CHAPTER - I

INTRODUCTION
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1.1 GENERAL

Like Air, Water is an essential and a mandatory resource for all the living beings on the surface of the Earth. This is the reason why all the ancient man has started his habitations only in the river valleys and in the plains located in close proximities to the riverine systems. However, as the population has started growing, the man has started gradually spreading over to the adjacent plains and then to the uplands and finally even to the hilly areas. But wherever he has spreaded, he has moved and settled only in areas of rich water resources. Again, the phenomenal population explosion and its induced competitive and unregulated usage of surface water resources has started causing greater depletion of surface water resources. In addition, the human induced pollution has further caused depletion of available surface water resources. So, the man has started searching and tapping the groundwater resources. Such groundwater resources which became a bonanza for the mankind, too, has started depleting because of the over exploitation of the aquifers. So, the man was driven to hunt for more and more newer groundwater resources and obviously he started using modern technologies like hydro geological surveys, geophysical exploration, computer based numerical models, remote sensing, Geographical Information System etc.

Even then, the success rate in groundwater targetting was not that much appreciable in crystalline rocks which unfortunately covers 70 - 80 % of the planet Earth. The reasons for such low success rate in hard rock aquifers are due to the heterogeneity of the groundwater mobility and stability which are again due to greater variance in lithology, varying degree of deformation (fracturing), variance in depth of weathering etc. Hence, even after the advent of many modern technologies, groundwater targetting has been a challenging task for the man in hard rock aquifer systems.

However, after the availability of hyper altitude satellite pictures, the groundwater targetting in hard rock aquifer systems appears to have become little easier, as these space borne pictures have the credibility to vividly display the fracture systems which
generally act as the master conduits for the groundwater movement in hard rock areas. Even that happiness too became short lived because some of the fractures turned out to be water barren and only certain fractures seem to be water bearing. Hence, the Scientists and the technocrats were again driven to understand the fracture genesis, morphology, dynamics etc for precise ground water targetting in hard rock aquifer systems.

When such race for water hunting in hard rock region has continued on one side, the man was also driven to find measures to restore the fastly depleting water table all over the world. And thus, the geoscientists and technocrats of all over the world have started the race of finding “ways and means” for recharging the fastly depleting aquifer systems.

So, keeping all in mind, the present research study has been undertaken in an area of over 1300 sq.km, which represents a typical hard / fractured aquifer system, to understand the behaviour and the functions of groundwater systems and to evolve strategies there from for precise ground water targetting in hard rock aquifer systems.

In this study, a large amount of multivariate data were used both from the aquifer parameters as well as from the groundwater controlling variables and the NT ARC / INFO GIS has been extensively used in this study so as to understand the behaviour and the functions of groundwater systems.

Accordingly in this study GIS data bases were generated on various aquifer parameters such as water level, transmissivity, permeability, storage co-efficient, specific capacity, optimum yield, width of aquifer depletion, recovery rate and the overall aquifer performance and on the controlling parameters like lithology, lineament density, geomorphology, subsurface geological parameters etc. These were integrated using GIS technology so as to finally understand the ground water behaviour in hard rock aquifer systems. Deeper studies were also carried out between the fracture systems and the aquifer variables.

1.2 PREVIOUS WORK

Before carrying out the present research study, it was felt mandatory to scan all the available literature / studies carried out by various workers around the world and in the Indian sub continent too, so that, the experiences gained in each and every study and the
strength and the weakness could be understood in their studies and there from proper methodology can be carved out for the present study.

Such literature review was broadly grouped under the following five categories which have direct bearing for the present study

- General groundwater studies
- Aquifer parameters evaluation
- Remote sensing based studies
- Numerical / statistical analysis
- GIS based studies etc.

1.2.1 International Scenario

1.2.1.1 General Groundwater Studies

In the field of groundwater exploration, especially in the aspects of general groundwater exploration techniques, the studies of Meinzer (1923, 1934) have almost marked the beginning of groundwater research.


Similarly, the studies and the documentations made by Todd (1959) again marked the beginning of groundwater era and he has poured enormous information on groundwater occurrence, movement, well hydraulics and various groundwater investigation techniques and also some aspects of groundwater modelling techniques also.

The scanning of International literature have also shown that studies were also done by many bringing out a lot of details on the fracture systems, joints and the fault systems and the groundwater movement. Significant amongst them are the studies carried out by Larsson (1963, 1967, 1972, & 1983), Larsson and Cederwall (1980), in South Sweden, Simonot and Thauvin (1971) in Morrocco, Tate et al., (1971) and Bhatt et al. (1975) in parts of Kenya.
Garrels (1967) has brought out some first time details on the genesis of groundwater in igneous rocks.

Larsson (1968) has elaborated the common problems expected in hard rocks by taking precambrian rocks as test areas from southern Sweden.

Utility of borehole logging for artificial recharge was elaborately investigated by Keys and Brown (1970) in Ogallala Formation.

The geoscientists have also made detailed attempts to understand the control of lithology like granites and gneisses and also the degree of weathering over the groundwater movement (Thomas 1971, Larsson et.al 1972, Bannerman 1973, Taylor 1979).

The studies by Simonot and Thauvin (1971) appear to be good attempts in bringing out the groundwater behaviour in the fault systems associated with chains of dykes in Morracco.

Similarly, the studies by Tate et al., (1971) were some of the newer attempts made to understand the groundwater behaviour in bore holes.

Studies of Warner and Moreland (1972) have given some first time information on the artificial recharge and the related problems in Twin creek areas of California.

The efficiency of geoelectric methods towards hydrogeological interpretations were brought out by Deepermann and Thiele (1973)

Landers and Turk (1973) have brought out details on the groundwater quality variations and their controls in crystalline formations of Texas region.

The concept of using isotopes in groundwater hydrology appeared to have become popular during 1970’s (Gat 1974).

Similarly, Dincer et.al (1974) have extensively used stable isotope and salinity data for evaluating the groundwater recharge and movement in shallow as well as deep aquifers in Saudi Arabia.
On the contrary, again the studies by Bhatt et al. (1975) have brought out some newer information on the morphotectonic evolution of parts of Kenya and their linkage with groundwater system.

Again the studies of Levin et al. (1980) have thrown detailed light on the efficiency of the isotopes in understanding the precipitation, flood and groundwater behaviour in Negev highlands.

The second edition of the book entitled Groundwater Hydrology by Todd (1980) has given a very comprehensive synthesis on the various aspects of groundwater.

Cochran (1981) has brought out some details on the potentials of artificial recharge for Oklahoma city, for Ogallala aquifer.

The studies on the migration of pollutants in groundwater by Cherry et al. (1983) have given very new ideas in that field.

The utilisation of resistivity and magnetic surveys for groundwater prospecting in volcanic areas of Puy De Dome, France has given very new ideas in the field of groundwater research. (Aubert et al. 1984)

Khan et al. (1986) have brought out details on integrated studies for groundwater targeting in Rajshahi city and its surroundings.

Amongst many studies, the studies carried out by Erdelyi and Galfi (1988) have evaluated certain newer ideologies and methodologies in mapping the surface and subsurface geology which has bearing over the aquifer performance.

Studies have also been done on the effect of Soil types on groundwater recharge in Mallee region (Cook and Walker 1990).

The studies by Bromley et al. (1994) have brought out some newer information on the application of Airborne geophysical data for groundwater investigation in Botswana.

Studies of Khan and Sattar (1994) have discussed the environmental issues of the part of Barind due to over exploration of groundwater.

Kimblin (1995) has attempted to evaluate the origin of groundwater in Triassic sandstone and Quaternary deposits of northwest England from the geochemical data.
Farah et al. (1997) have explained some newer methodologies and ideas for groundwater resource mapping in semi-arid tracts of Sudan.

Azad and Bashar (2000) have prepared groundwater zonation maps of Nawabganj Sadar Thana from the groundwater geochemistry.

1.2.1.2 Studies on Aquifer Parameters Evaluation

As the days passed by, the geoscientists have started feeling that, there is a need to study the aquifer parameters for precise groundwater targeting and management and accordingly started studies on vital performances of the aquifers like transmissivity, permeability, specific capacity, specific yield etc.

The studies of Ambrose (1931) and Fox (1952) have enumerated the usage of radio active isotopes in groundwater movement studies.

The studies of Givan (1934), Hiekes (1934), Hatch (1940) and Fransini (1951) have brought out very significant information on the groundwater movements in general and in granular media in particular.

Chow (1952) has brought out some newer methodologies for the transmissivity and storage coefficient of the aquifers from the pump test data.

Brown (1953) has catalogued various procedures for analysing the aquifer characteristics data and brought out an International guide for the first time, which is still rated as the pioneering work all over the World.

Boulton (1954) has brought out newer information on the aquifer parameters of the unconfined aquifers.

Whereas, the studies of Irmay (1954) and Bouwer (1963) have dealt appreciably the hydrological conductivities of the aquifer systems.

Boreli (1955) and Hantush (1962 & 1969) have conceived certain new techniques of aquifer evaluation in partially penetrated wells in multilayered aquifer systems.

The studies of Kaufman and Orlob (1956) have explained the utility of chemical tracers for predicting the groundwater movement.
Then in 1960's Meyboom (1961) and Ramasahoye and Lang (1961) have added further newer information in the sphere of aquifer parameter evaluation.

In addition, Ramasahoye and Lang (1961) have developed simple methods for determining specific yield from the pump tests.

On the contrary, Jacob (1963) has made a monumental contribution in the field of pump test analyses.

In the subsequent years, Knisel (1963), Ramussen (1964), Rofail (1965), Snow (1969), Boulton and Streltsova (1976) have added newer concepts in aquifer parameters evaluation in the typically fractured aquifer systems.

The technique of estimating the transmissivity through graphical method was profounded by Csallany (1966).

Whereas Hurr (1966) has introduced different technology for the estimation of transmissivity and specific capacity of the aquifers.

In the subsequent years Papodopulos et al. (1967), Gringarten and Witherspoon (1972) Zhdankus (1973) Sammel (1974), Boulton and Streltsova (1976) and Herbert et al. (1992) have evolved certain newer techniques to evaluate the aquifer parameters from the pump tests using some standard curves.

Schoeller (1967) has given many newer information on qualitative estimation of groundwater resource.


The studies of Gale's (1982) have given the first time lab and field based information on the hydraulic conductivity of the fractures.

Careera and Neuman (1986) developed a newer method for estimating the aquifer parameters under transient and steady state conditions.
Condon *et al.* (1993) and Pyne (1995) have identified some parameter estimates for developing groundwater models.

Begum *et al.* (1997) have brought out methods for groundwater targeting and management for Barind area, Bangladesh using hydrological parameters data.

### 1.2.1.3 Remote Sensing Based Studies

The birth of remote sensing technology has not only opened up a lot many new vistas in groundwater research but also has started giving well defined directions in achieving precise models for groundwater exploration, as these air borne and space borne pictures have unique potentials in displaying the pattern and the spatial designs of the various aquifer systems. Hence, the geoscientists seemed to have embarked in to a number of studies in mapping the lithologies, geological features, geomorphology, surficial features reflecting the sub surface geology etc.

Howe *et al.*, (1956), Ray (1960), Boyer and Maquen (1964), Lattman and Parizek (1964), Setzer (1966), Trainer and Ellison (1967) and Mollard (1968) have used black and white panchromatic aerial photographs for mapping the fracture systems / lineaments for groundwater targeting which all have provided first time remote sensing based groundwater research and exploration.

From 1973 onwards, after the launching of the operational remote sensing (ERTS) satellite by NASA, the geoscientists have started using multispectral orbital images for groundwater search.

During the earlier period of hyper altitude remote sensing era, many hydrogeological, structural and hydrogeomorphological studies were carried out in different parts of the world. (Brockmann and Fernandaz 1973, Anon 1974, Bowden and Pru 1975, Moore and Duestsch 1975, Brockmann *et al.* 1977, Versatappan 1983, Shih and Doo Little 1986, Mc Moore 1986, Ottle *et al.*, 1989 and Waters 1989a & 1989b). These workers have used both raw and the digitally enhanced satellite multispectral data for their investigations.

Schowengerdt *et al.*, (1979) have interpreted the lineaments and other geologic structures again from computer enhanced Landsat imagery for a large area and identified the promising areas for groundwater in Arizona.
Zall and Russell (1979) and Fransworth et al., (1984) have used satellite and aerial data and mainly identified the fracture traces for groundwater exploration in Africa and in Paris respectively.

Regan and Jackson (1980) have developed a runoff model using Landsat images.

Driscoll (1987) has stated that the interpretation of aerial photographs can help in identifying the important hydrologic information like faults, joint systems, old river courses and the contact between moraines and outwash plains and thus, the delineation of groundwater recharge and discharge zones as well as the differences in groundwater level etc.

1.2.1.4 Numerical Modelling

The geoscientists who were initially relying on the general mapping of the aquifer systems, assessment of the aquifer behaviour and remote sensing based appraisals, they were simultaneously driven to approach the groundwater problems using the quantitative techniques by using statistical tools and other computer models.

The work carried out by Domenico (1972), Clarke (1973), Clarke (1981), Ganoulls and Morel-Seytoux (1985) and Mc Cuen and Snyder (1986) have elaborated many statistical techniques for estimating the aquifer parameters quantitatively. Some of the workers appeared to have used the time series and trend surface analyses respectively for temporal forecasting and spatial extrapolation.

The research studies carried out by Ramson and Randolph (1958), Rockaway (1970), Jackson (1974), Yakowitz (1976) and Torelli and Tomasi (1977) have made attempts on time series analysis and trend surface analysis for groundwater appraisals. These researchers have widely used the above such analyses for water level and other aquifer parameter predictions.

Similarly, the statistical approaches like bivariate regression analysis and multivariate regression analysis including discriminate functions, cluster, principal component analysis and factor analysis were attempted very widely by many workers for understanding the hydro geological behaviours. And in numerical modelling, applied probability techniques involving linear correlation and multiple correlation also have been used very widely by many workers in hydrogeological studies. Significant amongst them


Boonstra and De Ridder (1981) have developed a numerical model for groundwater by duly analyzing the geological and hydrological nature of the basins in Wageningen, The Netherlands.

Govindarajulu and Koelliker (1994) have developed a linearised Boussinesq equation model for estimating certain aquifer parameters.

Hantush and Marrino (1994) have carried out a two dimensional stochastic analysis and optimum estimation in various aquifers.

Workman et al (1997) have developed an analytical model for the stream and aquifer interaction study.

1.2.1.5 GIS Modelling

The recently born GIS technology seems to have opened up many vistas both in surface and groundwater exploration owing to its special credentials of storing, manipulating and producing spatial designs.

The utility of Digital Terrain Model (DTM) has been discussed by many workers for water resources applications (Schut 1976, Doyle 1978, Faintich 1984, Makarovic 1984, Day and Muller 1989 and many others)

The study of Arnold et al. (1989) appeared to be mainly integrated models with GIS.

Fedra (1993) has brought out a lot of detailed studies in general resources modelling using GIS.
Biesheuvel and Hamker (1993) have integrated MICRO-FEM, a finite element groundwater model and ILWIS (vector and raster based GIS).

Hoogendoorn et al. (1993) have evolved a methodology for the execution of regional geohydrological models using GIS.

Loucks (1993) has narrated the potentials of incorporating video and audio within the GIS based simulation models.

Merkel and Sperling (1993) have evolved a first time model which enabled hydrogeologists, in flow modelling using raster GIS.

Whereas, the browsing of papers by Nachtnebel et.al. (1993) showed their experiences in the application of GIS in water management.

A water balance model was worked out by Van Deursen and Kwadijk (1993) for the river Rhine in The Netherlands.

The earlier workers like Elumnoh (1993) Parker (1988), Marble et al. (1983), Jackson and Mason (1986), Ehlers et al. (1989) and Davis and Simonett (1990) have contributed different models of integrated remote sensing and GIS.

De Lange and Van Der Maij (1993) have developed national groundwater model for The Netherlands by duly integrating the geohydrological data, bore hole data, geophysical data and groundwater data.

Furst et.al. (1993) have developed certain newer concepts on GIS for groundwater management, which is basically a Decision Support Systems (DSS).

Whereas, the studies of Olivier and Mc Pherson (1993) have provided ideas on GIS on water management in developing region like South Africa.

Whereas, Jemma (1993) has developed a New GIS based Methodology for water resources management at basin levels.

On the contrary, Stibiz et.al. (1993) have attempted GIS modelling for a multi layered aquifer system in Austrian-Bohemian border.

The studies on the subsequent years were also revolving around spatial analyses and modelling of aquifer functions, evaluation of hard rocks aquifers etc.
1.2.2 National Scenario

Remarkable contributions have also been made by the Indian Scientists in groundwater exploration, aquifer parameters evaluation and various aspects of aquifer modelling through conventional as well as modern techniques like remote sensing, geophysics and GIS.

1.2.2.1 General Groundwater Techniques

During late 19th century, in the Indian subcontinent too, the scientific methods of groundwater exploration have started.

Couison (1940) has brought out a very comprehensive picture on the undergroundwater of Calcutta.

Banerjee (1963) has brought out a detailed and elaborate picture on the groundwater conditions of the entire west Bengal including the deltaic tracts of the coastal aquifers.

Adyalkar (1964) has brought out the regional palaeogeography on the sedimentary tracts of the western India and there from he has attempted to bring out the groundwater potentials of western India.

Vast alluvial tract east of Durgapur, Burdwan district, was discussed in detail for it's Geology and Groundwater conditions by Das and Biswas (1969)

Adayalkar (1970) has contributed very significantly in groundwater exploration in multi-layered Trappean aquifer systems. Groundwater studies of Indravathi basin of Bastar district (Adayalkar and Radhakrishna 1972), groundwater possibilities of the metropolitan around Nagpur (Adayalkar 1973), the general groundwater exploration techniques (Adayalkar 1974) and groundwater hydraulics in the Trappean environment of Central India (Adayalkar and Gajbhiye 1975) were some of the very salient contributions made by Adayalkar and his co-workers.

Reddy (1973) has carried out a exclusive study on the groundwater condition in Siwalik tracts of Ambala district, Haryana.

Sharma (1973) has carried out a specific study in Chandra Palem basin, India on the relationship between rain and groundwater recharge.
Singh and Tiwari (1978) have made a special attempt to bring out the hydrological details for Artificial recharge.

The book on "groundwater and wells" by Johnson (1983) is an excellent thesis on the well Hydrology, drilling, borehole logging and the performance of the aquifers.

Pinjaur intermontane valley also studied in details for the groundwater hydraulics and the reasons for the ever flowing wells. (Singh and Dogra 1983)

Athawale (1984) has demonstrated nuclear tracer techniques for the measurement of natural recharge in fractured aquifer systems.

Krishnamurthy (1984) has dealt elaborately the utility of stable isotopes in groundwater systems.

Similarly, Navada et.al (1986) have demonstrated some techniques of applying of environmental isotopes.

Karanth (1987) has made pioneering efforts and brought out a very detailed account on the different aquifers, the exploration practices and also modelling the techniques in his book on "Groundwater Assessment, Development and Management".

Mani et.al (1990) have evolved a technique for estimating the recharge in Granitic tracts.

Agarwal and Mishra (1992) have carried out satellite image analysis for evaluating groundwater potentials in Jhansi city, U.P.

Karanth et.al (1992) have brought out some newer ideas on how the pegmatite could be used as potential guides for setting high yielding wells.

Chawala (1994) has evaluated the impacts of massive groundwater mining and also the remedial measures to nourish the over exploited aquifers.

Venkateswara Rao (1994) has made an integrated attempt for the evaluation of groundwater potential in the Khondalite terrain.

Morphology and nature of various aquifers in the granitic terrain of Mahaboob nagar district, A.P. was brought out in details by Pradeep Raj et.al (1996).
Groundwater quality picture was brought out in details for Varanasi city by Singh et al. (1996)

Ramasamy (1997) has demonstrated certain newer site specific mechanisms for artificial recharge in hard rock aquifer systems.

On the contrary, Ramasamy et al. (1997) have developed some new land management models to improve the efficiency of natural recharge.

Anbazhagan and Ramasamy (1997a) have identified potential sites for artificial recharge in Tamil Nadu through geophysical resistivity surveys.

Ballukraya and Ravi (1999) have classified the unconfined aquifers of the chennai city into number of zones on the basis of the hydrogeochemical parameters.

The impact of recent tectonics over the groundwater of Tamil Nadu was brought out for the first time by Ramasamy (2000).

1.2.2.2 Studies on Aquifer Parameters Evaluation


Similarly, a number of earlier workers have attempted to evaluate the health of many groundwater provinces in India by studying the transmissivity, permeability, storage co-efficient and specific capacity of the open dug wells, dug cum bore wells and the deeper boreholes (Narasimhan 1965, Adayalkar and Mani 1972, Panchanathan 1972, Sammel 1974, Sharma and Seetharam 1981, Karanth and Prakash 1988 and Ballukraya et al. 1989).

A good amount of information has been brought out on the various fractured, metamorphic and volcanic aquifer systems of India by Dixit (1972), Apte (1972), Siddiquie (1973), Acharya (1973), Radhakrishna et al. (1974), Murthy (1977), Raghava Rao (1979), Krishna Raju (1983) and Rao (1987).

Niwas and Singhal (1981) have developed simple methods to determine the transmissivity from Darzarroak parameters in porous media.
Mishra and Rao (1987) have carried out groundwater exploration by evaluating the aquifer parameters measured through geoelectrical methods. Similar studies were carried out by Kshirasagar and Nagamalleswara Rao (1989) also in Varaha river basin, A.P.

A conceptual hydrogeological model by calibrating the permeability value has been developed by Kulkarni and Deolankar (1990) for the basaltic terrain.

Significant aquifer parameter evaluation studies were carried out by Sankaran et.al (1993), Narashimha Reddy et.al (1994), Woobaidullah et.al (1996) and Muralidharan (1996) also.

In the recent times, very exhaustive work on the aquifer parameter evaluation using Remote sensing and GIS have been carried out by many workers. The significant among them are Vasudevan and Ramasamy (1997), Palanivel and Ramasamy (2000,2002), Kumanan and Ramasamy (2001).

1.2.2.3 Remote Sensing Based studies

The Remote Sensing technique has been effectively used by many researchers in India in groundwater exploration. National Remote Sensing Agency, (NRSA) Hyderabad and Space Application Centre, (SAC) Ahemedabad, set the trend in utilising the remotely sensed data for delineating regional groundwater potential zones.

Roy and Raina (1973) have brought out hydrogeological databases for Kotepally Catchment for Hyderabad, based on the black and white panchromatic aerial photographs.

Hydrogeomorphology of the Central Luni basin of Western Rajasthan was brought out by Chatterji et al., (1978) which has given certain newer details on the controls of geomorphology over groundwater movement.

Radhakrishna (1979) has carried out studies on the drought prone Ananthapur district for the identification of groundwater potential using ERTS imageries.

Deolankar et.al (1980) have correlated the photolinears and the groundwater movement in parts of Pune district.

The studies of Sharma and Seetharaman (1981) have demonstrated the capabilities of Landsat multispectral data in targeting groundwater reservoirs. They have used fracture pattern analysis and geomorphic appraisals for groundwater targeting.
Dhiman (1983) has incorporated the remote sensing techniques with other subsurface geological data and integrated them for the successful delineation of groundwater potential zones for parts of Rajasthan.

The areas suitable for bore wells, dug wells and dug cum bore wells were identified by Ramasamy and Bakliwal (1983) by preparing and analysing the regional geology, lineaments and geomorphology, derived from satellite images, for the Banded Gneissic Complex of Rajasthan.

Satyanarayana Rao (1983) has developed an integrated deformation model using remotely sensed data for groundwater targeting in hard rock areas for the parts of Andhra Pradesh.


Landsat and aerial photograph data were used to bring out potential hydrogeomorphic zones in parts of Vaigai, Manimuttar and Pambar river basins by Perumal and Roy (1983).

Prakasa Rao (1983) has made a very detailed attempt to evaluate the paleochannels for their groundwater potentials.

Bakliwal et al (1985) have identified various groundwater prospective zones in desertic tract, Rajasthan using satellite data.

Raju et al (1985) have critically analysed the potentials of Remote sensing for groundwater prospecting in hard rock area.

Sharma and Sharma (1987) have given a detailed account on the application of remote sensing data for targeting groundwater by preparing the maps on surface lithology, fracture patterns, vegetation and geomorphic indicators of shallow aquifer, areas of recharge and discharge etc., They have also described about the use of airborne geophysical sensors in the identification and mapping of synclinal structures that control groundwater movement and distribution pattern.
Gupta and Ganesha Raj (1989) have used satellite images and bore well data for the demarcation of possible groundwater potential zones by analysing hydrogeomorphology of the area.

Om Prakash Dubey et al., (1989) have developed a linear mathematical model in terms of land cover system operator matrix for the evaluation of groundwater recharge. The operator has been estimated from the Landsat CCT, band 5 and band 7 imagery blown up on 1:250,000 scale. The model was then used to predict the groundwater level fluctuations for the year 1933 which was comparable with observed data.

Lithology, lineament, drainage, geomorphology and geologic features favourable for groundwater potential were derived for parts of Banas river catchment by Tiwari (1989). He has used the digital enhancement techniques to delineate surface geologic features.

Rajiv Sinha and Tiwari (1989) have studied the geological and geomorphological parameters of groundwater occurrence through visual interpretation methods and digital image processing of Landsat MSS and TM formats for qualitative and quantitative analyses.

Usha et al (1989) have classified the fractures of central Tamil Nadu as extension, shear and release and demonstrated that the extensional fractures (perpendicular to the folds) have better groundwater potency in hard rock area.

Again Remote Sensing derived data were integrated with Geophysical resistivity data for detecting groundwater zones in parts of Jalaum district, U.P. by Prakash and Mishra (1991).

The potentials of IRS 1A satellite data were brought out in detail by Sahai et al (1991).

Chandu and Agarwal (1992) have discussed the hydrogeomorphological units and their direct relations with groundwater occurrence, movements and its storage and have developed a combined strategy of remote sensing and geophysical methods for the augmentation of drinking water supply to Katera town, Jhansi district, Uttar Pradesh.

Different digital enhancement techniques were used for groundwater exploration in hard rock terrain of Karnataka by Krishnamoorthy et al., (1992).
Rao et al., (1992) identified that the digital image processing methods in conjunction with visual interpretation keys will help the analyst to delineate the hydrogeomorphological features in a better way. They have delineated the hydrogeomorphic units in Lalitpur district, Uttar Pradesh by interpreting the digitally processed Landsat TM and IRS data.

Ravindran et al., (1992) have delineated the groundwater potential zones using IRS 1A LISS II and Landsat TM data, analyzed the water samples for quality and then estimated the groundwater balance in the command area of Salauli Irrigation Project in South Goa.

Ramasamy and Jayakumar (1993) have mapped the folds and fracture systems of pre cambrian tracts of South India using IRS / 1A data and brought out the performance and behaviour of the aquifers.

Ramasamy (1993) has brought out an exhaustive write up on groundwater targeting using satellite data by integrating the rock types, lineaments and various geomorphic features like fluvial, marine and aeolian.

Hydrogeomorphic mapping was attempted in parts of Jaisalmer and Bikaner districts of Great Indian desert, using satellite data by Sahai et al. (1993).

Tiwari (1993) has narrated how the lineaments could be utilised effectively for selection of bore wells.

The zones of groundwater mobility and stability of Precambrians in South India were identified by Ramasamy et al., (1995) by interpreting Landsat Thematic Mapper data for lithology, folds, deformatipnal display of rocks and lineament fabric and incorporating them with water level fluctuation, yield and transmissivity.

Krishnamurthy and Srinivas (1995) have narrated the role of Geological and Geomorphological features interpreted from satellite data for groundwater exploration.

Jayakumar and Ramasamy (1996) have identified the groundwater exploration targets in parts of South India and the areas of groundwater recharge and discharge by integrating the maps on geology, geomorphology, landuse and drainage, which were interpreted using black and white Panchromatic aerial photographs and IRS 1A LISS I images along with water level data.

Again Ramasamy (1996) has elaborately dealt about, how multiple data bases can be created and integrated for successful groundwater targeting.

Ramasamy et.al (1996) have again analysed the fold systems and fracture systems interpreted from satellite data for entire Tamil Nadu in conjunction with Transmissivity, Permeability and Storage co-efficient and demonstrated that the area north of Cauvery the groundwater is controlled by fracture systems and south of Cauvery - controlled by fold systems.

A specific appraisal was made by Reddy et.al (1996) on the utility of IRS 1C data in groundwater targeting.

Central Groundwater Board (1997) compiled their regional Remote sensing and GIS based groundwater explorations carried out in India.

Anbazhagan and Ramasamy (1997a) have documented certain facts and figures on how Remote sensing can be effectively used for selecting the site specific mechanisms for artificial recharge.

Ravindran (1997) has carried out Remote sensing based Drainage morphometric analysis and correlated them with geology, geomorphology and groundwater prospects in Zuvari basin, south Goa.
Ravindran and Jayaram (1997) have brought out possible groundwater prospect areas in Shahbad Tehsil, Baren district, Rajasthan on the basin of Remote sensing data analysis.

Ramasamy and Anbazhagan (1997) have suggested a number of Geological criterias such as rock types, folded structures, fracture systems, geomorphology, drainage, subsurface geology etc, for choosing site specific mechanisms for percolation ponds, check dams, pitting, en-echelon damming etc, in hard rock aquifer systems.

Rana (1998) and Viswa Nath Bajpai and Morteza Fallahpour (1998) have interpreted and classified the poly directional lineaments using IRS LISS-1 Band-4 and Landsat images. Directional filtering was carried out by them to pick out the lineaments and fault zones. From their further studies on exploratory bore hole lithology, field and other investigations and evidences along the lineament / fracture / fault intersection areas, they identified the zones of potential aquifers.

The information brought out on the configuration of basement topography and there from the aquifer geometry of Ken Garden region, India by Srivastava (1999) was the first time attempt.

Pratap et.al (2000) have narrated the efficiency of Remote sensing for groundwater investigation on the basis of their case study in Dala area.

Harinarayana et.al (2000) have suggested groundwater management plans for Keralapura watershed for Cauvery basin using Remote sensing.

Kumanan et.al (2000) have developed a new genetical Remote sensing and GIS amalgamated groundwater targetting strategies for parts of Western ghats region Tamil Nadu.

Neelakantan and Ramasamy (2000) have analysed the groundwater fluctuation in the Niligiris region and observed positive correlation between water level fluctuation and landslides.

Ramasamy et.al (2000) have evolved fracture pattern analysis for groundwater targetting in hard rock aquifer systems.
Kumanan and Ramasamy (2001) have analysed the orientation of satellite derived fractures, their lengths and their intersection and amalgamated all for precise targetting of groundwater.

1.2.2.4 Numerical Modelling

After 1950 modelling techniques, especially the numerical modelling of groundwater flow and pollution has become in the fray of groundwater studies.

A lot of numerical modelling studies have also been carried out in India. Ramachandra Rao et al., (1973), Chandra and Pande (1975), Shukla and Verma (1975) and Mithal et al., (1975) have developed statistical models to predict the water level changes, for the development of recharge schemes.

Rajagopalan (1983), and Singh and Gupta (1986) have used mathematical models in the evaluation of aquifer parameters.

Achutha Rao and Sridharan (1982) have developed a mathematical model for the Vedavati river basin. In this study, they proposed a modified leaky aquifer model for the hard rock aquifer systems.

Chachadi and Mahapatra (1982) have used principal component models for the hydrogeochemical evaluation for the quality management of the groundwater.

Rajinder Singh et.al. (1983) have developed a simulation model for the groundwater management for the parts of Hariyana State.

Rushton and Sakthivadivel (1988) have brought out detailed information on the inadequacies of the existing analytical and empirical methods and advocated new numerical methods for analysing the pump test data, especially in larger diameter wells.

In Tamil Nadu, numerical models have been attempted by many workers.

Balasubramanian (1986) has developed a flow model for Tamarabarani river basin.

Jayakumar (1993) has presented groundwater quality model for vellar sub basin by using multivariate statistical analysis such as Principal Component analysis and Multiple Regression analysis.
Raviprakash et.al (1993) have carried out a flow modelling through krigging in parameter evaluation procedure. Similarly Ratha and Sahu (1995) and Sahu (1999) have developed a mathematical model for relating porosity and permeability in fractured hard rock terrain.

Jayakumar and Ramasamy (1995) have developed a Principal Component model for correlating the groundwater yield with fracture systems in central part of Tamil Nadu.

Jayakumar and Ramasamy (1997) have also developed a multivariate statistical model for understanding the hard rock aquifer system in central part of Tamil Nadu.

Palanivel and Ramasamy (1998) have come out with the quantitative land management model to improve the efficiency of natural recharge in hard rock aquifer systems, in which factor varimax analysis and multiple regression analyses have been used for understanding the control of natural recharge.

Thangarajan (1999) has developed a numerical simulation of groundwater flow model for the weathered hard rock aquifer.

Nagaraj (1999) has done exhaustive parameter estimation in regional groundwater analysis.

Hiondi (2000) while studying the hard rock aquifer in and around Dindigul has developed a flow model.

Ramasamy et.al., (2002) have carried out detailed GIS coupled numerical modelling studies and found that even in fracture controlled aquifer systems, only certain fractures act as better groundwater conduits.

1.2.2.5 GIS Modelling

The importance of GIS in India too has been well understood and many workers have started applying GIS for resource management. Space Application Centre (SAC) has been in the GIS field for the past 10 years and the thrust of all their efforts has been to establish and demonstrate that the GIS technology is best suited to organise information systems for natural resource management.

The recently born GIS technology has also started finding a place in groundwater management studies (Rao Mukund and Dasgupta 1987 and Rao Mukund 1993).
Different GIS application studies were undertaken by SAC during nineties. A GIS case study was undertaken (Anon 1992 a) for Mumbai Metropolitan region. The other important case studies under taken by SAC are the GIS based information system for regional planning for Bharatpur District, Rajasthan and District level planning for Panchmahal District, Gujarat State (Anon 1992 b).

Project Vasundhara carried out jointly by Geological Survey of India and Department of Space has been the first major attempt to integrate multilevel data sets through GIS for geological exploration.

Similarly Venkataraman (1993) has carried out GIS analysis for prognostic modelling to target potential areas for various mineral deposits in general and gold in particular.

Singh et.al (1993) for their hydrogeological investigation in Imphal valley, Manipur, have used both Remote sensing and GIS in their study.

Later, many researchers have started using this GIS technology for precise assessment of groundwater. Vasudevan (1995) has effectively used the GIS technique in aquifer function modelling of vellar basin, Tamil Nadu.

Khansubhan and Asif Mohd (1997) have carried out water resource assessment in parts of Rajasthan and Haryana through a GIS approach. Similar study was carried out by Pal et.al (1997) in Bala valley in parts of Yamuna nagar and Sirmaur districts.

Again Vasudevan and Ramasamy (1997) have made a detailed account on the groundwater functions by GIS analysis.

Saraf and Choudhary (1998) have attempted an integrated (Remote sensing and GIS) approach in identification of artificial recharge sites.

Ramasamy (1999b) has made a very exhaustive Remote sensing and GIS analysis in targetting groundwater resources in hard rock terrain of Tamil Nadu.

Kumar et.al (1999) have developed DBTM through GIS and inferred fractures in Godavari sub-watershed groundwater development study.

Similar studies have been carried out by Choudhary (1999) in parts of Batwa basin, Pratap et.al (2000) in Dala - Ranukoot area, Sonbhadra district, Uttar Pradesh.
Kumanan et al. (2000), have attempted an GIS integrated approach for rapid groundwater target in hard rock terrain.

Palanivel (2000) has effectively used the GIS technology in developing a groundwater aquifer function model for the parts of Westernghats.

Ramasamy et al. (2001) have demonstrated that how Remote sensing in GIS could act as efficient tool for making rapid appraisals in groundwater systems.

Palanivel and Ramasamy (2001) have correlated the folded structures with groundwater flow and observed that the synclinal structures act as potential water holding zones.

Ramasamy et al. (2002) have compared the fracture systems of multiple orientation with groundwater depletion and developed technique for identifying the sustaining fractures and the groundwater depleting fractures.

1.2.3 Hard Rock Aquifers of South India

In addition to general browsing of literature (Sections 1.2.1 and 1.2.2), critical evaluation was done on the studies carried out by various workers specifically on the hard rock aquifer systems of South India.

Though a lot of studies have been carried out by many workers using conventional tools in the past and high tech tools like Remote Sensing, Geophysical methods, GIS etc in the recent decades, the studies of Sathyanarayana Rao (1983), in parts of Andhra Pradesh, appear to be the first time integrated deformation model which documented that the fractures of different morphologies have different controls and prospects of groundwater in hard rock aquifer systems. The conjunctive analysis carried out between the satellite derived hydro geological data and the bore hole lithology data by Gupta and Ganesh Raj (1989), in parts of Pavagada Taluk of Karnataka, again brought out tangible information that the Remote Sensing derived geological Features, especially the tectonic features, and the geomorphic features, can be used as effective guides for groundwater targeting in hard rock areas.
A new technique of manual thematic integration of lithology, structure, geomorphology, drainages, landuse/landcover etc attempted by Jayakumar and Ramasamy (1996) for identifying zones of recharge and discharge in the typical hard rock systems of Central parts of Tamil Nadu again has been a newer attempt those days. Similar hierarchical analyses of different geological variables in identifying suitable sites for artificial recharge in hard rock aquifer systems appear to have laid a foundation in this field (Ramasamy and Anbazhahan, 1997 and Anbazhahan and Ramasamy, 1997a).

However, majority of the studies carried out by the scientists of National Remote Sensing Agency and the various State Remote Sensing Centres in India appear to have followed predominantly the concept of hydro geomorphic mapping for groundwater targeting and augmentation in hard rock aquifer systems.

Specifically, Thillai Govindarajan and Balasubramanian (1995) have brought out a series of hydro geomorphic maps for parts of Tamil Nadu.


Usha et.al (1989) have classified the lineaments of hard rocks of Tiruppathur area, Tamil Nadu into extensional, shear and release fractures which are respectively perpendicular, conjugate and parallel to the fold axes and inferred that the fractures perpendicular to the fold axes (Extensional) have better prospects for groundwater.

Ramasamy and Balaji (1993) have classified the lineaments of Tamil Nadu into Precambrian, Precambrian reactivated in Pleistocene times and the exclusive Pleistocene fractures and amongst them, they observed more groundwater possibilities in the Pleistocene fractures followed by the Precambrian fractures reactivated in Pleistocene times.
Again, Ramasamy et.al (1999) have carried out regional structural analysis for entire South India and classified the lineaments as follows:-

- ENE - WSW — Precambrian extensional fractures
- NE - SW — Precambrian dextral strike slip faults
- WNW - ESE to NW - SE — Precambrian sinistral strike slip faults and
- NNW - SSE — Precambrian release fractures

and observed that the Precambrian extensional fractures should have better groundwater potency in Tamil Nadu.

Again, Ramasamy and Balaji (1995) have developed a Pleistocene tectonic model for South India in which the Pleistocene fractures were classified as follows:-

- N - S — extensional fractures
- NE - SW — sinistral strike slip faults
- NW - SE — dextral strike slip faults and
- E - W — release fractures

They have also opined that the N - S Pleistocene extension fractures should have maximum groundwater potential and must control the groundwater movements in South India.

Recently, a concept of time transgressive tectonic model was propounded for south India by Ramasamy (2001) and in which he has demonstrated that the NE - SW trending Precambrian dextral faults (deep main faults of Grady, 1971) have been transformed into sinistral faults and again the NW - SE / WNW - ESE trending Precambrian sinistral faults have been reversed into dextral strike slip faults, both in Pleistocene times. It was further observed by him that these dextral to sinistral and sinistral to dextral conversions might have opened up and closed these faults in some segments and those opened up segments must have better groundwater prospects.
The analysis carried out on the lineaments and the drainage anomalies of northern Tamil Nadu by Elliott et al. (1998) suggested that the tectonically active lineaments falling in NE-SW and NW-SE directions act as good groundwater carriers.

Again detailed studies carried out by Kumanan (1998) and Kumanan and Ramasamy (2001) classifying the lineaments to various azimuthal frequencies, derivation of concerned maxima diagrams and the GIS based integrated analysis indicated that NE-SW lineaments act as loci for groundwater.

1.3 NEED FOR CHOOSING THE PRESENT THEME FOR RESEARCH

The scanning of all the previous work carried out by various workers both in the International and National levels (Section 1.2) have shown that the geoscientists have used different techniques, such as old traditional methods, aquifer parameters evaluation, numerical modelling and modern technologies viz, Remote Sensing, Geophysics, GIS modelling etc, for groundwater prospecting. But these studies by and large appear to be stand alone models, (ie) individually, study wise, these have added newer information to the field of ground water but appear to have given less information in understanding the aquifer behaviour in totality.

Hence, the present research study has been conceived to evaluate the ground water behaviour of the hard rock aquifer system in totality and evolve strategies and models for precise ground water targetting in hard rock aquifer systems.

1.4 AIMS AND OBJECTIVES OF THE STUDY

Hence, after evaluating thoroughly all the International and National literature, precise aims, objectives and methodologies were set out for the present research.
This involves:

- Creation of thematic and GIS data bases on various aquifer parameters such as Water Level, Transmissivity, Permeability, Storage Co-efficient, Specific Capacity, Optimum Yield, Width of Aquifer Depletion, Recovery Rate and Overall aquifer performance,

- Creation of thematic and GIS data bases on rock types, fracture density, thickness of regolith cover, geomorphology etc and

- Carry out GIS modelling studies for precisely understanding the input of various geological variables over the aquifer systems and finally evolve precise ideas for groundwater targeting and management in hard rock regions.

1.5 ABOUT THE STUDY AREA

1.5.1 Location and Approach

The study area is almost a plain tract falling in parts of Salem, Perambalur and Tiruchirappalli Districts of Central Tamil Nadu. The study area is bounded by North latitudes 11° 20' 00" and 11° 40' 00" and East longitudes 78° 40' 00" and 79° 00'00" (Fig 1.1). It covers an area of 1340 sq.km. The study area falls in parts of the Survey of India topographic sheets 58 I/10, 58 I/11, 58 I/14 and 58 I/15.

The important towns located within and the adjacent parts of the study area are Kallakurichi, Vridhachalam, Perambalur, Attur, Talavasal, Chinnasalem, Viraganur, Pulambadi etc.

The study area is well connected by metal roads. The National Highway 45, which is connecting Capecomorin with Chennai and the main live link of the state, is crossing the study area in the South eastern fringe. The study area is also approachable by train both from Chennai and Tiruchirappalli upto Vridhachalam. It can be also approached by air from Chennai to Tiruchirappalli and by road there from.
1.5.2 Geology of the Study Area

1.5.2.1 Rock Types

Lithologically, the study area is covered by Charnockite, Hornblende biotite gneiss and Fissile hornblende gneiss (Fig. 1.2). The Charnockite covers 42.93 %, hornblende biotite gneiss covers 1.56 % and the Fissile hornblende biotite gneiss occupies 55.51 % in the study area. The Geological Survey of India (Anon 1962), on the basis of lithology, has classified the rock types of the region as follows:

STRATIGRAPHIC SUCCESSION

\[
\begin{align*}
\text{Archaean} & : \\
\text{Peninsular Gneiss (younger phase)} & : \text{Fissile Hornblende Biotite Gneiss} \\
\text{Migmatitic Complex} & : \text{Hornblende Biotite Gneiss} \\
\text{Charnockite Group} & : \text{Charnockites}
\end{align*}
\]

They have classified the Archaean into Khondalite, Charnockite Migmatite and Peninsular Gneiss (younger phase) groups. Amongst them, the above three major rock types, namely the Charnockite belongs to Charnockitic group of the Archaean, the hornblende biotite gneiss belongs to migmatitic group of the Archaean and the fissile hornblende biotite gneiss belongs to Peninsular Gneissic complex (younger phase) of the Archaean.

1.5.2.2 Structural Fabric

The study area is a vast pediplain and the above rock types show some structural trends here and there. The Black & White panchromatic aerial photographs and the satellite images were interpreted and the tonal, textural, soil tonal, relief and the vegetational linearities and curvilinearities were studied. From the same, the broad structural trendlines were brought out for the study area. From the structural trends it is observed that the rocks trend in general NE-SW orientations. Ramasamy et al. (1999)
have mapped the trendlines of South India and from which they have grouped that the structural trendlines of the study area forms the eastern limb of the Cochin - Cape comorin - Madurai - Trichy - Salem - fold belt.

The study area is criss crossed with a large amount of lineaments and all these lineaments were interpreted by using Black & White panchromatic aerial photographs and IRS 1B LISS II satellite data. On the basis of their tonal, textural, drainage, relief and vegetational linearities and curvilinearities the lineaments / fractures were interpreted. The lineaments so interpreted in the area have generally fallen in NE-SW, NNE-SSW and NNW-SSE directions (Fig 1.3).

Grady (1971) has marked these NE-SW trending lineaments as deep main faults. But Ramasamy et al. (1999) have classified the lineaments of South India into four azimuthal groups with

- ENE-WSW Precambrian extensional
- NE-SW Precambrian dextral strike slip faults
- NW-SE to WNW-ESE Precambrian sinistral strikeslip faults and
- NNW-SSE Precambrian release faults

But Ramasamy and Balaji (1995) earlier have prepared a Pleistocene tectonic model for South India in which they have classified lineaments as follows :

- N-S Pleistocene extensional fractures
- NE-SW Pleistocene sinistral faults
- NW-SE Pleistocene dextral faults and
- E-W Pleistocene release fractures

But as far as the present area is concerned the fracture systems / lineaments are observed to fall in above both categories. That means some of the fractures are of Precambrian age and some fall in Pleistocene group. However, in the present study, all these lineaments were taken as such without classifying their age group.
LINEAMENT / FRACTURE PATTERN OF STUDY AREA

Fig. 1.3
1.5.2.3 *Geomorphology*

The raw and digitally processed satellite data was interpreted and geomorphological map was prepared. In general, this area is a vast pediplain punctuated by few residual hills. However, the general geomorphology of the area is represented by residual hills, residual slope, pediment, buried pediment deep, buried pediment medium, buried pediment shallow, and flood plain. (Fig. 1.4)

The occurrence and distribution of the above geomorphic features show that the denudational processes and the fluvial processes have acted in a combined way and generated such geomorphic features.

1.5.3 *Physiography*

Physiographically, the area is a pediplain punctuated by few hills. The general terrain elevation varies from 100 m to 737 m above MSL. The area has got a general easterly slope. The major streams flow in the area are Vellar river or Vashista nadi, Swetha nadi, and the Chinnar river.

1.5.4 *Landuse and Landcover*

The landuse/landcover plays a substantial role in the surface water movement and, therefrom, the groundwater prospects. The landuse/landcover map was prepared from IRS 1B LISS II satellite data and the area is represented by dry crop, wet crop, sandy area, tanks, fallow land, and the hills. (Fig. 1.5).

1.6 *METHODOLOGY IN BRIEF* (Fig 1.6)

1.6.1 *Data Base Generation on Aquifer Variables / parameters*

Over 65 dug wells of equal dimension located in near grid pattern were identified in the study area. Pump tests were conducted. From the drawdown/recovery curve, following databases on the various aquifer parameters (except Water level and Aquifer depletion) were generated using Jacob’s method in the APE (Aquifer Parameter Evaluation) programme developed by Balasubramanian(1986).
Legend

- Residual Hill (11.3 Sq Km)
- Residual Slope (3.2 Sq Km)
- Piedmont (17.8 Sq Km)
- Buried Pediment Deep (596.2 Sq Km)
- Buried Pediment Shallow (140.1 Sq Km)
- Buried Pediment Medium (494.5 Sq Km)
- Flood Plain (76.3 Sq Km)

Fig. 1.4
For water level and Aquifer depletion, monthly water level data collected for 216 months (18 years) from the year 1973 to 1990 were used.

These data were entered into surfer software and contours were generated for each variable independently. These contours were imported to ARC/INFO GIS software and GIS data bases were generated independently for each of the above showing the minima and maxima zones as the case may be as follows.

1. Water level minima
2. Transmissivity maxima
3. Permeability maxima
4. Storage Co-efficient maxima
5. Specific yield maxima
6. Optimum yield maxima
7. Aquifer depletion minima and
8. Recovery rate maxima

Such buffered zones show the healthy zones (the prospective zones of the aquifer) in each variable.

Such numerical data bases generated on these above eight aquifer parameters of 65 wells were independently stretched from 1 to 100 by using linear stretching algorithm (Lillesand, 1989) used for stretching the satellite digital data. While doing so firstly the numerical data bases were generated for 65 well locations for water level and width of aquifer depletion by superposing the well location map over the respective contours prepared using 20 control well data. The inverse of such 65 data were worked and then linearly stretched.
Nextly, such linearly stretched 65 data of the above eight parameters were added and averaged for each of 65 wells and numerical data base was thus generated for 65 wells on the overall aquifer performance. These were also fed into ARC / INFO GIS software and buffered GIS image was generated showing aquifer performance maxima zones.

1.6.2 Data Base Generation on Geological Variables

As this present study is basically aimed at understanding the groundwater behaviour and the contribution of these geological variables over the groundwater systems, various data bases were generated on the following geological variables:

- Lithology
- Lineament density
- Geomorphology
- Thickness of Top Soil
- Thickness of Weathered Zone
- Thickness of Fracture Zone
- Cumulative thickness of Top soil and weathered zone
- Cumulative thickness of top soil and fracture zone
- Cumulative thickness of weathered zone and fracture zone
- Over all depth to bed rock

The GIS images were generated showing the lithology and geomorphology as such. As far as the fracture / lineament density is concerned the lineament density diagram was prepared for the area by counting the total length of lineaments per 2.25 sq.km, plotting them in the grid centres and contouring them. From these contours, the more than mean zones were buffered out and GIS data bases were generated using NT ARC / INFO GIS.

In the case of subsurface geology, namely the thickness of Top soil, weathered zone and fractured zone, detailed field surveys were conducted, existing geophysical resistivity data and the well geology data collected from PWD were analysed and the data bases were generated accordingly. These were also contoured and buffered images were generated showing more than mean zones which used be the possible conducive zones for ground water mobility and stability.
1.6.3 GIS Modelling

Subsequent to the generation of GIS data bases on various aquifer parameters and on various geological parameters, each of the aquifer parameter data was overlaid with GIS images of the various geological variables one after the other and the zones of coincidence were identified between each aquifer parameter and each of the geological variables and thus the input of each geological parameter over each of the aquifer parameter were evaluated. Thus the final model was evolved to bringing out the actual input of different geological variables over the groundwater systems.

Subsequently, separate analysis was carried out between the aquifer parameters and the lineament / fracture systems because it is a hard rock area and more over the above GIS based spatial analysis have given indications of lineament control over the aquifer systems. This was done by azimuthically classifying the lineaments into 18 classes of 10 degree each. These 18 lineament classes were converted into density diagrams and the numerical data bases were generated on such lineament density for 576 grids of 2.25 sq.km each. Similarly, the numerical data bases were generated for each of the nine aquifer parameter data for the same grids. Then factor varimax analysis was carried out by notionally keeping each of the aquifer parameter data as the dependent variable and 18 classes of lineaments as the independent variables and thus the final relation between the lineaments and the ground water systems was brought out.(Fig 1.6)

1.7 SYNTHESIS

The groundwater targetting is very enigmatic in fractured aquifer systems owing to its inherent heterogeneity. Hence, the present study has been undertaken in a typical hard rock terrain from Central part of Tamil Nadu. In the said study, GIS data bases were generated on various aquifer parameters bringing out the maxima / minima zones in different aquifer variables as the case maybe. Similarly, GIS data bases were generated bringing out possible conducive zones on various geological variables using ARC / INFO GIS. Then one to one GIS overlaying was done between each the GIS image showing the aquifer maxima zones and the maxima zones in each of the geological variable and thus the actual controlling geological variable was identified. A specific statistical approach, namely the Factor Varimax Analysis, was also carried out between the various aquifer variables and 18 azimuthically grouped lineaments using 576 grid / sample data and finally models and ideologies were built on groundwater behaviour and the input of geological variables on the aquifer performance.
METHODOLOGY IN BRIEF

METHODOLOGY

- Data Bases on Aquifer variables through pump tests
- Data Bases on Geological variables from Remote Sensing
- Creation of Numerical data bases for 576 grids of 2.25 sq.km each for all 9 aquifer variables
  - Creation of Numerical data bases for 576 grids on lineament density of 18 azimuthally classified lineaments of 10° each
  - Factor Varimax Analysis using aquifer variable and various lineament variables
  - Evaluation of relation between Aquifer Parameters and the orientations of lineaments

- Generation of GIS data bases showing the healthy zones (maximas / minimas) in each Aquifer variable
- Generation of GIS data bases showing the probable conducive zones/maxima zones for Ground Water

- GIS data integration and Evaluation of functional parameters of Ground Water

Fig.1.6