for suggesting suitable land use plan.

Development of a district depends upon proper planning based on reliable information about its natural resources, socio-economic conditions and demographic set up. Gupta et al. (2001) conducted a study to develop a spatial model for Dehra Dun district under GIS environment for planning. The model would assist in identifying the villages that lack the infrastructure facilities and the villages where new developmental inputs have to be provided in the least developed block of Dehra Dun district. The information thus generated would be useful to the planners and decision makers of Dehra Dun district.
Computer based natural resources information system is a vital tool in the development of management strategies of our vast natural resources. Soil survey was conducted in Bastar district of Chattisgarh by Maji et al. (2001) and information as extracted as an input to the soil resources database. Different thematic maps on soil depth, slope, soil erosion, pH status, etc., was extracted using GIS which could help the land users and land use planners in demarcating for alternate land uses.

Sharma and Ravindran (1999) prepared a land resources development action plan showing alternate land use practices like agro-forestry, gap afforestation, etc., in Arc-Info GIS Software by integrating land use / land cover, soil, slope and hydro-geomorphology in Uttar Pradesh.

Using the capabilities of remote sensing Rao et al. (1994) in Tettuvanka watershed of Andhra Pradesh suggested optimum land use plan farming systems for sustainable development of the area.

Remote sensing data was used by Balak Ram et al. (1995) to identify recent land use changes in the arid region of Rajasthan and finally with the help of land use and other resource maps. An alternative land use system for sustainable development has been suggested.

On integration of hydro-geomorphology, land use / land cover, slope, soil, water quality, surface water bodies / drainage maps along with other collateral data, an action plan depicting various packages like sand dune stabilization, agro-forestry, agro-horticulture, etc., was generated by Bora et al. (1995). They opined that these recommendations could lead to real need based strategy to combat drought.

Srivastava et al. (1995) with a view to ensure optimum utilization of land resources, classified different land use categories using satellite imagery and an action plan was suggested for better utilization of land resources.

The information on land use, soil, hydro-geomorphology, drainage, slope, climate and socio-economic data were integrated and suitable action plan packages like agro-horticulture, silvi-pasture, afforestation, etc., were suggested for sustainable development of Humnabad taluk, Bidar district (Ashoka Reddy et al., 1996).
A study conducted by Kushwaha et al. (1996) showed that upon integration of natural resources like landforms, soil, ground water, current land use, etc., along with climate, transport network, socio-economic data, a realistic action plan showing alternate land use practices in terms of areas suitable for sand dune stabilization, horticulture, agro-horticulture and agro-forestry could be prepared for sustainable rural development.

A study of Jaipur district has been taken to prepare a detailed resource evaluation for the district using Landsat and IRS 1A images for the period of 1972-1982 reveals that quaternary sediments of Aeolian origin cover the major part of the district with thickness varying from 10 to 100 m. Soils vary from sandy loam to clay loam and southern part of the district has deep calcareous sub-soils. Area under dense forest has decreased from 412 km$^2$ to 11 km$^2$. Dense forested area has been converted into degraded forest. In addition, the hydro-geomorphology analysis reveals that about 50 per cent area of the district has high to very high water potentiality. The water table ranges from 5 to 30 m and 31.31% of the total geographical area of the district was under wasteland in 1982 and sandy wastelands has decreased from 26.95 to 12.55% (Saini et al., 2001).

2.11 SOCIO-ECONOMIC STATUS AND ITS RELEVANCE TO SUSTAINABILITY

The information obtained on natural resources along with relevant socio-economic data and other inputs were integrated for taking up strategies for development of natural resources on long-term basis to combat drought (Rao, 1988).

Information on land resources and possibility for their sustained use is essential for the selection, planning and implementation of land uses to meet the increasing demands for basic human needs and welfare. Bronsveld et al. (1994) showed that an integrated information system using a GIS describes the current state of natural resources, socio-economic conditions and changes that result from actions of the people, which helps in decision-making.

Rao (1994) in his study concluded that the optimal utilization of land, appropriate soil and water conservation practices along with socio-economic development of the area would lead to sustainable increase in crop production.
Socio-economic data along with physical data on land use planning helps in knowing the constraints of recent land use and creates conditions in which specific social, economic or environmental goals like sustainability, food self-sufficiency, income generation and environmental conservation could be attained (Anaman and Krishnamra, 1994).

2.12 WATERSHED MONITORING

A review of performance of watershed programmes implemented during last 20 years reveals their potential for drought-proofing, agricultural growth, environmental protection and employment generation.

MoRD conducted a comprehensive evaluation of watershed programmes in 16 states covering 221 districts in 2001. A compilation of the results (TERI, 2004) showed overall improvements in land use, increase in net sown and gross cropped area, expansion in irrigated area, greater fuel wood and fodder availability, higher incomes and employment opportunities from majority of watersheds in all states.

During an exhaustive review of 311 watersheds under the 'meta analysis' of the impact of watersheds programmes by ICRISAT (Joshi et al. 2005), found in treated watersheds soil loss reduced by 0.82 t/ha/year in 51 watersheds, rate of runoff reduced by 13% in 36 watersheds, irrigated area increased by 34% in 97 watersheds, cropping intensity went up by 64% in 115 watersheds and an additional employment of 182 person days/ha/year has been created in 39 watersheds and in some watersheds it went up to 900 person days/ha/year. The benefit cost ratio (BCR) figures for most of the watersheds were around 2.14. Only 15% of watersheds had BCR > 3. The mean internal rate of return (IRR) was estimated at 22%. The maximum IRR was 94% and 35% of watersheds had IRR > 30%. The results clearly indicated that investment under watershed development programmes is justified under these fragile and uncertain environments.

A survey of 16 villages (Shah, 2005) in Gujarat indicated that more investment and intensification of effort is required to consolidate the gains from watershed development. A study of three watersheds under the IGWP in Ahmednagar district of Maharashtra (Crispino Lobo, 1996) showed nearly 300% increased
irrigated area and 50% cropped area after implementation of watershed programmes. A study conducted by Development support centre (Chaturvedi, 2005) in eight watersheds located in different parts of Gujarat indicated high BCR ratio's in the range of 4.06 to 15.72 that can be attributed to increase in cropped area shifts in cropping pattern and improvements in productivity due to adoption of advanced technologies and practices in cultivation.

A review of 120 selected households in four watershed projects in Gujarat (Shah, 2000) found that after four years of implementation irrigated area almost doubled in all watersheds, reaching about 18% of the land held by the beneficiaries, cropping intensity also showed a rise. The total net return increased by 63% and the drinking water availability increased in 87% of the households in these watersheds. About 71% of the landless reported better availability of employment opportunities in the post project period. The overall cost benefit ratio (BCR) observed was 4.07.

A study of impacts in five watersheds in Andhra Pradesh (Reddy and Ravindra, 2004) by Watershed Support Services and Activities Network (WASSAN) found that overall BCR of watershed intervention in four watersheds varied between 1.10 and 3.78 and found that the investment payback period of watershed project is 2 to 3 years. An evaluation study by State Water Mission in Andhra Pradesh showed that out of nearly 2000 watersheds, water level showed improvements in as many as 90%, despite a fall in rainfall by 28%. About 0.17 Mha of land brought under cultivation and the migration of labour reduced in the range of 10 to 40%.

A study of six IWDP watersheds (Sharda et al., 2005) showed that various mechanical and biological measures could reduce runoff by 58%, soil losses from watersheds were reduced by 52%. The study also reports that the water storage capacity created was on an average 47,400 cubic meters per watershed, which increased the recharge rate by 20 to 50%. The overall productivity of the watershed measured through a crop productivity index rose by 12 to 45% in treated watersheds.

The Action Research Unit (TARU) of the Rajiv Gandhi Drinking Water Mission for watershed development in Madya Pradesh showed that the cropped area increased in 46 of the 58 villages, improvement in ground water levels in all
villages and all households benefited from direct wage employment. The long-term employment impact was not clear. The direct impacts observed by TARU in these watersheds are the payment of equal wages to men and women and that reservation for women has far-reaching impact to gender quality.

At the instance of State Watershed Development Programme (SWDP), Government of Karnataka, monitoring and assessment of changes in 20 watersheds spread over 19 districts of Karnataka state were carried out using satellite remote sensing technology. IRS data pertaining to pre and post treatment periods of each watershed have been analyzed at RRSSC of ISRO in Bangalore. The changes in terms of increase / decrease in cropped area, plantations, land cover transformation to agro-horticulture and agro-forestry, changes in the number and spread of water bodies, reclamation of wastelands, biomass changes etc., were observed in the treated watersheds. Among the 20 watersheds of different agro-climatic zones studied, improvement and progressive changes ranging from 7 to 27% have been observed with in a span of 5 to 7 years. The performance is found to be better in dry land rainfed farming areas. Watersheds of the medium rainfall zones had given good results than high or low rainfall regions.

Under NWDPRA – Monitoring and Evaluation project using RS and GIS techniques was completed in 120 watersheds spread across 12 state of the country with the participation of five RRSSC’s of ISRO was recently completed. Rainfed Farming Systems Division (RFSD) of MoA, Government of India New-Delhi, sponsored the project. During first phase of the project, sixty watersheds spread over six states of Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu and Uttar Pradesh were identified for impact evaluation. Evaluation of 51 watersheds was completed. State wise reports were submitted in addition to consolidated report for all completed watersheds. It was observed that there were progressive changes in the treated watersheds. The change ranged from 5 to 40% depending on the rainfall regime and protective measures taken by the implementing agencies. The remaining 9 watersheds treated during 8th five-year plan of the Phase I and 62 watersheds of Phase II of the project treated during 9th five-year plan period, spread across the twelve states of Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Uttaranchal, Uttar Pradesh and West Bengal have been taken up. The
project work is initiated and shared among all the five RRSSC's of ISRO, Bangalore. The project is completed covering all the watersheds and state wise reports have been generated and forwarded. This report covers the results of monitoring and evaluation carried out for 62 watersheds in Phase II in twelve states.

A study on monitoring and evaluation of NWDPRA watershed of Andhra Pradesh was taken up using IRS 1C/1D LISS III and GIS. The overall improvement in the land and water resources development varied from 5.01 to 25.22%. The study indicated increased area under Horticulture / Forest plantations, expansion of area under cultivation, changes in cropping pattern, change in waterspread area and reclamation of wastelands for productive use (Anonymous, 2004).

The satellite based monitoring and evaluation of NWDPRA watershed of Gujarat, carried out using IRS 1C/1D LISS III data indicated that there are no remarkable changes in land use pattern in Guhai-5-1-L, REL-1-R and Sabarmati-27-R watersheds. However, the change is significant in Ru-2-1-8-L, which reveals that the land use change is towards the negative direction. On the other hand, for M-9-2 watershed i.e. the land use change is positive. Overall direction of changes in land use indicates that positive change in M-9-2 and REL-1-R, negative in Ru-2-1-8-L, unchanged in Guhai-5-1-L and Sabarmati-27-R. Highest positive change is observed in M-9-2 (32.14%), followed by REL-1-R (32.14%), Guhai-5-1-L (16.81%), Ru-2-1-8-L (14.05%) and Sabarmati-27-R (10.35%). On the other hand, highest negative change is observed in Ru-2-2-8-L, followed by Sabarmati-27-R (13.25%), Guhai-5-1-L (12.30%), M-9-2 (8.76%) and least by REL-1-R (7.81%). More than 50% area is under no change for all the watersheds indicate that the dynamics is active in half of the areas only (Anonymous, 2004).

Monitoring of land use/land cover and biomass changes of Peddakalavapalle watershed of Andhra Pradesh by using IRS 1C/1D satellite data and GIS reveals that area under waterbodies and irrigated lands increased by 18.06 ha (0.21%) and 486.48 ha (5.9%) respectively. The area under Kharif croplands increased by 657.62 ha (7.98%) due to the fact that more areas of wastelands and scrubs were brought into cultivation (Naidu, 2002).
The satellite based monitoring and assessing the changes in nine watersheds spread over nine districts of West Bengal State carried out using IRS 1C/1D LISS III data indicated that the overall improvement in the land and water resources development has been observed varying from 15 to 42% in the nine watersheds distributed in different districts of West Bengal State after the implementation of NWDPRA development programmes (Anonymous, 2004).

Landuse change of Bei-Tun region of Taichang city in Taiwan was studied using SPOT -HRV XS satellite images, results show that urban region has grown rapidly, while the metropolitan area in a level terrain, and the surface area or district of the region will be a large and valuable development site at the Da-Kan region (Chou et al., 2005).

Satellite based monitoring and evaluation of selected treated NWDPRA watersheds of Tamil Nadu using IRS 1C/1D LISS III Satellite data indicates increased area under cultivation both dry and irrigated, horticulture, agro-horticulture / agro-forestry (tree cover), and more number of waterbodies, reclamation of wastelands for productive use, better live stock management in these watershed. The overall improvement in the land and water resources development in these six watersheds of Tamil Nadu state after the implementation of watershed development programs during 9th five-year plan period varies from 9.55 to 19.24% (Anonymous, 2004).

A study on monitoring and evaluation of NWDPRA watershed of Uttar Pradesh was taken up using IRS 1C/1D LISS III and GIS. The results indicate that almost 40-50% positive improvement in vegetation characteristics is noticed in the watersheds due to the fact that more areas of wastelands, scrubs, change in the cropping pattern, reduction in the current fallow etc. were brought into cultivation and about 35-40% of land area within watersheds does not bear any significant change in their vegetation density status. These areas belong to arable land being cultivated where cropping pattern remains same or the un-treated wastelands. Almost 15-20% area of watershed has witnessed negative trend in vegetation characteristics during the period 1997-2002. These may be attributed to changes in cropping pattern i.e., from irrigated to dry land crops, land left fallow, etc. (Anonymous, 2004).
A study was undertaken to assess the landscape dynamics in Hokersar Wetland, one of the best resorts of migratory waterfowl in Kashmir using IRS 1D LISS III image of May, 1994 and October, 2000. The analysis reveals that the cultivated land is increasing at the cost of marshy land while the marshy land is taking place of the open waterbody. It also experienced the loss of habitat for varied aquatic flora and fauna. The number of macrophytic plant species has decreased from 90 to 25 and the species of high economic importance have disappeared from the areas (Joshi et al., 2002).

The foregoing discussion reveals that problems in surveying and inventory of land and water resources are varied and wide. Remote sensing seems to provide a shot in the arm by either substituting or supplementing the conventional technology with reasonably faster and efficient methods of survey and inventory in the domain of landuse and water resources planning, conservation, development, management and utilization. Its application culminates in harnessing the natural resources with incredible speed and reasonable accuracy, it stands unique in respect of its use in collecting meaningful data from remote sensing and inaccessible areas, it differentiates itself clearly from the conventional data collection techniques and renders information on natural resources from aerial and orbital platforms through its spatial, spectral and temporal attributes. The necessity of resource planning and management at the earliest mixed with the above said benefit tempt us to make use of the vast scope of remote sensing.