King Fahd University of Petroleum and Minerals
Dhahran-Saudi Arabia

Department of City and Regional Planning

CRP-514
Geographic Information Systems (GIS)
Fall 2002(021)

Final Draft Report
(Term Paper)
Title

APPLICATION OF REMOTE SENSING AND GIS IN GROUNDWATER RECHARGE INVESTIGATION

Submitted to:
Dr. Baqer Al-Ramadan

Submitted by:
Naeem Akhtar
Student ID# 210237

TABLE OF CONTENTS

ABSTRACT

Groundwater is a big source of fresh water on earth. Approximately 97% of the fresh water comes from groundwater. So we can see that groundwater is a major source of freshwater. As the population of the world increasing rapidly, so the demand of fresh water is also increasing, there is need that we should use water carefully and proper water management should be carried out. Also the groundwater recharge investigation should be carried out to meet the future demands of fresh water. GIS is a tool for storing, manipulating, retrieving, and presenting both spatial and non-spatial data in a quick, efficient and organized way. Remote sensing technology is being used successfully in many fields, especially in water resources. Now a days both GIS and remote sensing are proving to be very helpful in groundwater recharge investigations. We take a case study Silai watershed, Bankura district, West Bengal. For the investigation of groundwater recharge we use IRS-LISS-II and LISS-III data. Also we will use the existing maps and other existing data sets for such investigations.

1. INTRODUCTION

Groundwater is the most important natural resource required for drinking ,irrigation and industrialization. As it is the largest available source of freshwater lying beneath the ground it has become crucial not only for targeting of groundwater potential zones ,but also monitoring and conserving this important resource. More money is needed for providing a facility of fresh water from surface water as compared to groundwater; also the surface water resources are inadequate to fulfill the water demand. Productivity through groundwater is quite high as compared to the surface water, but groundwater resources have not yet been properly developed through exploration. So it is advisable that we should proceed to groundwater the GIS technology provides suitable alternatives for efficient management of large and complex databases. Remote sensing with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within short time has become a very handy tool in assessing, monitoring and conserving groundwater resources. Satellites data provides quick and useful baseline information on the parameters controlling the occurrence and movement of the groundwater like geology, lithology/structural, geomorphology, soils, landuse etc(D. Das, n.d.).Now a days both GIS and remote sensing are being used successfully to investigate the groundwater recharge and also for the selection of artificial recharge sites. We take a case study of Silai water shed, Bankura district, west Bengal to show that GIS and remote sensing are useful in groundwater investigations.

2. PROBLEM STATEMENT

In terms of human necessities, water is considered most important next only to air. We know that groundwater is the biggest source of freshwater on earth. Groundwater lies almost everywhere below the earth's surface. More than two million cubic miles of fresh water is stored in the earth, and half of that is within a half mile of the surface. Groundwater supplies are replenished, or recharged**,** by rain and snow melt. In some areas of the world, people face serious water shortages because groundwater is used faster than it is naturally replenished. In other areas groundwater is polluted by human activities. The problem is that how groundwater management and planning may be effective in order to meet the demands of fresh water. There is need that the ground water should be used properly and its proper evaluation is also required.

My purpose here is to explain that how GIS and remote sensing can be useful for the investigation of groundwater. And we will see that GIS and remote sensing are being used successfully now a days.

3. OBJECTIVES

I took a case study to explain that how GIS and remote sensing can be helpful for groundwater recharge investigation. My objectives are as follows.
My objective is to develop and an integrated remote sensing and GIS technique to investigate groundwater recharge. Also to have a quantitative assessment of groundwater recharge. To establish relationship b/w geology, geomorphology etc. of an area and the groundwater recharge. To locate the artificial recharge zones of an area that can be helpful in future to meet the increased demand of freshwater.

4. REVIEW OF LITERATURE

GIS is a system of hardware and software used for storage, retrieval, mapping and analysis of geographic data. However GIS has been defined by many ways by many people. A geographic information system is a facility for preparing, presenting, and interpreting facts that pertain to the surface of the earth. In common parlance, a geographic information system or GIS is a configuration of computer hardware and software specifically designed for the acquisition, maintenance, and use of cartographic data. (Englewood Cliffs, 1990). The term "remote sensing" is itself a relatively new addition to the technical lexicon. It was coined by Ms Evelyn Pruitt in the mid-1950's when she, a geographer/oceanographer, was with the U.S. Office of Naval Research (ONR) outside Washington, D.C.. No specific publication or professional meeting is cited in literature consulted by the writer (NMS) in which the words "remote sensing" were stated. The term Remote Sensing means the sensing of the Earth's surface from space by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resources management, land use and the protection of the environment(Principles Relating to Remote Sensing of the Earth from Space, Principle I).Groundwater is the water beneath the surface that can be collected with wells ,tunnels ,or drainage galleries etc. Groundwater is the water that is pumped by wells and flows out through springs. Groundwater recharge in water that infiltrates into the zone of saturation also called the water table. Both GIS and remote sensing plays an important rule in groundwater studies. In recent years ,the interpretation of satellite data in conjunction with sufficient ground truth makes it possible to identify and outline various ground features that serve as direct or indirect indicators of the occurrence of groundwater. Using remote sensing data(IRS-1D -LISS-III)the thematic maps of geology and structure ,geomorphology ,and hydromorphologeology were interpreted and finalized by checking in the field and collected data(Y.Srinivasa rao, n.d). Satellite data gives fast and important information of the parameters that control the movement of groundwater like geology, lithology, geomorphology etc. However all of the parameters are considered rarely. So if in some case studies all the parameters are considered then the results regarding groundwater will be more close to the field observation (D. Das ,n.d.).With geoelectrical and drilling data, clay thickness and aquifer thickness maps can be prepared through GIS techniques. To find out the more realistic groundwater potentiality map of the area ,the relevant layers which include hydromorphology, lineament ,slope ,overburden thickness and aquifer thickness can be integrated in Arc View. Criteria for GIS analysis is defined on the basis of groundwater conditions an appropriate weightage is assigned to each information layer according to the relative contribution towards the desired output. The groundwater potential zone that is prepared by this model is verified with the yield data and proves the validity(Amaresh Kr.Singh,n.d.).

5. APPLICATION OF REMOTE SENSING AND GIS: SILAI AS A STUDY AREA

5.1 STUDY AREA

The Silai watershed (a carrot like shape) lies between latitudes 22o45’ and 23o24’ and longitudes 86o37’ and 87o35’ (figure 1). The watershed mainly falls within the Bankura district of West Bengal, India.

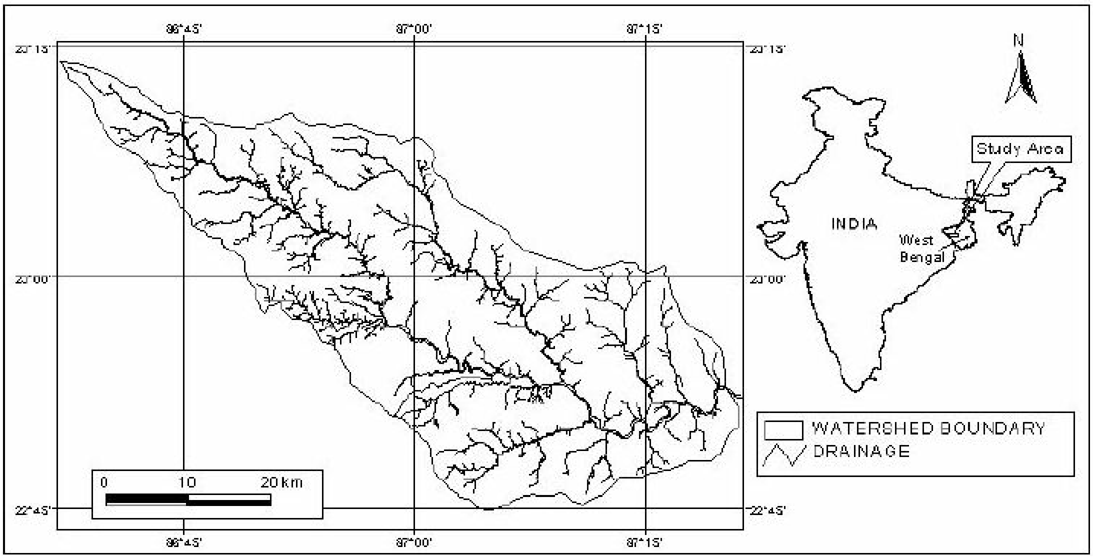

Figure 1: Location of the study area. Also shows Silai watershed and the drainage network.

5.1.1 PHYSIOGRAPHY

The watershed can be divided into three major topographic regions viz.

(a) The hilly areas in the west,

(b) The connecting tract in the middle and

(c) The alluvial plains in the east.

5.1.2 LITHOLOGY

The lithology of the Silai watershed can be divided into three broad units. The western part consists of pink granite and granite gneiss (figure 2). The thick mantle of laterite and older alluvium that lies over it, is the second prominent lithologic unit in the central part of the watershed. This third unit consists of the gradually eastward thickening newer alluviums, which are basically sand, silt and clay.

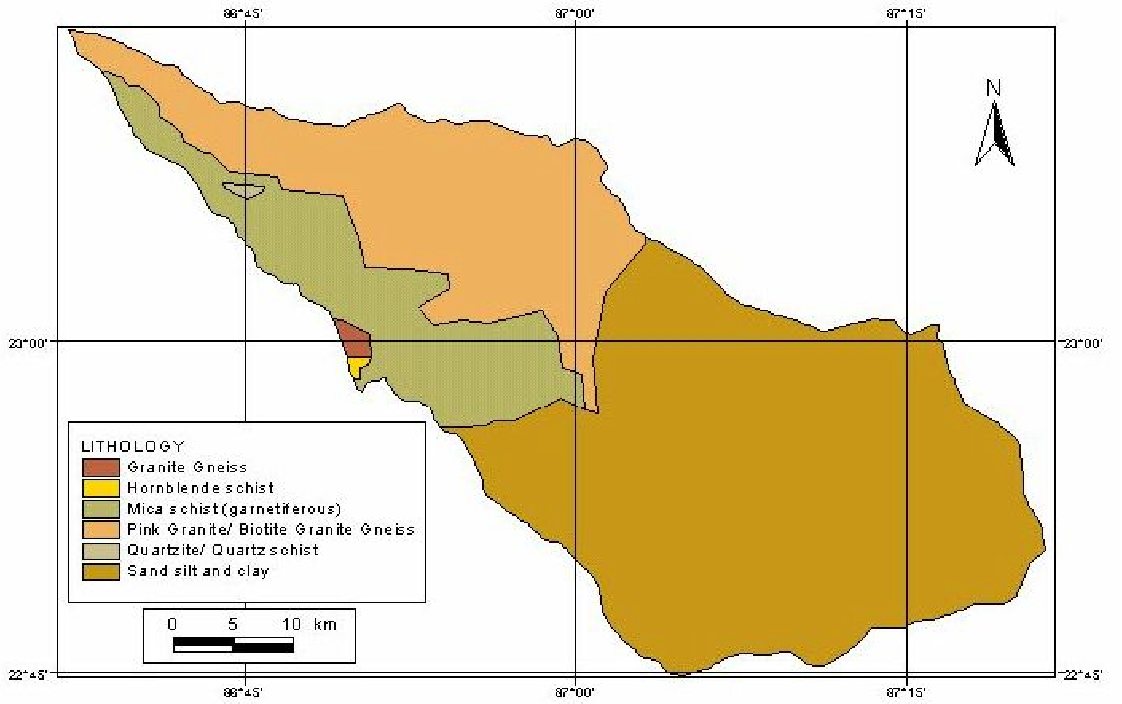

Figure 2: Lithological map of the study area (after GSI, 1997).

5.1.3 GEOMORPHOLOGY

The eastern part mainly consists of flood plains and alluvial fills. The central part has gently to moderately sloping land characterized by isolated mounds and valleys.

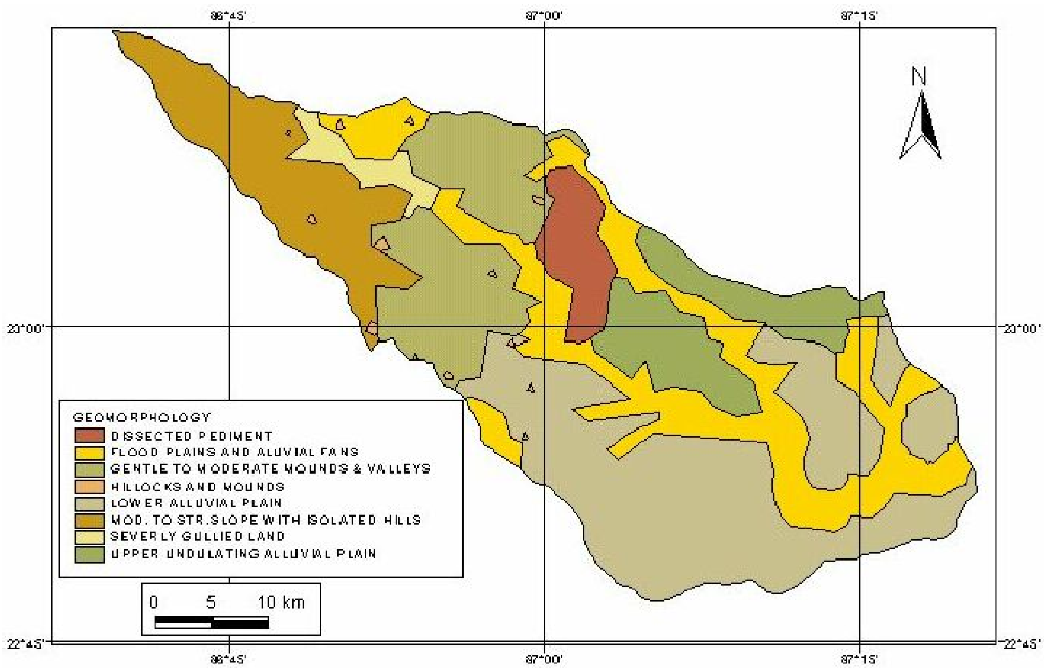

Figure 3: Geomorphological map of the study area (after NBSS & LUP, 1992).

5.1.4 SOIL

The soils of the watershed can be grouped under following types: (1) Red and yellow soils, (2) Lateritic soils, (3) Alluvial soils and, (4) Red gravelly soils (figure 4).

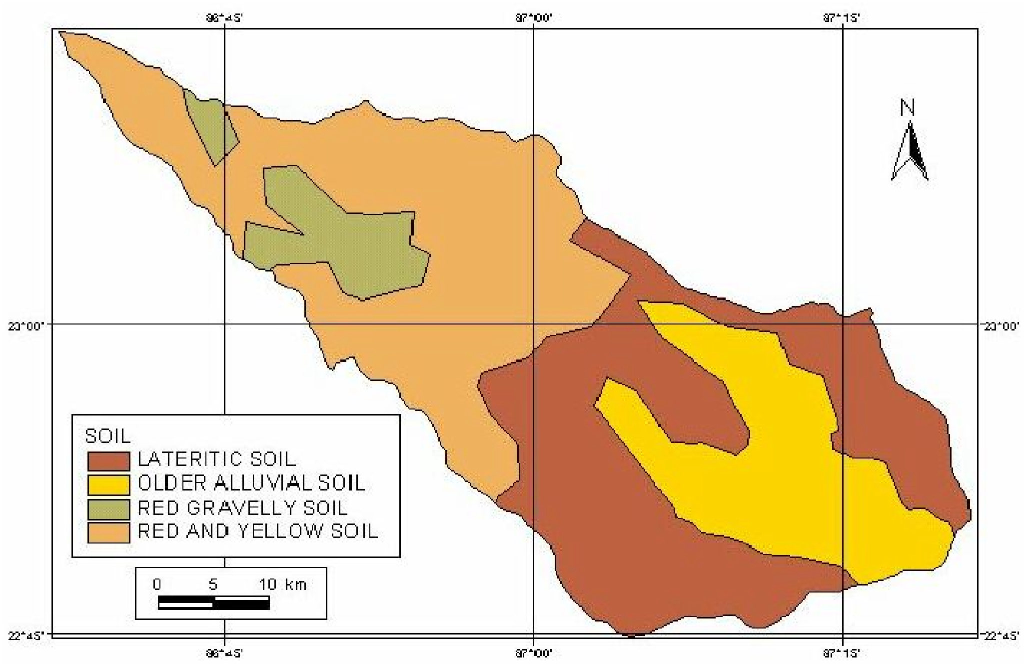

Figure 4: Soil map of the study area (after NBSS & LUP, 1992).

5.1.5 CLIMATE

The area falls under tropical, dry, sub-humid climatic belt .The maximum day temperature ranges from 120 C in winter to a maximum of 480 C in summer with a mean annual temperature of 270 C. Normal annual rainfall in the western part averages around 1100 mm while the same in the eastern part averages around 1400 mm.

5.1.6 LANDUSE

The western part of the watershed has very little forest cover as compared to the eastern part. In the eastern part, large areas are covered by dense forest or degraded forest. Agricultural lands are restricted along the Silai river. The main water body in the area is the Silai river, which is the third major river after Damodar and Dwarkeshwar.

5.1.7 GROUNDWATER CONDITION

In the hard rock areas in the western part, groundwater occurs in an unconfined condition within the fractured hard rocks and its weathered mantle. Although, the annual rainfall in the watershed is relatively moderate, the availability of groundwater is problematic because of Low recharge rate, generally high runoff mainly from western part of the watershed, unsuitable aquifer conditions over the parts of the western hard rock areas, long and hot dry season, and excess withdrawals of groundwater in parts of the eastern alluvial tract, for irrigation purposes have caused continuous lowering of the groundwater table over the years.

5.2 DATA USED

For this case study different data sets are used. Details of various data sets used in the study are in the table (1).Whereas details about IRS-1A-LISS-II and IRS-1C-LISS-III sensors are in table (2).The tables are given in the appendix B.

5.3 METHODOLOGY OF THE STUDY

The methodology of the study is presented in figure 5 and can be summarized as follows First the analogue maps were converted into digital format by using ILWIS software. Secondly the landuse maps of 1988 and 1996 were prepared and both were compared to calculate overall change patterns. Thirdly all the above themes were brought into GIS Arc View 3.1.And at the last integrated analysis of multi-disciplinary data sets was done to construct composite information.

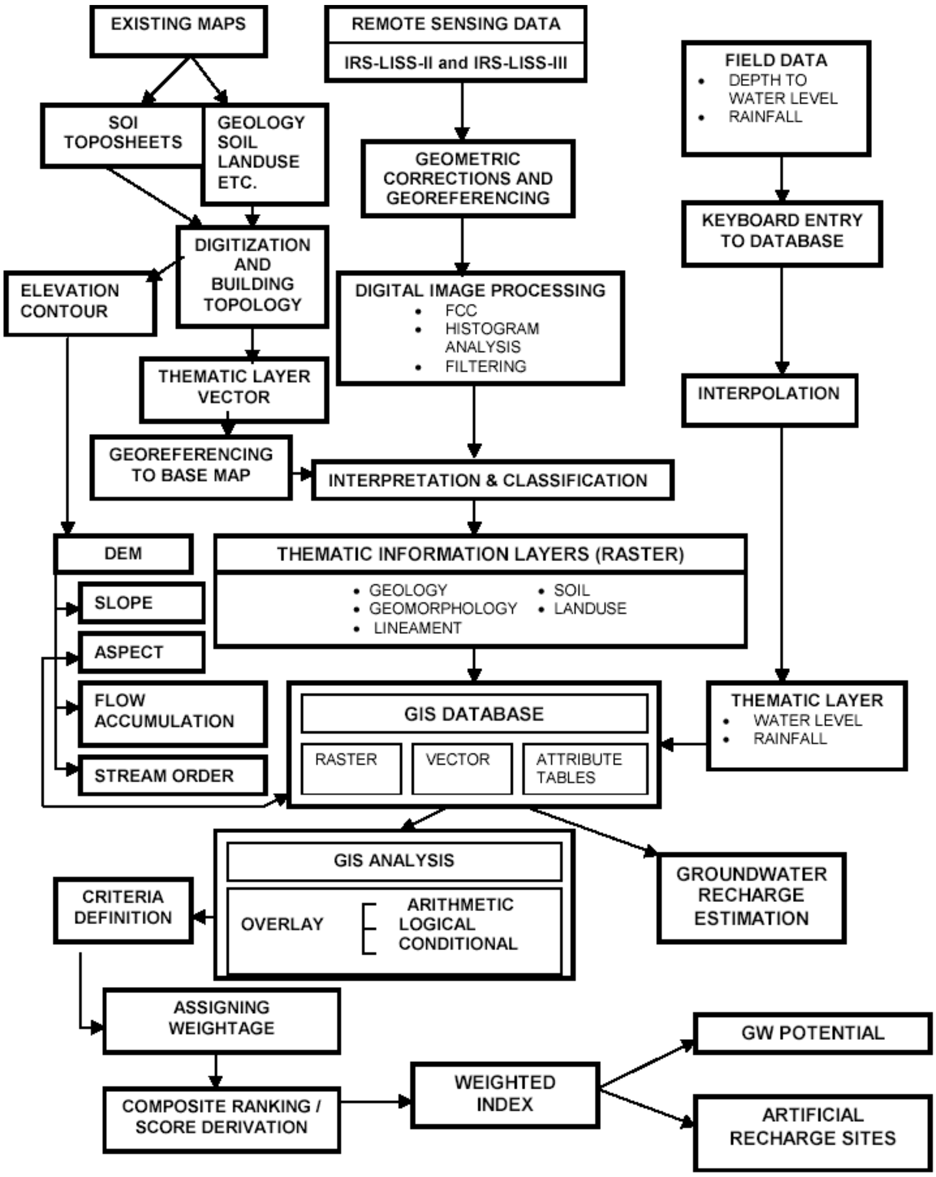

Figure 5: Flow chart showing data flow and different GIS analysis operations followed in the present study.

5.4 GROUNDWATER RESOURCE EVALUATION

Quantitative assessment of groundwater recharge is an important issue in groundwater development. There are various methods in use for the quantitative evaluation of groundwater recharge e.g.:

(a)groundwater level fluctuation and specific yield method

(b) rainfall infiltration method and

(c) Soil moisture balance method

The groundwater level fluctuation and specific yield method is used for the quantitative estimate of groundwater recharge in the Silai watershed.

This is the simplest method for seasonal groundwater recharge estimation. Average water level fluctuation of 3 years has been taken and interpolated to give rise to a water level fluctuation image. The recharge image thus generated gives a rough estimation of dynamic groundwater recharge. However, it has helped to prepare the groundwater recharge volume map for the Silai watershed (figure 6). It is important to note that the groundwater recharge depends not only on the specific yield of the aquifer material, but also on many other factors viz. soil properties, geomorphic features and land use.

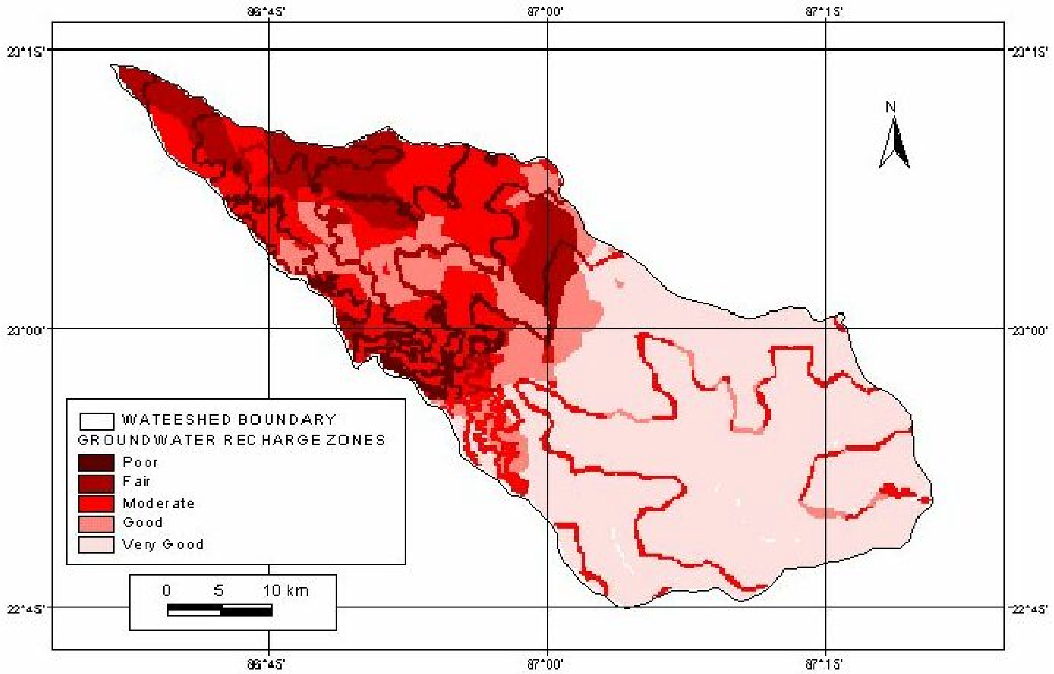

Figure 6: Groundwater recharge volume map of Silai watershed computed by water level fluctuation and specific yield method.

5.5 SELECTION OF ARTIFICIAL RECHARGE ZONES

Artificial recharge is a process by which excess surface water is directed into the ground- either by spreading on the surface, by using recharge wells or by altering natural conditions to increase infiltration to replenish an aquifer.

A remote sensing and GIS based method is very useful for the selection of artificial recharge sites. The following thematic information layers are used for suitable selection of artificial recharge zones.

(a) Geology, (b) Geomorphology, (c) Soils, (d) Slope

We use weighted index overlay method to locate the suitable zones for artificial recharge sites (graph 7).For this selection table (3) is used which is given in appendix B.

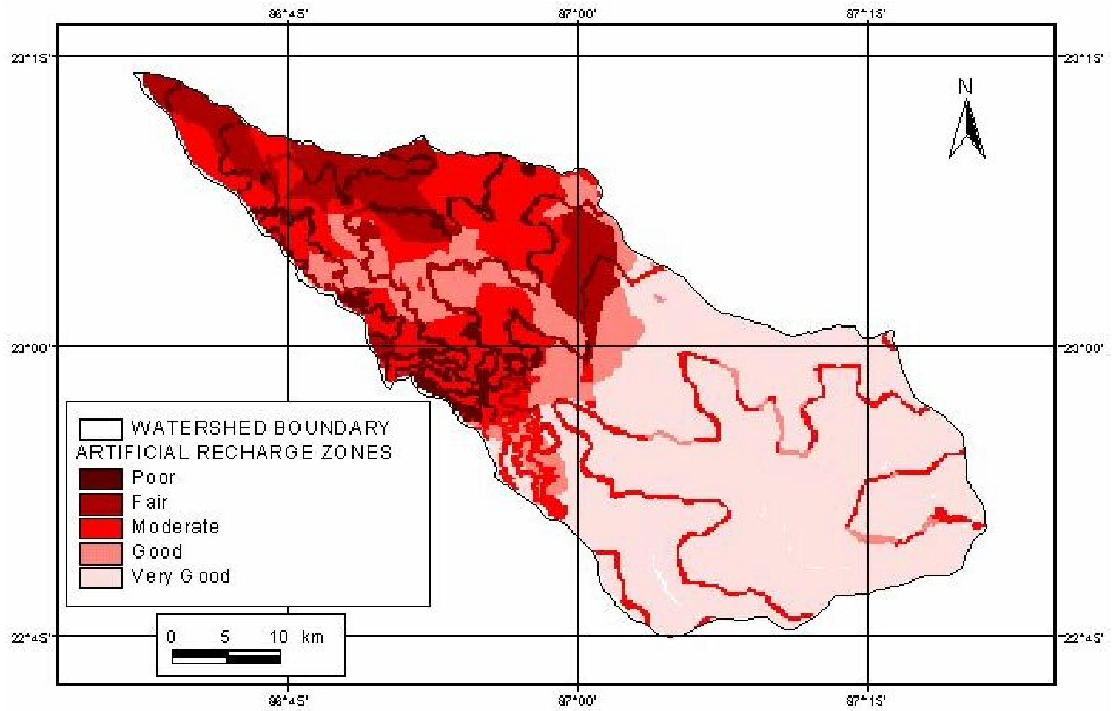

Figure 7: Potential zones for future artificial recharge sites to provide better groundwater recharge conditions. This map is prepared using the slope map derived from DEM together with the geology, geomorphology and soil maps.

6. EVALUATION OF THE CASE STUDY

Water resources assessment of a region involves a detailed study of the surface and sub-surface water. To integrate the entire surface and sub-surface data manually requires huge manpower and time. By adopting a GIS platform the result obtained will be faster and more accurate. Till recently, ground water assessment was based on laboratory investigation, but the advent of Satellite Technology and GIS has made it very easy to integrate various databases. Now we evaluate the case study which we described. First one can ask that what is meant by evaluation of the case study? The following question may be helpful to evaluate the case study .e.g. Is the title informative, approximately creative? Has the case been presented in an interesting or creative way. Is the case study involves some controversy? Are the stages of the case study developed logically and clearly? Is the current study gives us a full idea of how we can apply GIs and remote sensing in the investigation of groundwater recharge and also for the selection of artificial recharge zones. There may be many such type of questions to evaluate the case study. Here we consider some important question and answer those questions for the evaluation of the case study. We can see that the title of the case study is informative and also justified. The stages of the case studies are developed logically and clearly. The information (e.g. maps and tables) present in this case study are accurate e.g. data used in this study was taken from IRS-1A-LISS-II and IRS-1C-LISS-III sensors. The illustration in the case study is clear, instructive and properly cited. The case study demonstrates that how remote sensing and GIS can be used for groundwater recharge and also for the selection of artificial recharge zones. In this case study the method adopted for the evaluation of groundwater recharge is “water table fluctuation method”. A GWAM-model (groundwater assessment model) allows engineers and planners to assess the groundwater more efficiently, accurately and at a faster pace (S. M. Kharad, n.d). Ground water assessment is based on the water table fluctuation method also and calculated based on the norms recommended by National Groundwater Estimation Committee (GEC).In this method certain parameters are considered e.g. normal Monsoon rainfall data for 20 years, normal yearly rainfall data for 20 years, depth to water table for pre and post monsoon water level, specific yield data for the zone of water table (this is expressed as fraction and varies with geological formation),geomorphology map, canal map, surface water irrigation (For Monsoon and Non-Monsoon),return seepage from ground water irrigation during monsoon, surface reservoir map / water body map and other conservation structure, well data, landuse/landcover map and slope map. In the case study the method was same as used in GWAM model. Groundwater is a most important natural resource required for drinking, irrigation and industrialization. The resource can be optimally used and sustained only when quantity and quality of groundwater is assessed. It has been observed that lack of standardization of methodology in estimating the groundwater and improper tools for handling the same, leads to miscalculation of estimation of groundwater. It is essential to maintain a proper balance between the groundwater quantity and its exploitation. Otherwise it leads to large scale decline of groundwater levels, which ultimately cause a serious problem for sustainable agricultural production. So we should also consider this thing when we evaluate the case study. We can also see that in this case study we have not considered the quality of groundwater. In order to fulfil growing needs, pollutants are being increasingly added to the groundwater system through various human activities and natural processes. Applications of fertilizers and pesticides to enhance crop production have become a common practice. In case fertilizer application exceeds the plant uptake, the residual joins the water table. This increases nitrate concentration in groundwater. Similarly, excess applications of pesticides that are complex organic chemicals may have adverse health effects. Long-term use of saline irrigation water combined with poor management and adverse climatic conditions for example, low rainfall and high evaporation, leads to accumulation of salts in the root zone. Poor agricultural practice results in a loss of crop yield and deterioration of soil structure. Poorly designed and improperly managed waste disposal sites contribute significant amount of leachate. This leachate may affect the water quality. Improperly designed and maintained septic tank becomes a threat to groundwater quality. Disposal of waste through wells adds pollutant to the groundwater and also accelerate their movement towards a production well. In and around major pollutant is industrial waste that includes heavy metals, toxic compounds and radioactive material. Another significant source of metal contaminants are tailing produced at mining sites. In recent years, land and water sectors were put to stresses in order to meet the demand of the growing population. Groundwater is more dependable source of water as compared to surface water. Therefore, gradually, quality of water in addition to quantity is gaining importance in the selection of suitable sites for the groundwater development. Groundwater Pollution Potential (GWPP) of any given geographical location depends upon a wide range of above surface, surface and subsurface environmental parameters(O. P. Dubey, D. C. Sharma, n.d).Therefore there is need that in the case study the quality of water should also be considered. For over all developments of a region reliable estimate of groundwater quality and quantity is of paramount importance. Satellite data can be analyzed to generate database required for GWPP studies. Generated database can be put to FAM (Factor Analytic Model**)** for extracting the most influential composite and subsequently the variable loading. Using the proposed FAM an area can be classified in to different classes in terms of their potential to pollute the groundwater. So there is need to consider groundwater quality in the study area also.

7. CONCLUSION

Groundwater resources are dynamic in nature as they grow with the expansion of irrigation activities, industrialization, urbanization etc. As it is the largest available source of fresh water lying beneath the ground it has become crucial not only for targeting of groundwater potential zones, but also monitoring and conserving this important resource. The expenditure and labour incurred in developing surface water is much more compared to groundwater, hence more emphasis is placed on the utilization of groundwater which can be developed within a short time. Besides targeting groundwater potential zones it is also important to identify suitable sites for artificial recharge usage cycle. When the recharge rate cannot meer the demand for water, the balance is disturbed and hence calls for artificial recharge on a country wise basis.We can draw the following conclusion

1. Both remote sensing and GIS based has been applied successfully for evaluation of groundwater resources.

2. We see in this case study that remote sensing and GIS are also very efficient in predicting the artificial recharge zones in the study area.

3. The quantitative assessment of groundwater is very important. In the case study we use groundwater level fluctuation and specific yield method for the evaluation of groundwater recharge. Now a days Groundwater assessment is based on the water table fluctuation method and calculated based on the norms recommended by National Groundwater Estimation Committee (GEC).

4. We can see that in the case study high-resolution remote sensing data (IRS-LISS-II and LISS-III) provide details of the study area. It helps us in evaluating the groundwater recharge and also for the suitable selection of artificial recharge zones.

5. We can also conclude that the same type of methodology can be applied to other areas for the groundwater recharge zones.

6.We see that the GIS and remote sensing contributes significantly to the assessment, development and management of the groundwater resources of study area which we were considering by providing spatial information (geology, soils, land use, topography etc).

7.We can also say that the GIS enables quicker assessment of a potential resource, effective planning of monitoring networks ,better understanding of the relationship between land management changes and groundwater and improved presentation of groundwater data

8 REFERENCES

A.K. Gupta, J.R. Sharma, G. Sreenivasan, Rajendra,Dharmavat and Rajat Misra ,2002,Rising ground water levels in jodhpur city -solutions from remote sensing techniques., ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad, India

A.N. Manoharan1 and A. Balasubramanian2,2002, Remote sensing and geoelectrical assessment of hydrological characteristics of lineaments around sargur, Karnataka, ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad, India

Ai Nakagawa, Shiro Ochi and Ryosuke Shibaski,An Application of R. S. and GIS for Hydrological Modeling in Continental Scale Institute of Industrial Science, University of Tokyo(n.d)

Amaresh Kr. Singh, S. Ravi Prakash & Devendra Mishra ,An Approach to demarcate groundwater potential zones in Harai Subwatershed Mirzapur District, U.P., through remote sensing, Geoelectrical and Geographical Information system Remote Sensing Applications Centre, U.P. ,India(n.d)

Anthony Caniano, Teng-fong Wong and Ronald J. Paulsen, Groundwater Modeling of Recharge and Seepage in Coastal Area of Shelter Island West of Coecles Inlet,Department of Geosciences,State University of New York at Stony Brook Stony Brook, NY and Suffolk County Health Services - Bureau of Water Resources Hauppauge, NY (n.d)

B. V. M. Rao Toleti, B. S. Chaudhary, K. E. Mothi Kumar, G. P. Saroha,Manoj Yadav, Ajeet Singh, M. P. Sharma, A. C. Pandey and P. K. Singh, Integrated Ground Water Resources Mapping in Gurgaon District, (Haryana) India using Remote Sensing and GIS Techniques, Scientists, Haryana State Remote Sensing Application Centre (Deptt. of Sci. & Tech., Govt. of Haryana) CCS HAU Campus, Hisar, India (n.d)

Basab Mukhopadhyay et. Al, Mineral potential map by a knowledge driven GIS modelling: An example from Singhbhum copper belt, Jharkhand Geological Survey of India, Geodata and Database Division, Kolkata(n.d)

Biswajit Sarma et. al,Study of Landuse – Groundwater relationship using an Integrated Remote Sensing and GIS approach,Department of Earth Sciences,Indian Institute of Technology, Roorkee,India(n.d)

Biswajit Sarma, A. K. Saraf,Study of Landuse – Groundwater relationship using an Integrated Remote Sensing and GIS approach, Department of Earth Sciences Indian Institute of Technology, Roorkee, India (n.d)

C. P. Kumar,Assessment of ground water potential National Institute of Hydrology ,Roorkee,India(n.d)

Cong Nguyen Kim Minh ,Study and application of Remote Sensing techniques for groundwater investigation: Case-study of coastal zones of Red River and Mekong River deltaic plains of Vietnam ,Center of Geography and Natural Resources, NCSR of Vietnam (n.d)

D. Das ,GIS application in hydrogeological studies ,Department of Environmental Science, University of Kalyani, India(n.d)

D. Das,GIS application in hydrogeological studies,Department of Environmental Science, University of Kalyani, W.B. , India(n.d)

Debapriya Dutta ,AVSWAT- a Spatial Decision Support System for Land and water management and its application for watershed management in Bankura district of West

Bengal NRDMS Division, Department of Science and Technology Technology Bhavan New Delhi, India(n.d)

C. Dana Tomlin's definition, from Geographic Information Systems and Cartographic Modeling (Englewood Cliffs, NJ: Prentice-Hall,1990), page xi:

Dilip Kumar,2002, Remote sensing and gis in the morphometric analysis of drainage pattern in the drought prone area : a case study of firozpur jhirka block of gurgaon district, haryana, ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad,India

Dutta Venkatesh et. al,Five - point guidelines for urban development with groundwater dimension, School of Environment Management, Guru Gobind, Singh Idraprastha,University, Kashmere Gate, Delhi (n.d)

Goyal Sandeep,R.S.Bharadwaj, D.K.Jugran,Multi criiteria analysis using GIS for ground water resource evaluation in Rawasen and Pili Watershed, U.P., Remote Sensing Applications Centre, Bhopal, M.P. Indian Institute of Remote Sensing, Dehradun (n.d)

I. Z. Poonawala , S. D. Ranade, S. Selvan, C. Gnanaseelan , Anuja Rajagopalan,Detection of shallow water depth using remotely sensed data, Rajagopalan Central Water and Power Research Station Pune (n.d)

Jeyram, Y.V.N. Krishna Murthy ,Ground water potential and assessment using Geographic Information System ,Regional Remote Sensing Service Centre, Department of Space, Nagpur.(n.d)

K. Chellpandian ,Application of remote sensing technique integrated with resistivity profiling in delineating groundwater potential zones - A case study. Chennai India(n.d)

K. Ravi Shankar,1994 , Affordable water supply and sanitation,Groundwater exploration, 20th WEDC Conference Colombo, Sri Lanka,Colombo, Sri Lanka

K. Sankar and S. Venkatraman,2002,Remote sensing and gis approach for ground water Resource assessment: a case study in and around bharathidasan university, tiruchirappalli and pudukottai districts, tamilnadu,India, ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad,India

K.K. Rao, Prof.A.G.Krishnamurthy*, Dr. S.K. Singhai*, Shri Feroz Zafer ,Ground Water Targeting Using Remote Sensing - A Case Study of Raisen City and Vidisha District (MP) Deptt. Of Applied Geology, Barkatullah University, Bhopal , Deptt. of Civil Engg. SATI, Vidisha (M.P.) (n.d)

Kumar Ashok et. al ,GIS and GWW is tool for creating Ground Water Information System (GWIS) - a case study of upper Barakar basin, Bihar Remote Sensing Application Centre, IGSC-Planetarium, Patna, India(n.d)

Kumar Manoj, K. K Rao1 and Pramendra Dev2,2002, Integration of remote sensing, geophysical and hydrogeological monitoring systems for development and management of ground water resources in nandini nagar area, durg district, chhattisgarh, India, ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad,India

L.P. Chourasia,2002,Application of remote sensing data to ground water exploration - a case study of a part of hard rock terrain of central india. ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad,India

M G Chandrasekhar, A K Gupta, V Jayaraman, P P Nageswara Rao, K Radhakrishnan, B Manikiam ,Remote Sensing activities in India, Earth Observation System ISRO Headquarters Bangalore, India (n.d)

Md. Babar,2002,Application of remote sensing in hydrogeomorphological studies of the purna river basin in parbhani district, maharashtra, India, ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad,India

Musa Khairul Anam et. al,Groundwater Prediction Potential Zone in Langat Basin using the Integration of Remote Sensing and GIS,Malaysian Centre for Remote Sensing (MACRES),Kuala Lumpur , Malaysia (n.d)

N. Subba rao,2002,Groundwater prospecting zones in a crystalline terrain using remote sensing techniques, ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad,India

O. P. Dubey, D. C. Sharma,Integrated Remote Sensing and factor analytic GIS model for evaluating groundwater pollution potential, Irrigation Research Institute, Roorkee, India(n.d)

P K Champati Ray,GIS in Geoscience: The recent trends , Indian Institute of Remote Sensing,4-Kalidas Road, Dehradun- India(n.d)

P.V. Shivraj & P. Jothimani ,GIS based software solution for ground water studies: GWIS,Pentasoft Technologies Limited, Tidel Park, Taramani, Chennai,India (n.d)

Per Sander ,1996,Remote Sensing and Gis for Groundwater Assessment in Hard Rock Areas Applications to Water Well Siting in Ghana and Botswana ,School of Civil Engineering,Department of Geology

R. P. Gupta,2002,Remote sensing: from qualitative to quantitative geological studies ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad,India

Ramalingam M.,Delineation of groundwater recharge zones using remote sensing and GIS IRS. Anna University(n.d)

Ri Kuk-Hun1, S.K. Srivastav2, R.C. Lakhera2 and D.K. Jugran2,2002,Application of remote sensing and gis techniques for mineral exploration in the purbanera area, rajasthan, India, ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad,India

S. M. Kharad et. al,GIS based groundwater assessment model,L&T Information Technology Limited, Mumbai- India (n.d)

S. S. Mahapatra, M. K. Sanabada, S. Jena and G. Behera ,Integrated Groundwater Management in Micro-Watersheds Using Remote Sensing Technique,Orissa Remote Sensing Application Centre, Bhubaneswar (n.d)

Saraf, A. K. and Choudhury, P. R., 1997, Integrated Application of Remote Sensing and GIS Groundwater exploration in hard rock terrain, Proceedings. Int. Symp. On Emerging trends in Hydrology, Department of Hydrology ,Roorkee India

Singh Amaresh Kr., S. Ravi Prakash and Devendra Mishra,R. Mamallan, S. N. Kak, A. K. Bagchi and R.K.Gupta,2002,Integrated approach for delineation of ground water potential zones through remote sensing, geoelectrical and gis techniques in city block of mirzapur, u.p., India, ISPRS Commission VII Symposium on Resource and environmental monitoring Hyderabad,India

Srivastava Ajay, Nitin Kumar Tripathi and K.V.G.K. Gokhale ,Hydrological Investigations In Gangetic Basin Using Remote Sensing And Basement DEM - A Case Study,Department of Civil Engineering,Indian Institute of Technology, Kanpur, India(n.d)

T.J. Renuka Prasad and H.V. Shashibhushan Kumar, An Integrated Remote Sensing and

GIS Techniques for Delineation of Groundwater Potential Zones - A Case Study of Channagirihalla and Soppinahalla Watersheds, Karnataka Department of Geology, Bangalore University, Bangalore – 56, India(n.d)

V. R. Desai ,Better water management through GIS/Other strategies Assistant Professor, Water Resources Section Civil Engineering Department Indian Institute of Technology, Kharagpur, West Bengal (n.d)

Xie, Hongjie, Granillo et.al,Examples of Applications of Integrated Remote Sensing and GIS Technologies to water-related problems in far west texas. Department of Geological Sciences, Univ of Texas(n.d)

Y. Srinivasa rao and D.K. Jugran, Application of GIS in Delineation of Groundwater Potential Zones of Chittoor Area, Andhra Pradesh, India Department of Geology, S.v. university, Tirupati Geosciences division, IIRS, Dehradun (n.d)

9. Appendices

9.1 APPENDIX A

ABBREVIATIONS AND TERMS USED

IRS-LISS-II and IRS-LISS-III data:

IRS-1D is the latest in a series of Indian earth observation satellites and was launched 29th September 1997.It orbits the earth at an altitude of 817 km.

This satellite carries 3 sensors.

- Panochromatic(IRS Pan)
- Linear Imaging Self-scanning Sensor(LISS III)
- Wide Field Sensor(WiFS)

IRS-LISS data is generally supplied on CD-ROM.

Physiography: The study of physical features of the earth's surface

Lithology: The science which treats of rocks, as regards their mineral constitution and classification, and their mode of occurrence in nature**.**

Geomorphology: The branch of geology that studies the characteristics and configuration and evolution of rocks and land forms.

Groundwater: Groundwater is the water beneath the surface that can be collected with wells ,tunnels ,or drainage galleries etc.

Surface water : Surface water is the water such as from lakes and rivers, rain water, desalination of ocean water, and treatment and reuse of wastewater.

GIS:A geographic information system is a facility for preparing, presenting, and interpreting facts that pertain to the surface of the earth. Also geographic information system or GIS is a configuration of computer hardware and software specifically designed for the acquisition, maintenance, and use of cartographic data.

Remote Sensing: The term Remote Sensing means the sensing of the Earth's surface from space by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resources management, land use and the protection of the environment.

GSI: Geological Survey of India
DEM: Digital Elevation Models

NBSS & LUP: National Bureau of Soil Survey and Land Use Planning

9.2 APPENDIX B

List of Tables

Table 1: Details of various data sets used in the present study.

Type of Data	Details of Data				Source of Data
Survey of India (SOI) toposheets	73 I, 73J, 73 M, 73N (scale 1:2,50,000) 73 I/12, I/16, J/13, M/4, M/8, N/1, N/5 (Scale 1:50,000)				Survey of India (SOI), Dehradun
Thematic maps: Geomorphology, Soil, geology	(Scale 1:2,50,000)				National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur, Geological Survey of India (GSI), Calcutta
Remote Sensing digital data sets of IRS-1B-LISS-II & IRS-1C-LISS-III	**LISS-II**		**LISS-III**		National Remote Sensing Agency (NRSA), Hyderabad
	Scene	**Date**	**Scene**	**Date**	
	19/51/A2	03.11.88	106/55	09.11.96	
	19/52/A1	03.11.88	106/56	04.11.97	
	20/51/B2	26.11.88	107/55	14.11.96	
	20/52/B1	26.11.88	107/56	14.11.96	
Groundwater data: Depth to water level of 34 wells	The depth of water level for the month of January, April, August, and November for years from 1984 to 1997				State Water Investigation Directorate (SWID), Calcutta

Table 2: Specifications of digital data sets used in the present study.

Year	1988	1996
Satellite	IRS-1A	IRS-1C
Altitude	904 km	817 km
Repetivity	22 Days	24 Days
Numbering of Paths	East To West	West To East
Sensor	LISS-II	LISS-III
Spatial Resolution	36.5 m	23.5 m and 70.5 m (SWIR)
Swath (km)	146.98	141 And 148 (SWIR)
Radiometric Resolution	7 (bits)	7 (bits)
Spectral Resolution (µm)	0.45-0.52 0.52-0.59 0.62-0.68 0.77-0.86	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70

Table 3: Weightage of different parameters for Groundwater prospects & Artificial Recharge zones.

SL NO.	CRITERIA	CLASSES	WEIGHTS FOR GROUNDWATER PROSPECTS	WEIGHTS FOR ARTIFICIAL RECHARGE
1	Geology	Calcareous Gneiss	1	1
		Granite Gneiss	1	1
		Hornblende schist	2	2
		Mica schist	2	2
		Pink Granite/ Biotite Granite	1	1
		Quartzite/Quartz schist	2	1
		Sand, silt and clay	5	5
2	Geomorphology	Dissected Pediment	2	2
		Flood plains and alluvial fill	5	5
		Upper undulating alluvial plain	4	4
		Gently to moderately sloping land interspersed with mounds and valleys	3	3
		Moderate to strongly sloping land interspersed with isolated hills	2	2
		Lower alluvial plains	4	4
		Severely gullied land	1	2
3	Soil	Lateritic soil	3	3
		Other alluvial soil	4	4
		Red gravelly soil	5	5
		Red and yellow soil	2	2
4	Slope	0 – 1°	5	4
		2 –5°	5	5
		5 – 10°	4	3
		10° - 20°	2	2
		>20°	1	1