Hydromorphogeological Microzonation to Infer Groundwater Potential and Quality

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Abstract

Multi-sensor satellite data integrated with Global Positioning System enabled geophysical and geochemical information has the potential to infer the availability and quality of groundwater in metamorphic Aravali formation of National Capital Region. Surface manifestation of satellite data has the potential to infer subsurface geology as well as soil moisture in weathered aquifer material. Normalized Difference Vegetation Index computed from the vegetation above the inferred lineament has the potential to infer groundwater quality. Electrical resistivity, X-Ray diffraction (XRD) and Induced Couple Plasma Emission Spectrophotometer (ICPES) analysis further support the spectral reflectance anomaly in litho units. Deep seated fractures with interconnected morphological manifestation have been inferred by using Proton Precession Magnetometer anomaly data. Although it was not possible to infer very deep seated potential fractures by using satellite data but the accurate ground truthing by geophysical investigations has been used to provide a clear hydromorphogeological attribute of potential aquifers. Drilling litho logs supported by thin section petrography suggests that high grade metamorphism is suggestive of good fractures in quartzite-schist-granite-pegmatite terrain of Aravali formation of Research and referral Hospital and Jawaharlal Nehru University areas. ICPES and XRD analysis of these metamorphic litho-units, weathered material, soil and groundwater confirms that groundwater quality improves with the grade of metamorphism of the Precambrian formation. Eleven deep tube wells were drilled in this terrain down to 150 meter to 185 meters below ground level (bgl) are showing five to seven sets of potential aquifer zones from 25 meter to 165 meter bgl. In most of the cases the shallow aquifer zone ranging from 25 meter to 32 meter bgl were dried up due to over pumping and improper land use practices. After successful tapping of multiple fracture zones in this unconfined aquifer, the piezometric head has shown a substantial rise. Raised groundwater level has laterally recharged the dried aquifers in the water starved Aravali terrain. NDVI attributes further confirm good health of vegetation, which is suggestive of the quality and quantity of groundwater in this area.

1. Introduction

The National Capital Region (N.C.R) falls in the Western zone of the country. It gets an average rainfall of 632mm/year. Moreover, National Capital Territory (NCT) is situated on the banks of Yamuna which is a tributary of Ganges. Yamuna's water has been channelized to other areas. By the time Yamuna reaches Delhi, it does not remain a river but turns into a drain. The water problem in National Capital Territory is well known. Unprecedented growth of urbanization in the area has resulted in the destruction of the traditional surface water structures for constructing buildings. This has resulted in the scarcity of water for various uses. With the rising population of NCR and the declining availability of water due to industrial pollution & destruction of surface tanks and pond, the water scenario of NCR is alarming. Frequent failure of monsoons, increasing demand and over exploitation leads to depletion of groundwater resources in many parts of the country. Groundwater is not only an important component of the hydrological cycle but also an important source of drinking water. Comparative estimation indicates that probably at least two hundred times the volume of annual run off from the world's river is stored as groundwater beneath the land surface(Maning, 1987).Therefore detailed investigation regarding the occurrence and renewal of groundwater has become necessary. Safe use, tactical exploration and management of groundwater resources require good knowledge and proper understanding of the groundwater regime and its control.

2. Material and Methodology

Survey of India Toposheets

S.No	Toposheet No.	Scale
1	53H/1	1:50,000
2	53H/2	1:50,000
3	53H/3	1:50,000
4	53H/5	1:50,000
5	53H/6	1:50,000
6	53H/7	1:50,000
7	53D/13	1:50,000
8	53D/14	1:50,000
9	53H	1:250,000
10	53D	1:250,000

Multisensor satellite data were georeferenced for interpretation and delineation to infer potential zones for groundwater exploration and assessment of its quality. Based on the anomalous attributes of satellite data, groundwater exploration sites were selected. Interconnected fracture zones in the Quartzites and Pegmatites shows anomalous NDVI values. Resistivity and magnetic surveys were conducted in these places to recommend sites for drilling. NDVI values of satellite data were further correlated to infer the quality of groundwater. Deep rooted vegetation extracts groundwater from the interconnected fractures. ICPAES study of the groundwater in some areas of Pegmatite and quartzite friction zone shows higher concentration of dissolved ions, which was correlated with the higher attribute of near infrared reflectance. The hydromorphogeological information were interpreted in GIS format to infer the microzonation of units showing qualitative and quantitative character of groundwater.

Software Used

(i) Arc/Info GIS Workstation version 9.1

(ii) Arc View GIS 3.1

(iii) Auto CAD Map 2000

(iv) ERDAS Imagine Image Processing Software Version 8.4

(v) Rockworks 6.9.8

(vi) Geoimage

(vii) SPSS 14 for Windows

3. Pre-Processing of Satellite Images

(1) The LISS- III image was obtained from NRSA for the year 2005.

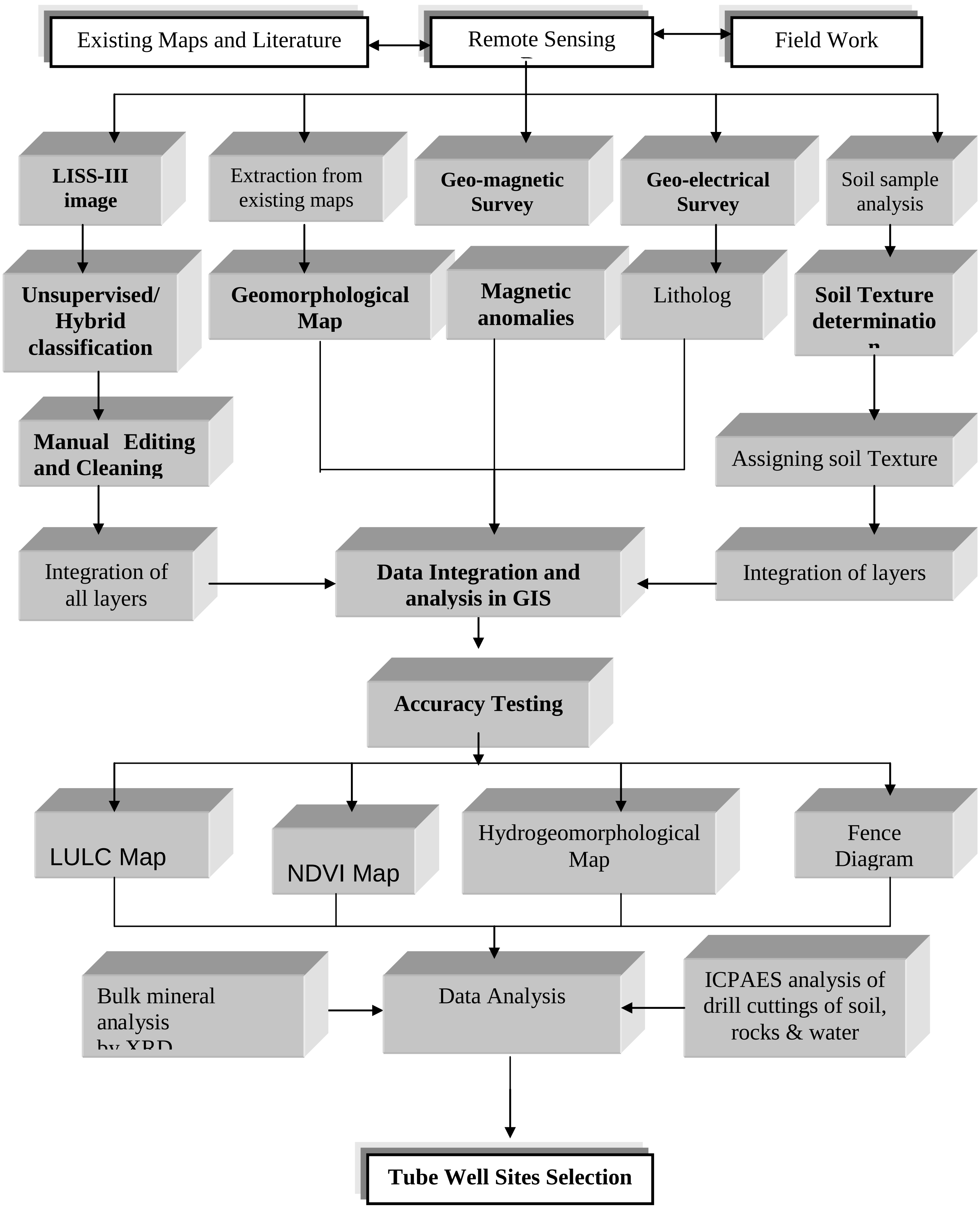
- Satellite image from IRS-1D, LISS-III sensor, on a scale of 1:50,000(geo-coded) representing synoptic view of earth’s surface at 25mX25m ground resolution in three spectral bands have been procured. The details of the IRS data used to accomplish the study are given below.
- Data product –Standard FCC (False colour composite), bands 1, 2 and 3 in the range of (0.52-0.59 microns) B2, (0.62-0.68microns) B3 and (0.77-0.86microns) B4 respectively.
- Projection: The image was projected to Lambert Conformal Conic Projection, Spheroid and datum Everest.

(2) The SRTM data were processed to transform it into product usable in GIS:-

- Conversion of raw data: the image was converted from the DTED Level-2 format to ESRI grid format (resolution 79.6mX79.6meter).
- Mosaicking: the individual tiles were mosaicked and then was clipped using shape file of study area.
- Projection: The final output of step b was projected into Lambert Conformal Conic projection, spheroid and datum Everest.

The Resourcesat-1 (PAN and LISS III merged) satellite image was projected in the same manner. This ultimately helps in increasing the spatial resolution which helped to determine the lineaments in the area easily.

Flowchart.1 Flowchart showing hydromorphogeological microzonation



4. Geophysical Investigation

Delhi ridge lineaments were inferred using RESOURSESAT-1 (IRS-P6) Sensor-AWIFS data show a strong trend in NE-SW direction only. Further, the area was studied using IRS-1D Panchromatic and LISS-III sensor data has shown detailed lineament which passes though Asola Bhati sanctuary, J.N.U. Sports Complex (stadium), RR Hospital and extends up to Bahadurgarh in Haryana (adjacent to north west Delhi). Panchromatic sensor shows detailed land use patterns of Delhi area, which are useful information in water resource management. Measurements were taken along this lineament, which is inferred as sudden decrease in resistivity and magnetic values (average magnetic value of Delhi region is 47,000 gammas). Groundwater recharge map of whole Delhi and specifically ridge area has been prepared by using multisensor satellite data and geophysical investigations. Based on the spot magnetic values in and around NCR region, 20 profiles were done. Contour maps were made along the profile. Contour lines were drawn at every ten gammas interval; Low magnetic values were noticed in lineaments intersections which were showing low resistivity on ferruginous quartzite. Selections of drilling sites were based on the points inferred by magnetometer showing low magnetic values and interconnected lineaments.

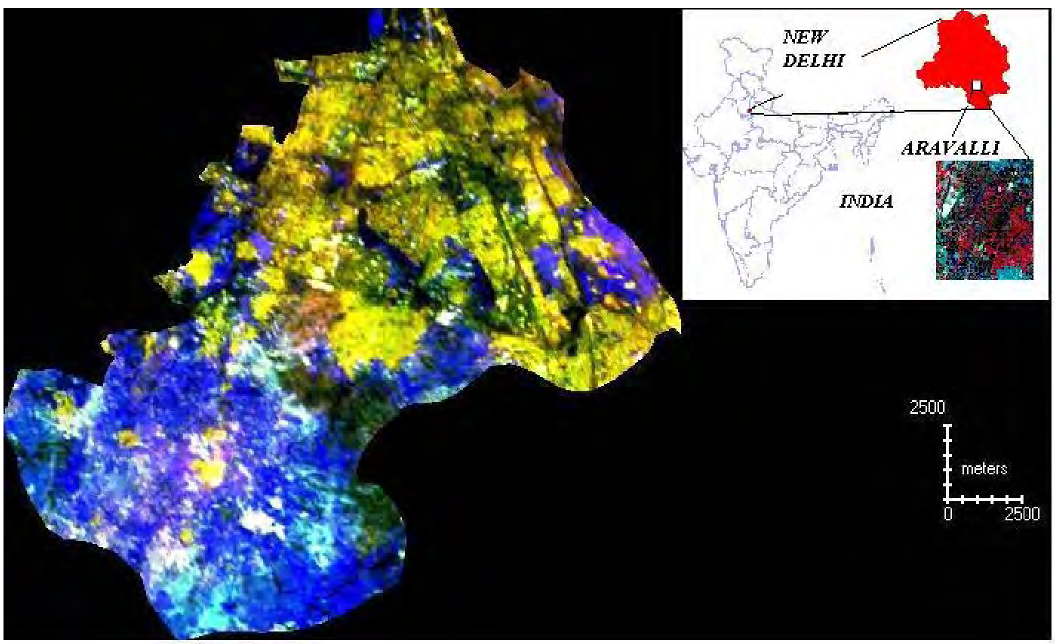


Figure.1AWIFS data of Delhi showing geomorphic microzones

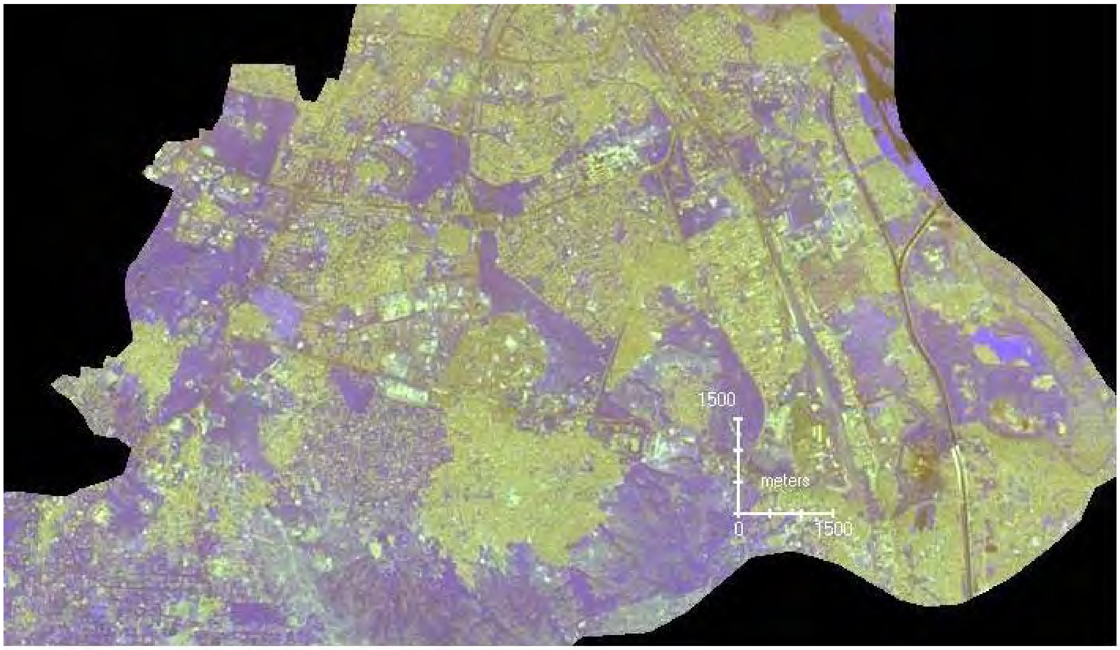


Figure.2.LISS-III sensor showing Hydrgeomorphic microzonation

Figure.3.IRS-1D PAN Data showing Hydrogeomorphic microzonation

5. X- Ray Diffractometer: - Bulk mineral composition and concentration of the various elements in the drill cuttings were analyzed using the X-Ray diffractometer. Model used is PW 3040/60 X/ Pert PRO Console (Phillips, The Netherlands). Interpretation of modern x-ray diffractograms requires several steps

1. Completely drying the samples

2. The rocks (drill cuts) samples were crushed – 200 mesh in agate pestle and mortar for analysis.
3. Slides are prepared from the meshed samples and put in the X-ray diffractometer to get the x-ray diffractometer in the rd, dat and udf format.
4. The results were then analyzed on X-Pert High Score software.

6. ICP-AES Analysis: - Multielement Analysis by BRGM Procedure

The geological materials such as rocks, soils and stream sediment samples were crushed – 200 mesh in agate Pestle and mortar for analysis. The geological samples were digested with mixed acid (HF, HCI, HNO3 and $HCIO_4$).

Methodology adopted for ICP-AES analysis

Alkaline and acid fluxes are also very effective for the decomposition of refractory minerals. Basic Fluxes efficiently decompose complex silicate and minimize volatilization of minerals. Among these Fluxes, Sodium Hydroxide, Carbonate, Peroxide and their mixtures have been used. Sodium Peroxide is very effective for decomposing materials containing Sn, W, Cr and Mo. The flow sheet scheme for sample treatment, decomposition and dissolution for multi element analysis of rocks, soils and stream sediments by ICP-AES is shown in the figure. BRGM program for the determination of major, minor and trace elements, special wavelengths and limits of detection in solid materials, for geotechnical exploration samples, based on l gm sample in 100 ml.

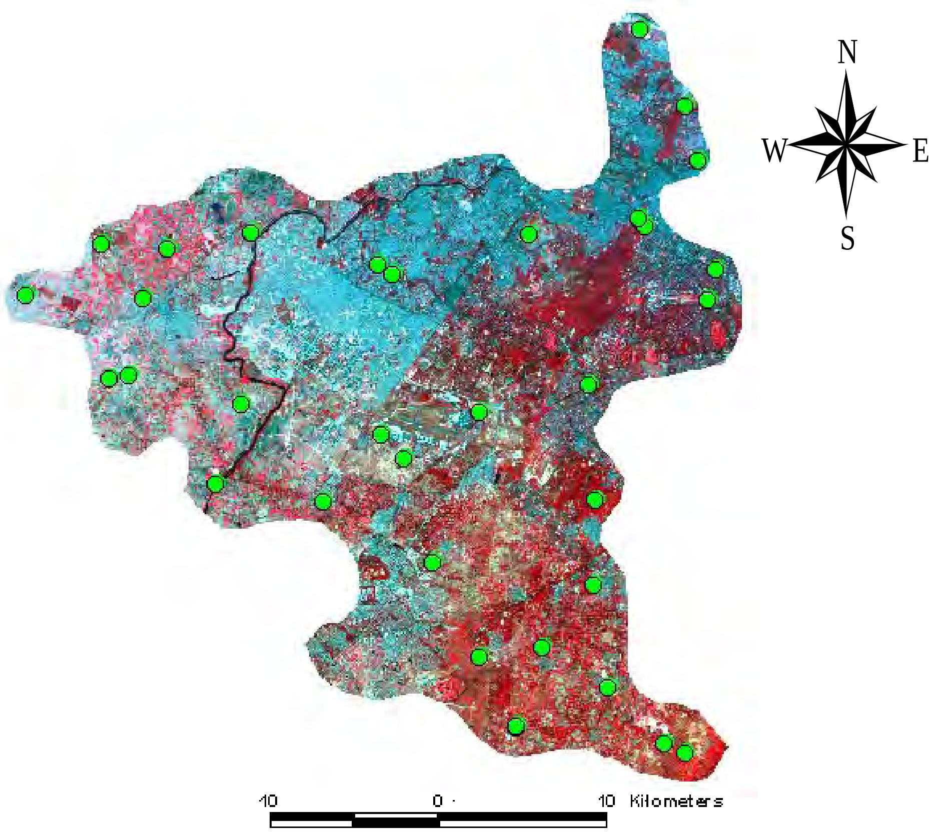


Figure.4.Sampling Sites of the Water Quality data in NCR region

7. Soil Particle Size Analysis

The particle size analysis of soil estimates the percentage sand, silt and clay contents of the soil and is often reported as percentage by weight of oven dry and organic matter free soil. The analysis is usually performed on air-dry soil. Based on the proportion of different particle sizes, a soil texture category may be assigned to the sample. The first stage in a particle size analysis is the dispersion of the soil into individual particles - sand (>1000μm - <600μm), silt (>600μm - <37μm) and clay (>37μm). The hydrometer method of silt and clay measurement relies on the effects of particle size on differential settling velocities within a water column. Theoretically the particles are assumed to be spherical and have a specific gravity of 2.65. If all other factors are constant, the settling velocity is proportional to the square of the radius of the particle in accordance with stoke's law.

8. Drilling details

Based on the Remote sensing and Geophysical investigation, exploratory drilling were carried out in 7 locations at JNU and 4 locations in RR Hospital in NCR in 2006-2007. The details of wells drilled in JNU are shown in Table:1.

Table.1.: Drilling site details in part of NCR

Bore	Longitude	Latitude	Easting	Northing	Elevation (in Metres)	Total Depth (in Metres)
JNU 1	77.17186	28.54092	712494.9	3159050	248	182.92
JNU 2	77.17406	28.54642	712698.5	3159663	236	182.92
JNU 3	77.17019	28.54608	712321.4	3159619	250	164.63
JNU 4	77.17078	28.54283	712385	3159260	253	160.06
JNU 5	77.1563	28.5381	710977.6	3158710	263	166.15
JNU 6	77.1619	28.544	711513.9	3159374	250	198.17
JNU 7	77.17251	28.5376	712565.1	3158683	256	146.34

9. Yield Description:-

Groundwater occurs in Aravaliis in confined aquifer at various levels in JNU area (24mbgl to 185mbgl). After drilling on scientifically selected suitable sites, 100% success was achieved in this water starved, metamorphic terrain. Based on the lithologs prepared by Remote Sensing Application Laboratory, SES, JNU, slotted pipes were lowered down to scientifically corrected accurate depth zones. The compressor test was carried out. In this process a pipe of diameter inch with orifice diameter of 2.5inch was fitted in the dischrge pipe. Head of the orifice was measured through a transparent rubber tube. Table.2 Shows discharge of groundwater in Lt/hr from circular orifice.

	JNU 1	JNU2	JNU3	JNU4	JNU5	JNU6	JNU7
Head of water in tube above centre of orifice in (inches)	9	18	25	10	20	9	20
4 inch pipe with 2.5 inch opening in (Lt/hr)	20,475	28,938	34,125	21,840	30,576	20,475	30,576

Table .2. Tabulation of dischjrge in Lt/hr from circular orifice

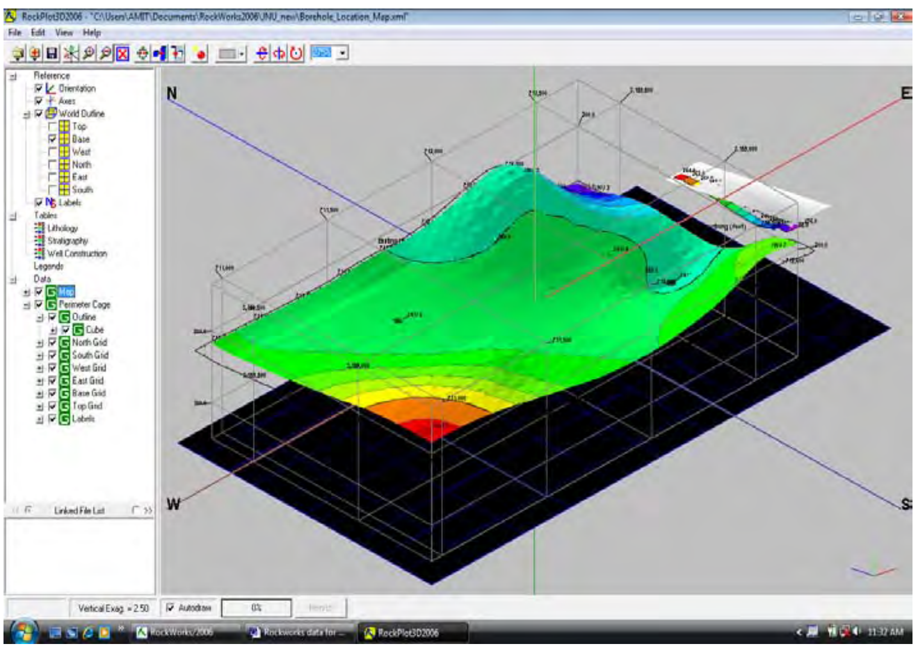


Figure.5.Rockware modelling of elevation contour in NCR area.

Figure.6.Elevation contours of the sites within study area selected for drilling indicate that elevation naturally increases towards south-west region. Towards eastern and north-eastern parts of study area elevation decreases sharply.

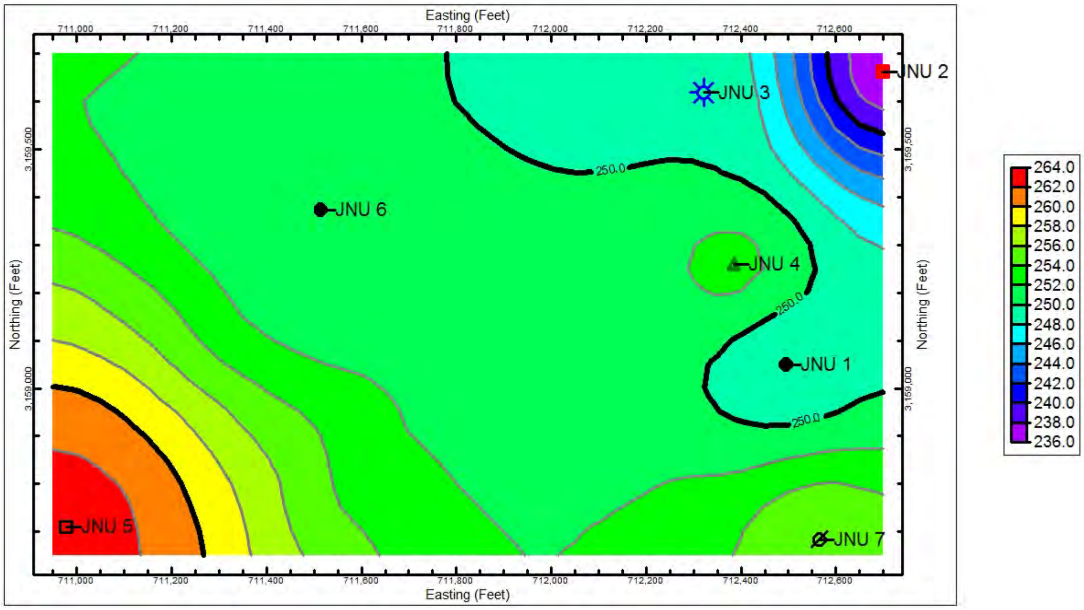


Table.2. Litholog of Drilled wells in a part of NCR (JNU)

Bore	Depth1 (in metres)	Depth2 (in metres)	Lithology
JNU 1	0	9.14	Top soil dry
JNU 1	9.14	18.29	Clay and silt
JNU 1	18.29	32.01	Sand and Clay
JNU 1	32.01	45.73	Clay, Quartzite
JNU 1	45.73	64.02	Weathered Quartzite
JNU 1	64.02	82.31	Weathered Quartzite and Feldspar Veins
JNU 1	82.31	86.89	Quartzite veins and Feldspar veins
JNU 1	86.89	96.03	Weathered Quartzite and Aplite
JNU 1	96.03	105.18	Hard compact quartzite
JNU 1	105.18	114.32	Fractured quartzite
JNU 1	114.32	118.9	Non ferruginous quartzite
JNU 1	118.9	137.19	Fractured quartzite
JNU 1	137.19	150.91	Non ferruginous quartzite
JNU 1	150.91	164.63	Quartz and Feldspar veins
JNU 1	164.63	182.92	Coarse quartzite
JNU 2	0	4.57	Top soil
JNU 2	4.57	9.14	Clay and silt
JNU 2	9.14	13.71	Ferruginous intercalation
JNU 2	13.71	22.86	Sand and ferruginous quartzite
JNU 2	22.86	36.58	Sand , clay and quartzite
JNU 2	36.58	41.58	Ferruginous quartzite and mica
JNU 2	41.58	50.3	Weathered mica schist
JNU 2	50.3	59.45	Weathered mica schist and quartz vein
JNU 2	59.45	73.17	Ferruginous quartzite

JNU 2	73.17	96.03	Fractured quartzite
JNU 2	96.03	100.6	Hard compact quartzite
JNU 2	100.6	105.18	Quartzite and mica schist
JNU 2	105.18	109.75	Ferruginous quartzite
JNU 2	109.75	114.32	Mica schist and quartz vein
JNU 2	114.32	128.04	Ferruginous mica schist and quartz vein
JNU 2	128.04	132.62	Compact mica schist
JNU 2	132.62	137.19	Fractured quartzite
JNU 2	137.19	146.34	Ferruginous quartzite
JNU 2	146.34	150.91	Compact mica schist
JNU 2	150.91	169.2	Compact mica schist and quartzite
JNU 2	169.2	182.92	Compact mica schist

The lithology of primary drilling Sites Site 1 (JNU1) and Site 2 (JNU2) within JNU shows excellent aquifer has been encountered from 60mbgl down to 96mbgl. The litholog as well as compressor test in the field has further confirmed the high potential aquifer in this area. X-Ray and ICPAES a result shows that at a deeper level water quality remain excellent as in the upper level. At the depth 108.5mbgl the mineral peak shows mainly quartz with some accessories of calcium carbonate. Down to 146.34mbgl the fractured quartzite further shows another good layer of aquifer. Beyond ferrugenous quartzite at depth of 146 to 150mbgl the compact mica schist shows some garnet crystals in thin section petrography. The presence of garnet in mica schist is suggestive of high grade metamorphism which is further supported by X-Ray and ICPAES investigations. The presence of Barium is decreasing from 4.57mbgl to 77.74mbgl which is suggestive of the selective chemical mobility of the ions during metamorphism leading to pegmatisation.

The presence of different mineral studied in thin section under the petrological microscope, ICPAES and X-Ray diffraction confirms the presence of zoned pegmatite in this area. Groundwater quantity and quality in this area is dependent on grade of metamorphism i.e. pegmatisation and its structural anomaly. Presence of Barium Feldspar forms a weak zone through which the fractures have been developed down to 4.57 to 77.74mbgl. Groundwater estimation in this area is highly depend on mineral paragenesis and induced structural anomaly in this area.

Drilling at Site 2 (JNU 2) went up to 182.92metres depth. Here also upper layers up to 9metres depth (approx.) were composed of silt and clay. This was followed by several layers of sand and ferruginous quartzite. Zone around 36-40metres depth marked the transition to mica schist dominant layers.

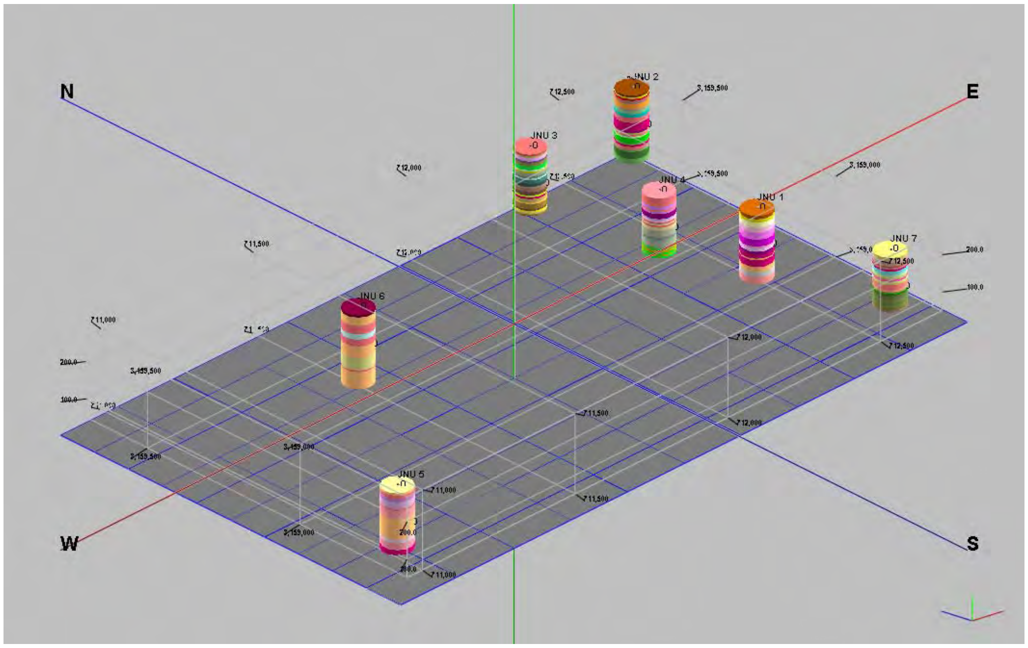


Figure.7.3D interpretation of drilled litholog in a part of NCR (JNU)

Sub-surface lithological information was used to generate a lithology solid model for drilling sites predicting the possible sub-surface lithological connections and extrapolating the information to the whole region apart from primary drilling sites. The software (Rockworks) determines the lithology types along each borehole in the project, and assigns certain values to those nodes along the wells. It then uses the "lithoblending" method to assign lithology to nodes lying between wells. Finally, it will reset those nodes above the ground surface to a value of 0.

Three dimensional fence diagrams generated for the part of study area covered by 7 drilling locations shows that top layers in most parts are predominantly composed of Weathered/Fractured Ferrogenous Quartzite. On the other hand the lower layers throughout this part of study area are mostly composed of Mica Schist and Compact Quartzite.

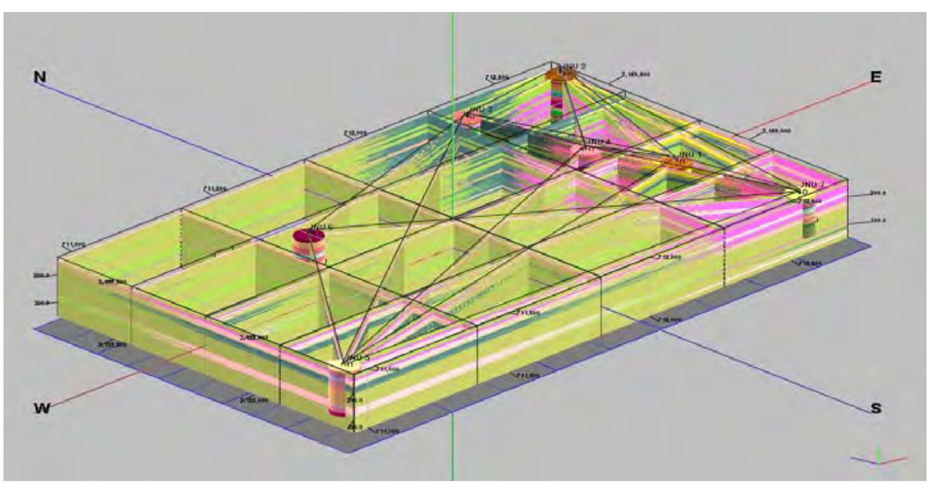


Figure.8.Fence Diagram in a part of NCR (JNU) showing litholog

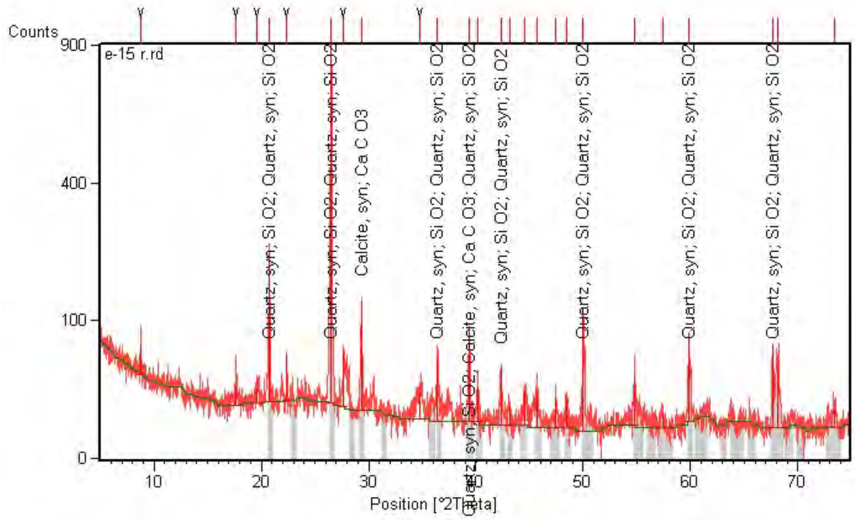


Figure.9.Mineral composition in JNU at 3.25 m bgl.

Figure.10.Mineral composition in JNU at 82 m bgl

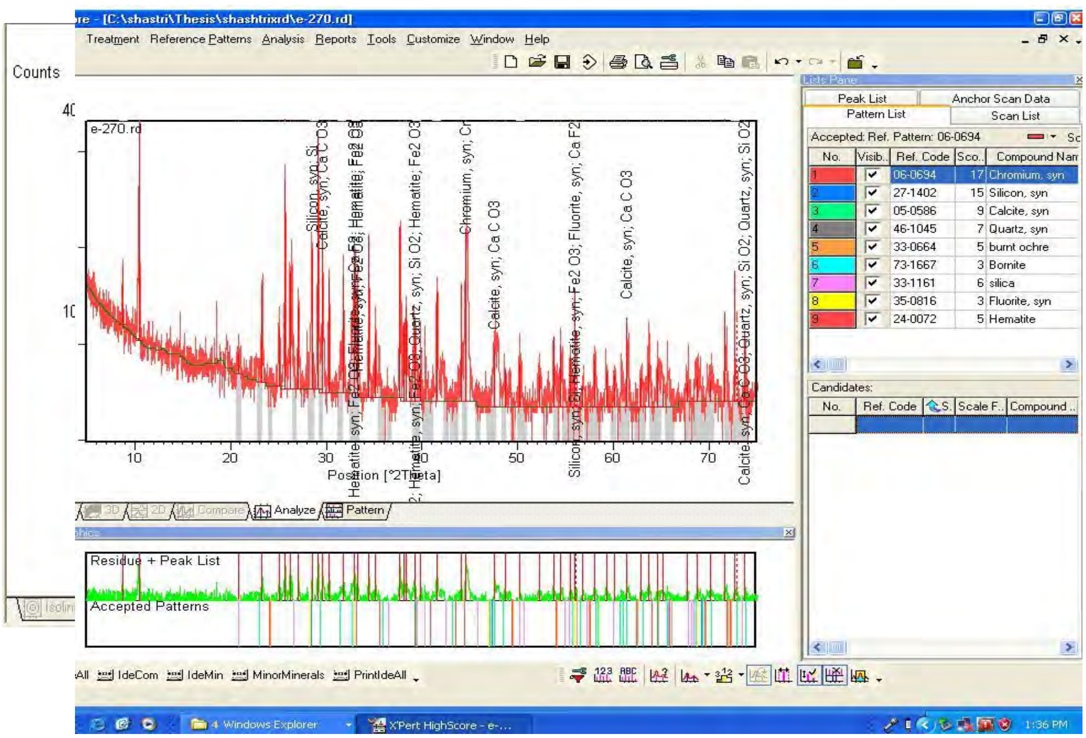


Figure.11.Mineral composition in JNU at 146 m depth

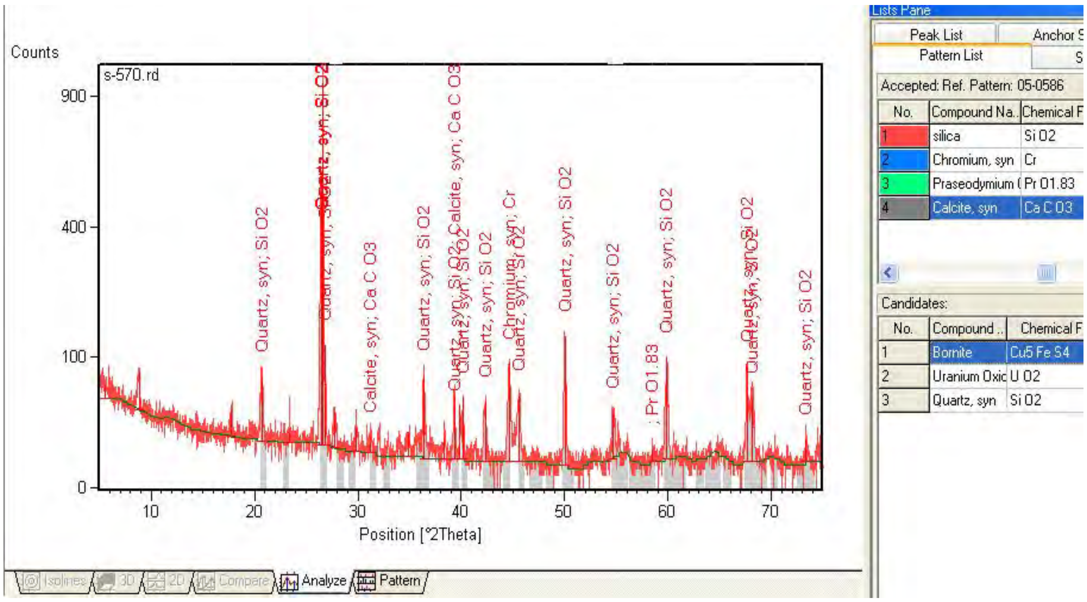


Figure.12.Mineral composition in JNU at 183 m depth

Table.3.ICPAES data of site1 at various depths

	Site1		
Element	**E-75(M)**	**E-90(M)**	**E-133(M)**
Major Element (%)	85.8	86.3	90.8
SiO_2 (%)	43.6	43.8	66.1
Al_2O_3 (%)	13.9	13.8	11.8
Fe_2O_3 (%)	9	9.7	5.1
CaO (%)	11.2	9.8	1.9
MgO (%)	6.8	7.3	1.2
K_2O (%)	0.7	1.2	3.5
MnO (%)	0.08	0.07	0.11
TiO_2 (%)	0.52	0.61	0.5
P_2O_5	495ppm	426ppm	425ppm
Li	<10ppm	<10ppm	<10ppm
Be	2ppm	2ppm	2ppm
B	40ppm	43ppm	102ppm
V	251ppm	272ppm	51ppm
Cr	410ppm	397ppm	42ppm
Co	49ppm	54ppm	9ppm
Ni	131ppm	120ppm	43ppm
Cu	37ppm	24ppm	32ppm
Zn	30ppm	33ppm	18ppm
As	<20ppm	<20ppm	<20ppm

Sr	52ppm	42ppm	37ppm
Y	<20ppm	<20ppm	<20ppm
Nb	26ppm	27ppm	25ppm
Mo	<5ppm	<5ppm	<5ppm
Ag	<1.0ppm	<1.0ppm	<1.0ppm
Cd	6ppm	7ppm	<2ppm
Sn	<20ppm	<20ppm	<20ppm
Sb	<10ppm	<10ppm	<10ppm
Ba	264ppm	124ppm	400ppm
La	<20ppm	<20ppm	27ppm
Ce	<10ppm	<10ppm	102ppm
W	<10ppm	11ppm	12ppm
Pb	37ppm	35ppm	20ppm
Bi	31ppm	31ppm	18ppm
Zr	301ppm	144ppm	119ppm

10. Summary and Conclusion

National Capital Region is a part of Precambrian Aravalli formation with little water availability. During pre- Mughal period the water conservation and extraction was restricted to the troughs of quartzite and pegmatite veins in hard rock areas. Although the study area is a grey zone according to Central Ground Water Board (CGWB). That is to say, CGWB does not recommend groundwater exploration in grey zones because of uncertainty of availability of groundwater.

The land use of National Capital Region in general and Delhi in particular has gone under drastic change. Change in land use, population growth and seismic instability have all contributed in changing the hydrgeomorphology of NCR.

Besides water resources, the growing awareness about the mountain ranges and the alarm of environmental degradation has forced the administration of NCR to arrest the deteriorating environment. The present work can help contribute its mite in mitigating looming ecological crisis. As has been said earlier that this work aims at hard rocks, colluvial and alluvial aggregates for exploration, exploitation and management of water resources. It required a geo-scientific database of water resources for generation of development plans for optimal use of potential resources. Although it is difficult to make all information relating to subsurface water available at one place, nevertheless the present thesis attempts to give a clear evaluation of a part of National Capital Region. To achieve above a systematic approach of understanding the terrain characteristic at a regional level and then going for detailed mapping by using geological, geophysical, drilling and analysis of drill cuttings and groundwater samples have been adopted. Remote sensing and GIS is used here which has emerged as the most optimal means for monitoring and management of water resources on global, regional and local scale. Being at higher elevation of NCR region with such condition i.e. fault zones, groundwater bearing fracture system and buried pediment plains, major part of the study area has become ideal recharge zone for better groundwater conditions. At higher elevations drainage system which follows the structural lineament and fault zone limit the capacity to hold and retain surface runoff of the rainwater.

An approach was made by drilling in Aravalli in seven locations in a part of JNU and four locations in Research and Referral Hospital.

Information from the drilled litholog was correlated with resistivity, magnetic and attributes of NDVI from satellite data. Analysis of drilled logs and groundwater samples from different zones were done to correlate these data with remote sensing geological and geophysical information.

These data along with ancillary information were analysed in Arc/GIS software for attribute data creation, derivation of secondary maps of groundwater prospects and quality zonation.

For the present investigation satellite data IRS 1C, IRS 1D (LISS III), Resourcesat and Landsat were used. For geo-referencing Survey of India toposheets and NATMO maps has been used. The data collected from different sources have been used as groundtruth information for the preparation of various thematic maps. Detailed ground truthing has been carried out in some selected points of study area. These ground truthing includes resistivity and magnetic surveys and drilling by Down the Hole Hammering (DTH) rig. This process involved following steps:

1) Interpretation of data available (Geophysical, Geological, Geochemical, Soil texture and Drilling) for locating suitable groundwater exploration points.
2) Interpretation of IRS, Resourcesat, SPOT, and Landsat data for demarcation of groundwater zone including its quality.
3) To identify the structural control of the area through Digital Elevation Model generated Shuttle Radar Terrain Mission (SRTM).
4) Interpretation of lineament and fracture system in the NCR region.
5) Collection of samples for detailed geochemical and petrological analysis.
6) Confirmation of recently identified groundwater zone based on distinct vegetation anomaly and lineament fabrics depicted on satellite images.
7) Identification of possible groundwater zones based on drilling data.
8) Identification of groundwater quality based on NDVI attributes.

<u>Remote Sensing and GIS</u>: - Remote Sensing has been found to be very useful in the study. These tools and techniques were useful for water resource management in following ways.

1) <u>Homogenization of the data</u>: - This enabled to bring all the old and new data on common platform and on uniform scale. This uniformity of scale is the prime need for any analysis on one common platform. In this process entire data have been organized in the common projection system, scale and on common GIS format.
2) Updating of information with the use of remote sensing technology, field verification and laboratory analysis. The information have been updated and correlated with each other.

<u>Field Observation</u>: - The interconnected fracture in Aravalli quartzite has been found to have potential for groundwater exploration. Within Aravalli quartzite the ferrugenous variety was found more fracture prone. Pegmatites, Aplite and Quartz vein intercalated with schistose rocks has multiple fracture system. Thin section analysis of rocks from different depth zones shows that the grade of metamorphism has relevance with groundwater quality and potentiality.

It has been observed that from Aravalli quartzite to river Yamuna there are three prominent watershed boundaries in existence. The buried pediment plains and alluvial plain boundary is demarcated by a very thick layer of fine grained sediments. Hydrogeomorphologically this boundary is not suitable for groundwater exploration.

Elemental composition (rock analysis) of the selected rock samples were analysed by ICPAES. The rock sample represents potential fracture zones encountered during groundwater exploration. The analytical data reveals the following features.

→In al the drilling sites silica content increases with depth which is suggestive of good to excellent groundwater quality at depth.

→ Concentration of Al_2O_3 decreases with depth which is also suggestive of excellent groundwater quality.

→ Concentration of Zr is found higher in upper zone (245ppm) which reduces to bare (<20ppm) at greater depth this suggest that emplacement of pegmatities are near the surface which is overlying on fractured quartzite at greater depth.

The conclusions inferred from the research work more than eloquent i.e. it was found that wherever the lineament density were high there were also resistivity and magnetic anomaly with lower values. At all those places groundwater available in large quantity. If Normalized

Differential Vegetation Index is high, the vegetation is thick due to high moisture laden lineament which is suggestive of high mineral availability and hence the groundwater availability.

Wherever there has been excessive use of land, it is difficult to find out the contours of the lineaments. Whereas the lineaments of the unperturbed lands can be easily brought to light.

Resistivity survey threw light on the different levels of water availability. One could infer from photomicrograph of rock shreds obtained during drilling that high grade metamorphism which has not disturbed the aquifers. Since all the aquifers are situated at great depth, they are beyond anthropogenic perturbations. On the other hand alluvial aquifers are more prone to anthropogenic pollution as they are shallow and therefore not potable. Further, it was found that wherever there has been change in the landuse the natural recharge potential too has declined. Digital Elevation Model (DEM) could tell us about the course of water run-off and it will help in recharging the aquifer. The study also came to the conclusion that wells may not be directly recharged. There can be indirect method of recharging them. Recharging the lateral dry wells can be done by the lateral homogeneity. In view of total area of study in JNU which is approximately 5sqkm the number of tube wells were restricted to seven based on the delineation of micro-watershed. As per the National Water Policy there should not be more than one tube well in one micro-watershed. The research work carried out in this thesis recommends that there should not be further drilling in JNU area for sustainable performance of the aquifers. Although the discharge of the tube wells are ranging between 24,475Lt/hr to 34,125Lt/hr with less than 10mts draw down in 72hrs of pumping but it is recommended that the groundwater can be pumped from the tub wells for 8Hrs then it should be allowed to recover for 5hrs. In this area most of the drilling site fractures are interconnected with high transmissitivity, it has been observed that 80% recovery of draw down takes place within 1hr, if surrounding tube wells are also stopped. Remaining 20% recovery takes 4hr due to elastic nature of the aquifer. Hence it will be safer if the tube wells are not pumped together with more than 8hrs. If the above recommendations are not followed and tube wells are operated continuously then it may result in permanent decline of groundwater level.

Similar work has been done from Remote Sensing Laboratory, SES, JNU in Humanyun Tomb, IGNOU and Research and Referral Hospital areas. The result and effect is arrest of lowering down of the water level in the areas mentioned above further supports the lateral recharge hypothesis in confined aquifers.

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