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INTEGRATED WATER RESOURCE MANAGEMENT USING REMOTE SENSING AND GEOPHYSICAL TECHNIQUES: ARAVALI QUARTZITE, DELHI, INDIA

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Information on land use patterns and changes are required for planning, utilization, and implementation of groundwater exploration and rainwater harvesting. Multispectral and multitemporal satellite data has the potential to delineate sites for water resource management. Magnetic and resistivity surveys can further confirm subsurface aquifer configuration. Due to heterogeneity of aquifer materials, it is essential to take a holistic approach that includes geological information supplemented with remotely sensed data and supported by resistivity and magnetic anomaly detection. This approach is used for locations of higher spectral reflectance and lineament density which are assumed to be areas of aquifer recharge. This investigation focussed on the Aravali quartzite terrain of Delhi, India at the Research and Referral Hospital and Jawaharlal Nehru University areas. Suitable areas are identified for construction of check dams, roof-top rainwater harvesting pits, and drilling sites in the difficult terrain of the Aravali quartzite.

INTRODUCTION

The management of a resource includes insuring a sustainable input of the resource to a place where it is in short supply from a place of excess. But to maintain the supply there should be exhaustive planning to manage the resource and at the same time consider the safety of the environment. Management includes bringing a balance to the resource availability at a place ensuring the benefit of the local population while keeping in view the well-being of the environment.

Jawaharlal Nehru University (JNU) and Research and Referral Hospital (RRH) resource management case studies invariably speak in favor of the above approach. The study area is situated in a part of the Delhi ridge, which is geologically a quartzite mass. This makes the probability of finding groundwater very small (Mukherjee, 2004). Interestingly, in such a terrain the movement and availability of groundwater depends on geological as well as structural inhomogeneity. Implementation of the project and popularizing the technique in those areas where depth of the water level is more then 25 m below ground level and have a declining trend is critical. Information on existing land use patterns, the spatial distribution and its changes is required for planning, utilization, and formulation of policies and programs for sustainable development of depleted water resources. Groundwater exploration in hardrock terrain is a challenging task. The occurrence and amount of groundwater in hard rocks is related to the complex interactions of lithological, structural, geomorphological, and pedological and climatological factors. Crystalline rocks, with little intergranular porosity, are generally impervious. Movement and storage of water can occur in the network of joints, fractures and faults and in weathered zones. The thickness and nature of the weathered layer is also related to lithological and structural characters and climatological conditions (Horton, 1945).

Remote sensing techniques using satellite images have become a powerful tool in groundwater exploration to supplement conventional methods. The importance of remote sensing in groundwater studies is based on the fact that images help in identifying morphological and structural features that influence groundwater movement and occurrence. Delineation of lineaments and fractures, drainage pattern, weathered zones, vegetation anomalies and their mutual relationships have been carried out utilizing resistivity and magnetic data (Mukherjee 1998).

DATA USED AND METHODOLOGY

Multispectral and multitemporal data merged with land use, geological, geomorphologic, hydrogeological and magnetic data have potential for identification of suitable areas for construction of check dams across drainage at appropriate locations. This is one of the successful methods of artificial recharge and selection of drilling sites for groundwater exploration.

Information derived from satellite image analysis and other collateral data were integrated together to synthesize and mark potential areas for artificial recharge.

Satellite data products inferred land use, geological, hydromorphological and ecological information. The satellite image covering the area was analyzed digitally to prepare a geomorphologic map on 1:12,500 scale. The following satellite data products were used in the analysis

1. IRS 1D PAN+LISS III merged acquired on PAN on 15 Feb. 2002 and LISS 15 Feb. 2002
2. IRS 1D PAN +LISS III merged acquired on PAN on 6 march 2004 and LISS on 23 Feb. 2004.

The Research and Referral Hospital (RRH) encompasses the western and southwestern parts of the national capital territory, Delhi, while Jawaharlal Nehru University is situated on the southern part of Delhi. The rock types of RRH and JNU are the same and are mostly Aravali Quartzite. The terrain has undulating topography with a regional slope toward the north-northwest. The low-lying area is filled with buried shallow to medium pediment plain. Due to this heterogeneity in aquifer material, water resources management in the RRH and JNU areas needed a holistic approach of geological information supplemented with remotely sensed data and detailed resistivity and magnetic surveys.

Sustainable fresh groundwater availability in the area can only be expected in the shallow fresh water aquifers, which are regularly recharged over suitable geological formations. In order to find the remedial measures it has become essential to identify suitable areas where optimum rainwater harvesting can be done.

LOCATION OF THE STUDY AREA

The JNU campus is situated on a low relief hill, northwest of Mehrauli and southwest of Hauz Khas in south Delhi, falling in topographical sheet No. 53 H/2 (SE quadrant). Latitude 28^{o}32’30” E and longitude 77^{o}10’00” N pass through the middle of the campus.

Physiographically, Delhi is at the northeastern culmination of the Mewat branch of the Aravalli mountain system. Here, this branch of the Aravallis is called the Delhi Ridge. JNU is situated on an easterly projecting spur of this ridge and forms an undulating and dissected plateau of quartzite. The general slope is towards north to northeast.

The campus area is drained by three drainage systems, forming structurally controlled sub-dendritic to sub parallel patterns. The main streams are controlled by a formational strike (NS to NE-SW), while the minor drainages by fractures and joints. All the drainages are dry except in the rainy season and all rainwater flows out of the campus in the absence of any structure to control the runoff. There are a few shallow ponds along drainage, but they are mostly silted and remain dry.

The RRH complex is located SW of the Dhaula Kuan, and is adjacent to Indira Gandhi international airport to the west. It is located on the line joining a portion of the ridge forest area of Delhi. This linear fracture of ridge reaches Yamuna at one end which is NE from the hospital.

The area is covered by latitude 28034’30” to 28^{0}35’30” and longitude 77^{0}8’30” to 77010’10” (Figure 1). The RRH complex boundary consists of the RRH hospital itself as well as residential areas, a parade ground and xerophytic vegetation characteristic of arid to semiarid conditions. The complex has an area of 146 acres situated in the southwest district of the national capital territory of Delhi.

GEOLOGY OF THE AREA

The area is occupied by an alluvium buried pediment plain, comprised of sand, silt, clay and kankar (agglomeration of clay and sand) underlain by bedded, highly weathered Alwar quartzite constituting a north - south trending low ridge in the area (Table 1). A clear lineament has been observed in a north-south direction and few lineaments have a diagonal relationship with the main one. The sequence of the rock formations in the area is:

Quaternary alluvium / buried pediment plain

Post Delhi intrusive – pegmatite and basic intrusive

Delhi super group – Alwar quartzite (ferruginous / siliceous)

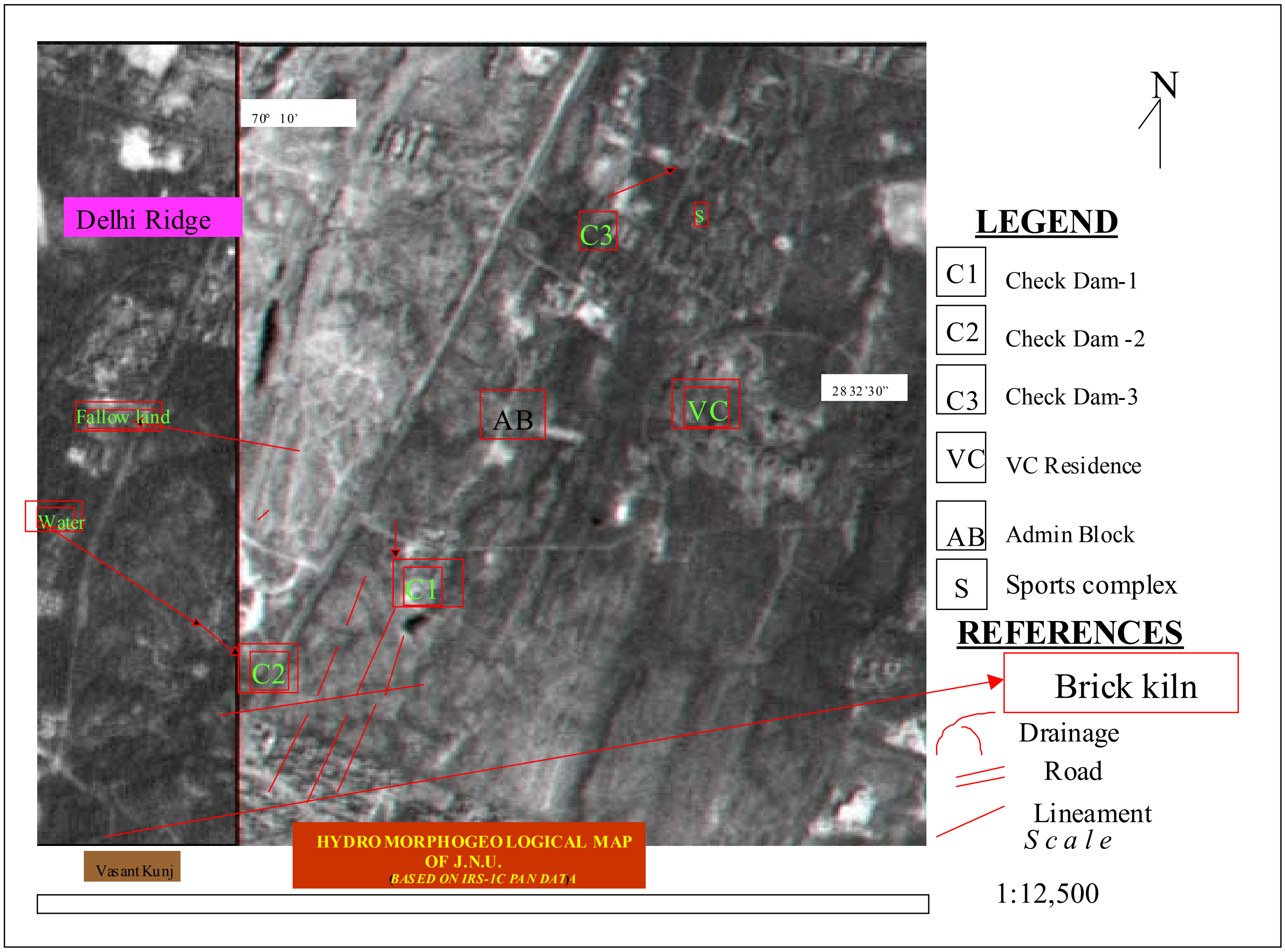

Figure 1. Hydrogeological study of JNU environs for integrated water resource management.

The Delhi region is a part of the Indo-Gangetic alluvial buried pediment plain at an elevation ranging from 198-270 m. A quartzite ridge extending roughly from north-northeast to the south-southwest transects the area. The thickness of alluvium on the eastern and western side of the ridge is variable. It generally thickens (>300 m) towards the west.

HYDROGEOMORPHOLOGY

From the hydrogeomorphological investigation of JNU and RRH of Delhi area it is clear that it includes the following features:

1) Low Residual Structural Hills: These are parts of Delhi ridge forming N-S to NS-SW trending structural ridges, tors, and mounds and composed of folded and jointed quartzite. Joints allow only limited groundwater infiltration. This unit has very poor prospects of groundwater. They are mostly barren, with scanty vegetation along joints and slopes.

2) Pediment: The undulating, eroded and dissected shallow, buried planar surface along the fringe and slopes of ridges and tors form this unit. The main drainage systems are developed in this unit. Weathering is shallow and soil thickness varies, the maximum being in the valleys near the streams. The soil is generally clay and fine silty, and partly gritty and gravelly. Drainage dissection is quite intense at places, often developing gullies. Weathering is more intense in coarse gritty or arkosic quartzite. Groundwater potential is generally low due to poor infiltration, with high runoff resulting from varying slopes and clay mantle.

Table 1. Stratigraphy of Delhi

Period	Formation	Description
Quaternary	Newer alluvium	Unconsolidated interbedded line of sand, silt, gravel and clay confined to flood plains Yamuna river
	Older alluvium	Unconsolidated interbedded, interfingering deposit sand clay and kankar, moderately sorted thickness variables, at places more then 300m
Precambrian	Alwar quartzite	Well stratified thick bedded brown to buff color, hard to compact, intruded locally by pegmatite and quartz vein inter bedded with mica sheets.

3) Buried pediment: This unit forms the almost flat terrain in the northeastern part of the RRH premises. In JNU this type of feature exists in the northeastern part mainly between the ridges where the depth of the buried pediment is shallow (Figure 1). It has a shallow to moderately thick soil cover, which is mainly silty and clayey, and at places gritty and gravelly. The surface slopes gently towards the northeast and merges with deeply buried pediment beyond the campus and with the Yamuna alluvial plain further east. This unit forms a moderate to good groundwater potential, especially along fractures and drainages.

Groundwater occurrence

Groundwater is the subsurface water that fully saturates pores or cracks in soils and rocks. Groundwater is replenished by precipitation and, depending on the local climate and geology, is unevenly distributed in both quality and quantity. When rain falls, some of the water evaporates, some is transpired by plants, some flows over land and collects in streams, and some infiltrates into the pores or cracks of soil and rocks. After the water requirements for plant and soil are satisfied, any excess water will infiltrate to the water table – the top of the zone below which the opening in rocks are saturated.

Role of remote sensing in groundwater studies

Space technology in the form of remote sensing can play a useful role in hydrological studies. Remote sensing is defined as the science of deriving information from measurements made at a distance from the object without the sensor actually coming in contact with it. Remote sensing though is a fledging phenomenon; either substituting or complementing or supplementing the conventional technology with reasonably faster, efficient and accurate methods of survey in the domain of water resource planning, conservation, development, management and utilization (Roy and Bhattacharya, 1982).

Remote sensing by virtue of its synoptic coverage, spectral behavior, repeatability, and availability, offers an effective first hand tool in mapping and monitoring resources in a reasonably short time frame. The synoptic view facilitates the study of objects and their relationships. Spectral signatures permit identification of various features, while the temporal aspect allows change detection in the environment. The real advantage is the real time measurement that facilitates constant and effective monitoring. The main advantage of the remote sensing is that the data is in the digital form and can be analyzed easily with the help of computers.

The application areas for remote sensing data are both wide and varied. Radiometric data potentially represent a very useful source of information in pedological research and in the study of water quality though remote sensing but cannot be used for groundwater studies (Sharma and Anjaneyulu, 1993). But remote sensing allows us to make indirect references regarding subsurface through sacrificial expression of the aquifer. The subsurface hydrological conditions are inferred based on identification and correlation of surface phenomenon involving geological features and structures, geomorphology, surface hydrology, soils and soil moisture anomalies, vegetation types and distribution, land use and many other indicators. The benefits that accrue in the use of remotely sensed data are usually greatest when they are applied for large-scale preliminary investigation of groundwater reserves.

Although remote sensing techniques can never replace conventional hydrologic observation network, remote sensing data have two distinct advantages. Remote sensing platforms provide data with high resolution in space and data and can be obtained for areas that has no record of measurements (e.g. remote areas). Remote sensing data, particularly satellite data can be most helpful for design and operation purposes if they are used in combination with ground truth (Usha et al., 1989). The disadvantages of satellite data are an unfavorable combination of resolution in time and space, Airborne geophysical exploration is highly used in groundwater prospects. Conventional prospecting tools viz., hydrogeological and geophysical instruments generally do not yield the relevant details and occasionally exhibit lack of resolution (Orellena and Mooney, 1966). Integration of satellite data and vertical electrical sounding (VES) data as well as magnetic intensity data, indirectly giving the potential fracture zones using other collateral data generated from the imagery as well as collected from various institutions is used to access the groundwater potential of various geomorphic units (Mukherjee, 1998).

In the present work, more thrust has been given to the detection of area which has high groundwater potential and areas which can serve as good point of recharge to groundwater. Also undertaken in this exercise is an effort to generate a model to find the trend of flow of the surface water during rainy months so that this water can be diverted toward the areas selected for recharging the groundwater. All this has been achieved using geophysical techniques viz. resistivity survey, magnetic survey, soil analysis, drawdown tests of existing pumps, and using remotely sensed data to correlate the data. New data like trends of the lineaments are also used to detect the reflectance values and to generate a model to find the trend of flow and help in locating suitable sites for check dams (Figure 1).

Electrical Resistivity Method

The electric resistivity of a rock formation limits the amount of current passing through the formation when an electric potential is applied. It may be defined as the resistance in ohms between opposite faces of a unit cube of the material. If a material of resistance R has a cross-sectional area A and a length L, then its resistivity can be expressed as

$$r=RA/L$$

Units of resistivity (r) are ohm-m.

Resistivity of rock formations vary over a wide range, depending on the material, density, porosity, pore size and shape, water content and quality, and temperature. There are no fixed limits for resistivities of various rocks. In relatively porous formations, the resistivity is controlled more by water content and quality within the formation than by the rock resistivity. For aquifers composed of unconsolidated materials, the resistivity decreases with the degree of saturation and the salinity of groundwater. Clay minerals conduct electric current through their matrix, therefore clayey formations tend to display lower resistivities then do permeable alluvial aquifers.

Actual resistivities are determined from apparent resistivities, which are computed from measurements of current and potential differences between pairs of electrodes placed in the ground surface. The procedure involves measuring a potential difference between two electrodes (potential electrode) resulting from an applied current through two other electrodes (current electrode) outside but in line with the potential electrode. If the resistivity is everywhere uniform in the subsurface zone beneath the electrodes, the current and equipotential lines will form an orthogonal network of circular arcs. The measured potential difference is a weighted value over a subsurface region controlled by the shape of the network. Thus the measured current and potential differences yield an apparent resistivity over an unspecified depth. If the spacing between the electrodes is increased, a deeper penetration of the electric field occurs and a different apparent resistivity is obtained. In general, actual subsurface resistivity vary with depth; therefore, apparent resistivities will change as electrode spacing are increased, but not in a like manner. Because changes of resistivity at great depths have only a slight effect on the apparent resistivity compared to those at shallow depths, the method is seldom effective for determining actual resistivities below a few hundred meters.

Electrodes consist of metal stakes driven into the ground. In practice various standard electrode spacing arrangements have been adopted; most common are the Wenner and Schlumberger arrangements.

The Wenner arrangement has the potential electrode located at the third points between the current electrodes. The apparent resistivity is given by the ratio of voltage to current times a spacing factor. For the Wenner arrangement, the apparent resistivity

r_a=2pa V/I

Where ‘a’ is the distance between the adjacent electrodes, ‘V’ is voltage difference between the potential electrodes, and ‘I’ is apparent current.

The Schlumberger arrangement used for this study has the potential electrodes close together. The apparent resistivity is given by

$r_a = (p(L/2)^2 - (b/2)^2 V)/ b*I$

Where ‘L’ and ‘b’ are current and potential electrode spacing, respectively. Theoretically L>>b, but for practical application good results can be obtained if L>=5b.

Typical resistivities of the geological materials

Resistivity near surface materials is heavily affected by groundwater, and water is a low resistivity material. In general finer grained sediments have low resistivities, and bedrock has high resistivities. Resistivity values for different rock types are shown in Table 2. Resistivities are reduced by increasing porosity, increasing ion content of groundwater, increasing content of clay and decreasing grain size.

Magnetic anomaly studies

Magnetic anomalies can be an useful geophysical component in groundwater management (Regan et al., 1975). A magnetic survey was carried out in and around, the RRH complex, using a proton precession magnetometer modal PM - 600 manufactured by Integrated Geo Instruments and Services ltd.

The proton precession magnetometer utilizes the spinning of protons or nuclei of the hydrogen atoms in a sample of hydrocarbon fluid to measure the total magnetic field intensity. Water, kerosene, alcohol etc. are taken as samples. The protons in these fluids behave as small spinning magnetic dipoles. These magnetic dipoles are temporarily aligned (polarized) by application of strong uniform magnetic field by sending a current through a coil wound on the bottle containing

Table 2. Typical resistivity of various geological materials of Aravalli Quartzites of Delhi

S.No.	Lithology	Resistivity (Ω)
1	Silt	10-100
2	Sand-gravel	300-8000
3	Fresh water sand	50-100
4	Argillaceous sand	25-50
5	Salt water sand	0.4-1.3
6	Pebble aquifer	100-several hundred
7	Limestone	80- several hundred
8	Clay marls	Several to 50

the hydrocarbon fluid / water. When the current is removed i.e., when the applied field is removed, the spin of protons causes frequency of which is proportional to the ambient field intensity. The total magnetic intensity as measured by a proton precession magnetometer is a scalar measurement i.e., it gives simply magnitude of the total earth's magnetic field independent of its direction. The RRH complex is in a region with normal magnetic intensity around 47000 gamma (Figure 2).

A lineament trespassing the hospital complex is inferred by IRS-1D PAN+LISS-III merged, acquired on 06-march-2004, LISS23-march-2004 respectively and the second data by IRS-1D PAN+LISS merged 15-feb-2002 and 15-feb-2002 respectively. It shows a strong trend in NNE-

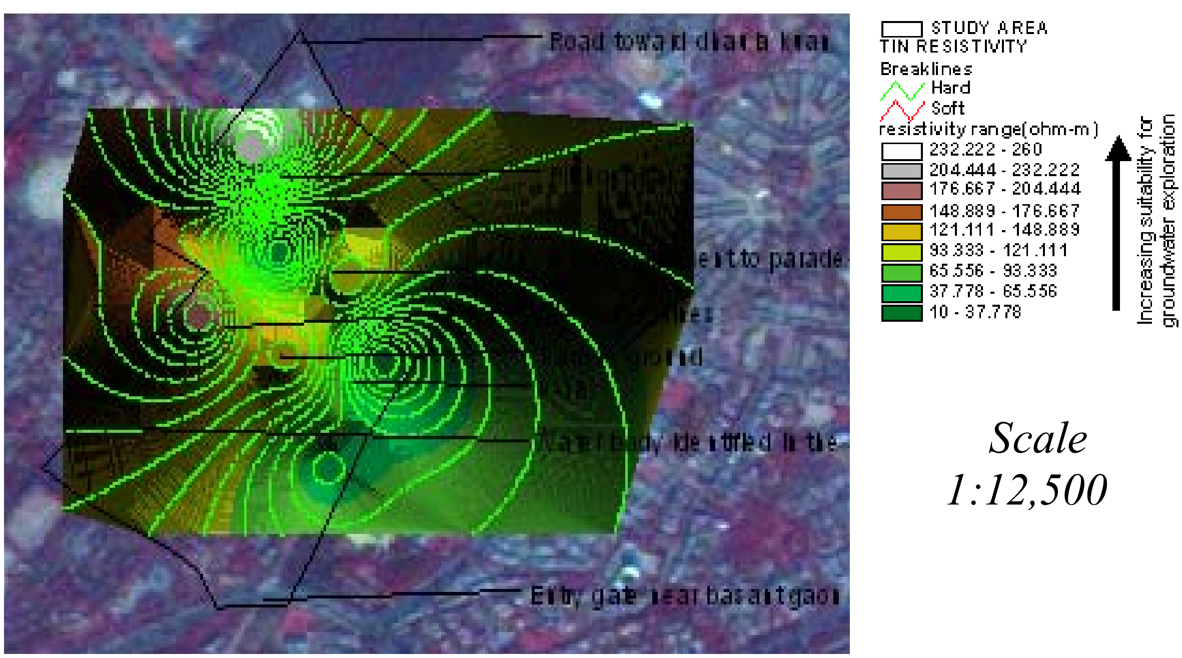

Figure 2. Hydrogeological study of RRH environs for integrated water resource management.

SSW direction, which passes directly through the hospital premises. On its NNE side from the hospital the lineament shows a water body at Subroto Park. And also on the SSW of the hospital the lineament has a water body inside the hospital premises. Measurements were taken along this lineament, which is inferred as a sudden decrease in magnetic values. Based on the spot magnetic values a contour map was made along the profile. Contour lines were been drawn at every 3000-gamma interval. Low magnetic values were noticed along lineaments and places with fractured ferruginous quartzite. Selection of check dams was based on the points inferred by magnetometer showing low magnetic values and interconnected lineaments.

DISCUSSION

Land use land cover and water resources management are directly linked with each other. It is clear that selection of the site for RRH and JNU was not done keeping this point in mind. However during that period, the latest knowledge of remote sensing as well as its integration with geophysical data was considered. The study area is on a series of parallel lineaments (Mukherjee, 1997). These lineaments are a connecting conduit of occasional surface water. In JNU the surface water is going out of the campus through seismically generated lineaments while at the RRH water logging takes place in the basement of the hospital. The JNU area has shown remarkable development (Figure 3) in its environment after the water resource management program and a similar development is expected in the RRH areas (Figure 2).

Keeping all these points in consideration a recommendation is given that can be implemented for the integrated water resource management in the terrain. Rainwater harvesting and groundwater exploration in selected areas may lead to sustainability to this area.

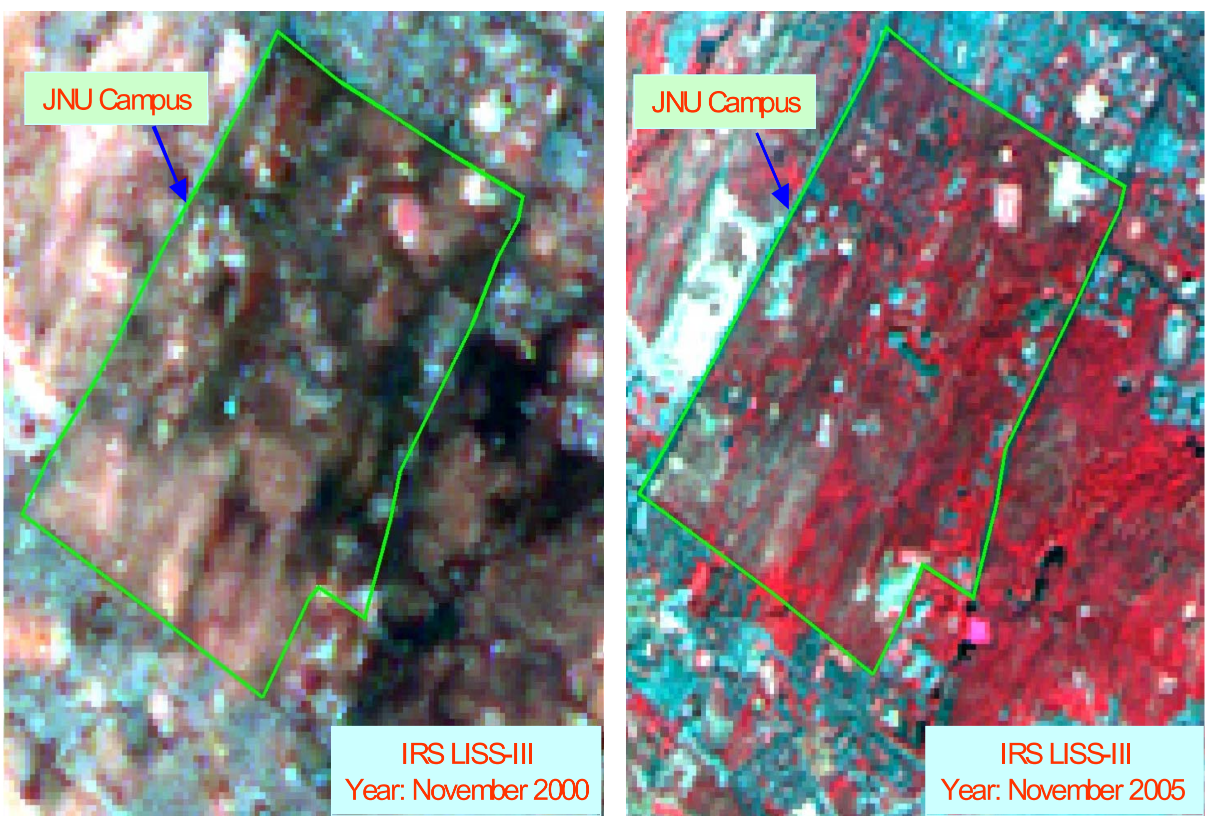

Figure 3. JNU area has shown remarkable improvement in terms of forest coverage.

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