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IRS-1A Applications for Groundwater Targetting

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ABSTRACT: *A large population in the world depends on groundwater not only for drinking and domestic use, but also for agriculture and industry. Search for groundwater, particularly in areas with consolidated and semi-consolidated rock formations, considered more difficult from the point of view of exploration, is considerably aided by the use of hydrogeomorphological maps prepared using satellite imagery. These maps depict spatial information on various hydrogeomorphological units including structural lineaments having different groundwater prospects. Districtwise hydrogeomorphological maps for the entire country on 1:250,000 scale have been prepared for the National Drinking Water Mission. These maps have been extensively used for locating prospective groundwater sites around problem villages as part of a scientific-source-finding approach involving remote sensing based hydrogeological survey geophysical investigations. This approach has raised success rates to better than 90 per cent in most cases. As examples of hydrogeomorphological mapping, three case studies are cited in this paper.*

INTRODUCTION

Water is an extremely important resource. Life on the planet Earth, evolved in aquatic environment, depends on water for sustenance. However, distribution of this resource is highly uneven. About 97.41 per cent of the water on the Earth is contained in the oceans as saline water. The balance of 2.59 per cent as fresh water is contained in ice caps and glaciers (1.953%), groundwater (0.614%), lakes (0.008%), soil moisture (0.005%), and in rivers, atmosphere and biota (0.0005%). Thus, only a tiny fraction of 0.014 per cent of the Earths total water in lakes and rivers, and contained in soil moisture, atmosphere and biota is available easily to human beings and other organism[1].

Because of the uneven distribution, shortage in local requirements of water can be met either by transporting (from reservoirs, lakes, rivers, storage tanks, etc.) or withdrawal of subsurface water. Fortunately, groundwater is a fairly widely distributed natural, renewable resource, which gets replenished almost regularly by precipitation. The resource, however, should be managed in such a way that the withdrawal is kept at pace with the recharge.

Groundwater occurrence at any place on earth is not a matter of chance but a consequence of the interaction of climatic, geologic, hydrologic, physiographic and ecological factors. The groundwater in India occurs mainly in three types of geological formations:

(i) Unconsolidated: This covers about 30 per cent of land area; primarily, the Indo-Gangetic Plain. The lithology comprises sand, gravel, pebbles, etc., which can store large quantities of groundwater;

(ii) Semi-consolidated: This covers only about 5 per cent of the geographic area. The lithology includes primarily semi-consolidated sandstone, formations of Mesozoic and Tertiary age; and

(iii) Consolidated: This constitutes 65 per cent of the geographical area comprising hard-rock formations. These include crystalline rocks – granites, gneisses, schists, etc., basaltic rocks and compact sedimentary formations like Cuddapahs, etc.

Search for groundwater is confined to the most promising zones in terms of porosity and permeability. Porosity, the volume of available pore spaces in rocks, determines the amount of water which can be held in storage. Permeability determines the ease with which water moves through the pores and fractures, and hence can be extracted.

Remotely sensed data from satellites provide quick and useful baseline information on the factors controlling the occurrence and movement of groundwater, like geology (lithology/structure), geomorphology, soils, landuse/land cover, etc. A systematic study of these factors leads to better delineation of prospective groundwater zones in a region. Such prospective zones identified from the satellite imagery are normally followed up on the ground through detailed hydrogeological and geophysical investigations before actual drilling is carried out for exact quantitative assessment and exploitation.

The usefulness of satellite data in identifying linear features such as fractures/faults, which are usually the zones of localisation of groundwater in hardrock areas, and certain geomorphic features, such as alluvial fans, buried channels, etc., which often form good acquifers is well established. The general keys for detection of groundwater aquifers have been summarised by Gerald K. Moore[2,3]. Certain specific applications were earlier reported using Landsat data[4,5,6]. These relate to identification of spring, seeps and phreatophytes indicating presence of shallow water table conditions, differentiation of vegetation that are closely related to depth and salinity of groundwater, and location and monitoring of groundwater systems under stress. Groundwater potential maps using Landsat data in hardrock areas have been prepared in the country using either the geomorphology as the base or through an integrated approach of studying various themes, depending upon the complexity of control over the groundwater occurrence and movement[7]. In some of the studies carried out by the Department of Space during the recent years, groundwater potential maps of large areas have been prepared employing a hydromorphological approach[8].

A major thrust to the utilisation of IRS-1A data on a national level was provided by the National Drinking Water Mission (NDWM); one of the technology missions launched by the Govt. of India in 1986. The mission desired inputs from remote sensing technology for locating groundwater sources. The work was initiated using the then available Landsat TM data. As soon as the IRS-1A imagery became available, the task was completed using IRS-1A data. The primary objective of NDWM was to provide potable drinking water to all the villages @ 40 litres per capita per day (lpcd), and an additional 30 lpcd for cattle in desert areas. It was stipulated that the source should be located within a distance of 1.6 km from a village. Further, it was envisaged that cost-effective technologies for exploration and development of water sources should be evolved ensuring sustained availability on long-term basis[9].

A scientific source finding approach was adopted for ground water exploration which had the following three components:

- Remote sensing based investigations.
- Conventional hydrogeological investigations.
- Ground geophysical investigations.

These investigations lead to drilling of exploratory bore-holes, pumping tests, etc., before a source was developed for use. It was noticed that a combination of two methods was more than twice as useful as using a single one. Thus, a combination of all three has presumably eliminated most of the uncertainties involved in locating an aquifer.

Remote sensing based-hydrogeological-geophysical approach has earlier been demonstrated as a highly successful one by Sahai *et al.*[10], while carrying out an end-to-end experiment jointly with the Gujarat State Water Resources Development Corporation in Saurashtra area.

It should perhaps be mentioned here, that the scientific source finding referred to earlier is based on logical considerations involving a careful study of the terrain, unlike the methods used by dowsers or water witches. It should, however, be noted that scientific methods were not unknown in ancient times in India. Varahamihira (A.D. 505–587) in his treatise Brihat Samhita has given an exposition of a highly multidisciplinary approach for ground water exploration[11]. Some of the present day methods like those based on geobotanical indicators have also been described in his treatise.

MATERIALS AND METHODS

The methodology adopted for the preparation of districtwise hydrogeomorphological maps on 1:250,000 scale (Figure 1) comprised the following six steps:

- Data procurement.
- Base-map preparation.
- Preliminary interpretation.
- Ground Checks.
- Final interpretation, and
- Final map preparation.

The data used initially was Landsat Thematic Mapper imagery (in the form of false colour composite imagery (FCC using bands 2, 3 and 4) with 30m spatial resolution, and later IRS-1A LISS-II (FCC) imagery with 36m spatial resolution. In some cases, LISS-I imagery with 73m spatial resolution

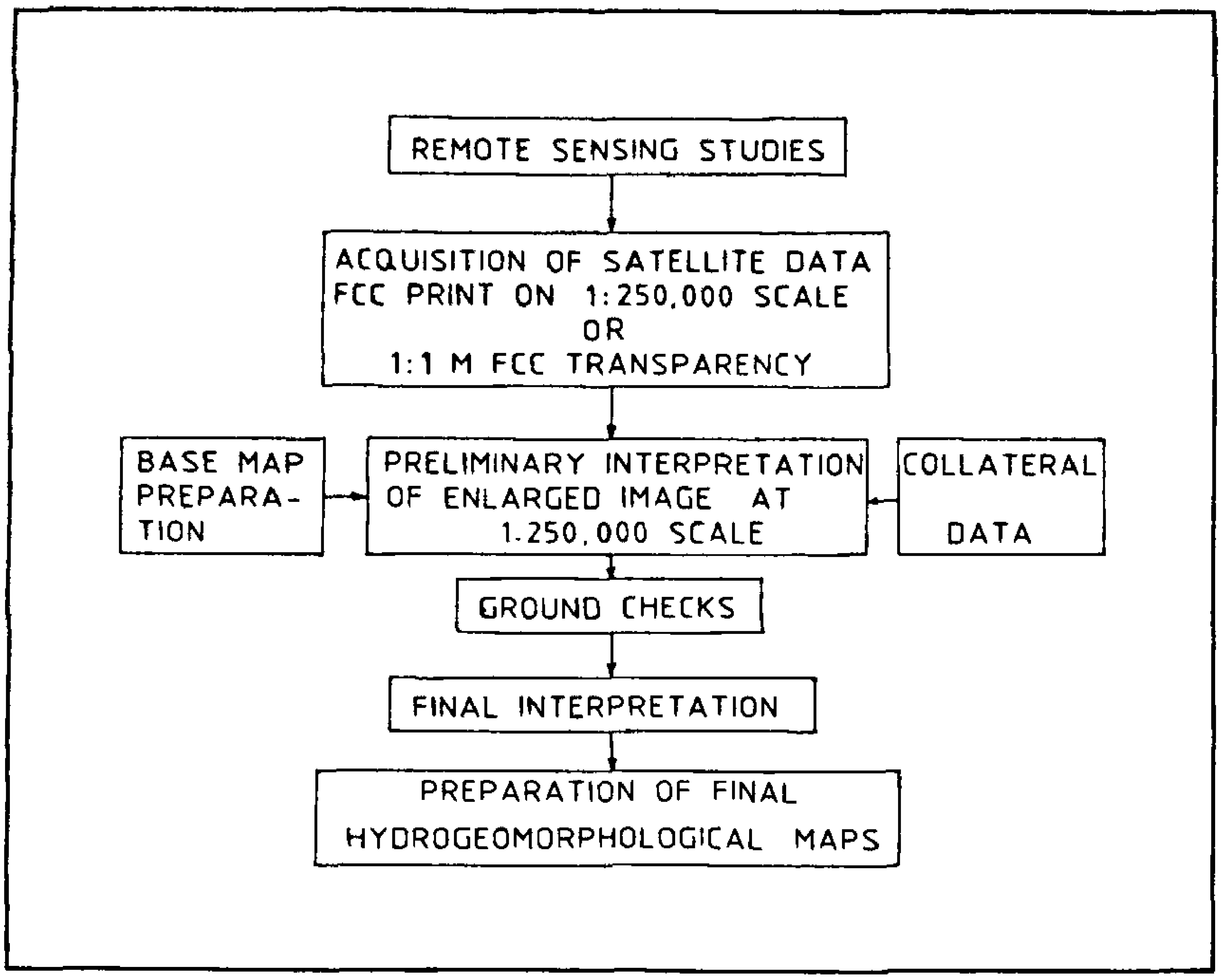

Figure 1. Steps involved in hydrogeomorphological mapping using satellite imagery.

has also been used. The imagery used was either in the form of paper prints on 1:250,000 scale or transparencies which could be enlarged to 1:250,000 scale. The legend used for mapping was developed and finalised under the Department of Space in consultation with Central Ground Water Board and the National Drinking Water Mission Directorate[12].

To start with, districtwise base maps were prepared on 1:250,000 scale, showing major drainage courses and important localities, roads, rail lines and a few other cultural features like canals, etc. The next step involved a systematic visual interpretation of the satellite imagery to delineate various geomorphic features/landforms and their depiction on to the base map. These geomorphic features/landforms were then evaluated critically in terms of the broad lithology they are comprised of, the associated structural features, the development of drainage around and on them, the broad soil type and its effective depth, the thickness of weathered mantle in case of hard rock country, and the type of land use/land cover prevailing in the area to finally arrive at the groundwater prospects. Existing geological maps and other collateral data were also used, supplemented by supportive field checks. Districtwise hydrogeomorphological maps were thus prepared for all the districts of the country.

The synoptic, near orthographic, multispectral view of the terrain under uniform illumination conditions provided by the IRS data has the unique capability of providing regional level information on all the above mentioned factors with a fair degree of accuracy and reliability. Though no detailed lithological interpretation was possible from the IRS imagery, differentiation of broad rock groups was made based on factors like spectral reflectance of rock types themselves (when exposed), in conjunction with associated structural, drainage and landform characteristics etc. Fractures, faults and their intersections in hardrock terrain as well as certain synclinal structures which at places are the loci for groundwater occurrence in sedimentary rocks were interpreted carefully from the IRS imagery. Such features are often missed in ground surveys for want of a synoptic view. While certain landforms like buried channels, present day valley fills, alluvial fans, bazadas, etc. having known relationship with groundwater occurrence were readily mapped from the IRS imagery, the utility of the satellite data in studying the drainage pattern/ density etc. including the palaeo drainage (which have a bearing on the recharge conditions and localisation of groundwater) were also fully harnessed. The distribution of soils with regard to their broad textural classes and land use/ land cover pattern mappable from the IRS imagery were given due consideration.

In addition to the districtwise hydrogeomorphological maps, other types of facilitative outputs were also generated in respect of specific problem villages of certain districts, in conformity with the stipulation of NDWM. One such output relates to maps showing significant ground-water bearing features within a circle of 1.6 km radius around a problem village. Such maps on 1: 50,000 scale, have been provided in respect of thousands of villages falling in the states of Gujarat, Rajasthan, Bihar, Jammu and Kashmir, Madhya Pradesh, Haryana, etc.[9]. Where a single factor like fracture/fault was found to be the predominant indicator of groundwater in a region, as in case of the Gulbarga district of Karnataka, occupied mainly by the Deccan traps and granitic rocks, a map showing the locations of Problem Villages vis-a-vis structural lineaments has been provided.

Observations and results

The mapping on 1:250,000 scale for the entire country comprising 447 districts (the number has changed recently as a result of reorganisation of districts in some states) was completed by March 31, 1990. *It may be appropriate to remark here that it is for the first time in the country that district-level mapping has been done for any theme on 1:250,000 scale for the entire country.* Various remote sensing organisations in the country were involved in this task.

Based on these hydrogeomorphological maps prepared by various participating organisations, an 18-volume atlas of Hydrogeomorphological Maps of India has been compiled. This was necessitated by the wide variations in the size of the maps produced. For example, whereas Diu district covers an area of 40 sq. km, the district of Kachchh has an area of 45,652 sq. km. The atlas contains 427 maps with legend given on the corresponding facing page.

IRS-1A data have been utilised for groundwater targetting in various parts of the country including extremely inaccessible regions such as thickly forested hilly tracts of north-eastern states with the highest rainfall in the country on one hand, and the desertic areas of Rajasthan experiencing perpetual drought due to aeolian topography and scarce rainfall on the other.

Three typical examples are discussed below. These are :

1. Palghat district in the State of Kerala,
2. North-eastern States, and
3. Jaisalmer and Bikaner districts of Rajasthan.

1. *Hydrogeomorphological Map of Palghat District (Kerala)*

Figure 2 shows a typical hydrogeomorphological map prepared by visual interpretation of IRS-1, LISS-II FCC imagery with limited field checks. This map of Palghat district (Kerala) shows various hydrogeomorphic units that have developed over crystalline rocks of Precambrian age like denudational hills, highly dissected pediment, buried pediment, residual hills, valley fills, flood plain, structural lineaments, etc.

Valley fills essentially depict pockets of relatively thick loose unconsolidated sediments. These pockets are sometimes fracture controlled and have a very good scope for putting dug wells and borewells. The buried pediments in the central part of the district are gently plain landforms with thick alluvial cover underlain by hard compact gneissic basement. The thick alluvial cover provides good prospects for dug wells. The combination of thick alluvial cover and lineaments have better prospects. Lineaments depicting fractures, joints, shear zones, faults, etc. criss-cross the district at several places suggesting the presence of shallow weathered zone and high secondary porosity. Groundwater prospects along these lineaments are inferred to be good and excellent at their intersections. The highly dissected pediment and denudational hills have poor groundwater prospects except along the intervening narrow structurally controlled valleys.

2. *North-eastern States*

Even though the North-eastern states, in general, record the highest rainfall in the country, the region suffers acute shortage of drinking water due to its geomorphic set-up. The perennial springs which are the usual water sources for the people are drying up due to infiltration losses, surface runoff along steep slopes, deforestation and soil erosion. The entire region, on IRS images, shows rugged topography except the vast alluvial plain of the Brahmaputra and Piedmont plain in the Himalayan foothills. The hills are mostly structurally controlled and comprise the anticlinal structural hills, the denudo-structural hills and the denudational hills. Intermontane valleys are, in general, narrow and synclinal. Wherever the softer rocks are encountered, the valleys are wider. In the alluvial plain of the Brahmaputra and other major rivers, several fluvial landforms like palaeochannels, abandoned channels, meander scars, and natural levees have been mapped. The major rock types that could be delineated are Archaean gneisses, quartzite and phyllites of Shillong formation, sandstones and shales of Disang, Barail, Bhuban, Bokabil, Tipam and Dupitila formations. Intermontane valleys and

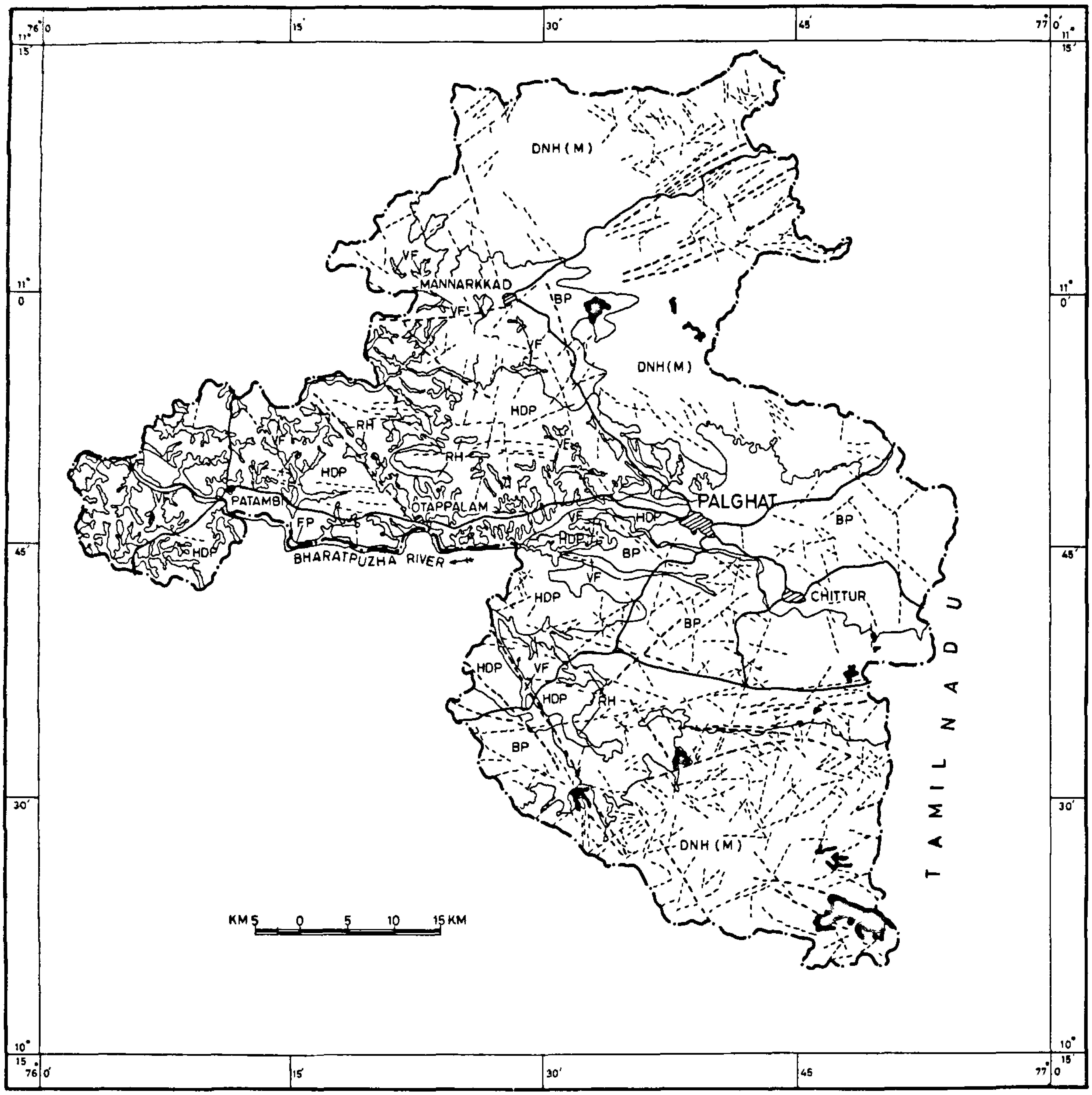

Figure 2. Hydrogeomorphological map of Palghat district (Kerala) prepared using IRS data with limited field checks. Legend is given on page 179.

the vast Brahmaputra valley contain colluvium and alluvium. Structurally all North-eastern states, except Arunachal Pradesh, show anticlinal ridges and synclinal valleys trending north-south. They are cut across by several NE–SW, NW–SE and ENE–WSW lineaments and faults. In Arunachal Pradesh, the trend of the rocks are mainly E–W.

Considering the landforms, lithology and structures the groundwater prospects of the entire region seem limited. In the hilly terrain good ground water prospects exist in the intermontane valleys and along the foothills. Within the hills, the intersection of fracture zones are the sources for spring water collection. In general, Tipam sandstones form good aquifers. In Meghalaya metamorphic rocks having criss-cross lineaments, weathered zone and flat disposition also have good groundwater prospects. The different fluvial features in the Brahmaputra valley also show good groundwater prospects.

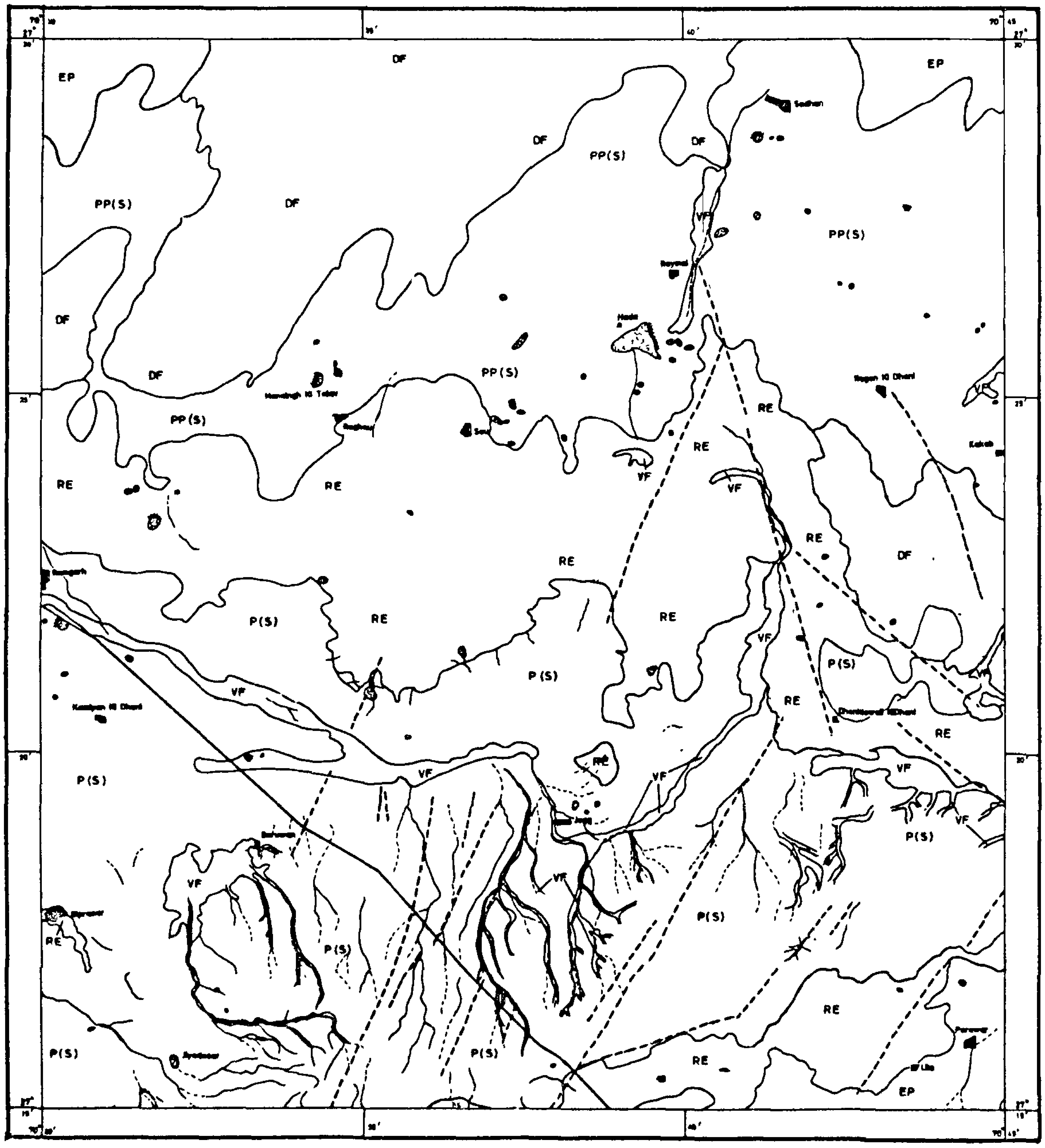

Figure 3. A typical hydrogeomorphological map from Jaisalmer district on 1:50,000 scale. Legend is given on page 179.

3. *Hydrogeomorphological Mapping of Jaisalmer and Bikaner Districts (Rajasthan) on 1:50,000 Scale*

Detailed preliminary mapping at 1:50,000 scale using multitemporal data of IRS LISS-II and SPOT has been carried out using visual interpretation for Jaisalmer and Bikaner districts of Rajasthan. These districts experience perpetual drought due to aeolian topography and scarce rainfall. Aeolian topography not only renders some stretches of these districts inaccessible but the thick aeolian cover also conceals the rock exposures. Lack of surface exposures renders the conventional hydrogeological surveys almost impractical and the task of searching for ground water becomes very difficult. This part of the country is believed to have had a well developed drainage system in the geological recent past. The presence of extensive alluvial deposits further supports this belief. Sensitivity of remote sensors to subtle variations on the earths surface and availability of synoptic perspective are specially useful to trace the courses of such channels and also weak planes reflected as lineaments, contributing useful information for the groundwater search. In this study a systematic analysis of all available relevant data is being carried out to prepare the final hydrogeomorphological maps showing groundwater prospects of the mapped units. Jaisalmer district is covered in 80 and Bikaner district in 62 SOI maps. The same number of maps i.e., 142 are under preparation. A typical hydrogeomorphological map from Jaisalmer district is shown in figure 3.

Feedback

Many state governments have reported excellent success rates where 'the scientific source finding' approach has been used. For example, during 1986-87, the Gujarat Water Supply and Sewerage Board (GWSSB) had drilled 171 boreholes using remote sensing inputs. Out of these 158 were successful giving a success rate of 92.4 per cent. On the other hand, out of 149 boreholes drilled where scientific source finding methodology was not used only 87 were successful giving a success rate of 58.4 per cent only. A communication from the GWSSB quotes the following results for their 1987–88 drilling programme.

Bore diameter in mm	No. of bores drilled	No. of successful bores	Percentage success
100	13,080	12,398	94.8
150	416	356	85.6
Total	13,496	12,754	94.5

Feedback received from some of the other states, alongwith that from Gujarat (for 1986–87 and 1987–88 combined) is summarised below. A part of this feedback was received through the National Drinking Water Mission Directorate.

Sl. No.	State	Total no of bores drilled	Total no of successful bores	Percentage success
1.	Gujarat	13667	12912	94.47
2.	Rajasthan	116	108	93.10
3.	Orissa	136	134	98.53
4	Andhra Pradesh	216	169	78.24
5	Bihar	1044	951	91.09
6	Goa	628	560	89.17
7.	Karnataka	397	288	72.54
8	Madhya Pradesh	290	282	97.24
9.	Meghalaya	112	99	86.39
10.	Uttar Pradesh	437	421	96.33
	Total	17043	15924	93.43

Conclusions

Remote sensing inputs have accelerated the pace of exploration and have considerably reduced the failure rate. The approach "Remote sensing based-hydrogeological-geophysical survey" has thus proven to be the most dependable approach for groundwater exploration under the "Scientific Source Finding" programme of the National Drinking Water Mission.

Acknowledgement

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Legend for figure 2

MAP SYMBOL	GEOMORPHIC UNIT	LITHOSTRATIGRAPHY	STRUCTURE	DESCRIPTION	GROUNDWATER PROSPECTS
DNH (M)	Denudational Hills (Metamorphic)	Hornblende biotite gneiss, charnokitic gneiss & associated magmatic complex. (Pre-Cambrian).	Highly fractured, folded, faulted & jointed	Predominantly valley & spur landform, possibility of getting ground water exists mainly within the valleys having moderate thickness of unconsolidated sediments depending upon the recharge of the aquifer.	Poor escarpments, crests, divides, etc. Moderate along valleys.
HDP	Highly Dissected Pediment	Predominantly charnokities, hornblende biotite gneiss and at places gabbroic dikes with thin veneer of top soil (Pre-Cambrian)	Criss crossed by fractures, joints, faults, etc.	Gently undulating plain with thickness of weathered mantle & top soil cover High surface runoff. The wells observed are low yield & mostly dry up during summer.	Poor (over hard & compact basement) good (along fractures)
BP	Burried Pediment	Thick alluvium cover underlain by *gneissic basement* (Pre-Cambrian).	High, folded, refolded & fractured.	Occurs as isolated outcrops in the pediment country. The foot hill zone usually serves as good & perennial aquifer.	Good (along foot hills).
RH	Residual Hills	Predominantly charnockites with hornblende biotite gneiss (Pre-Cambrian).	High, folded, refolded & fractured	Occurs as isolated outcrops in the pediment country. The foot hill zone usually serves as good & perennial aquifer	Good (along foot hills)
VF	Valley Fills	Moderately thick veneer of alluvium underlain by predominantly hornblende biotite gneiss, charnockities, gabbro, etc.	Filled in depressions	Alluvial material filling the depression, serving as shallow aquifer. Predominantly used for constructing shallow dug wells.	Good, very good (along fractured basement).
FP	Flood Plain	Well sorted, unconsolidated fluvial *sediments*.	Unstratified.	Bordering the wet course of the riverine channel, well sorted fluvial material serves as good aquifer for very shallow dug wells.	Good.
- - - - - — — — —	Prominent Lineaments Inferred Lineaments	Cut across gneisses, charnockites, etc.	Joints, dykes, shear zones trending NE-SW, E-W & NW-SE	Linear features reflecting crustal structure which generally lack topographic expression. Fractures, joints, shearzones, etc. Serve as good source.	Good, excellent at intersection of lineaments.
f - - - f	Faults	Cut across gneisses, charnockites, gabbro, etc	NW-SE trending linear.	Relatively more weaker and shattered zone with wider scope of ground water existance.	Very good.

River Road Habitation Water Bodies Dist Boundary

DATA USED - IRS-1A, LISS-II
P 26 - R61 L2 B1 24 DEC 1988
P 25 - R61 L2 A1 23 DEC 1988
P 25 - R61 L2 A2 23 DEC 1988

Space Applications Centre (ISRO) Ahmedabad (Gujarat)

Legend for figure 3

Map Symbol	Geomorphic Unit	Lithostratigraphy	Structure	Description	Groundwater Prospects
VF	Valley fills	Unconsolidated material like sand, silt and gravel	Normally fracture controlled	Linear depressions filled or partly filled by unconsolidated sediments. More thickness at the centre and tapering at the periphery. Normally cultivated.	Good, depending on the thickness of filled material.
	Lineaments/ Faults	Cuts across various litho units	Fractures, joints/ faults/shear zones litho contacts, etc.	Linear topographic features of regional extent believed to reflect crustal structures. Represents zones of secondary porosity. Controls groundwater movement.	Good, at intersection of lineaments.
RE	Reg	Mainly gravel, silt and grit	–	Extensive desert plain from which fine sand has been removed by the wind, leaving a sheet of coarse, angular, wind polished gravel and small stones on rock cut surface. Flat, barren area.	Good.
EP	Eolian Plain	Mainly fine to medium grained sand and silt	–	Mainly formed by low to high dunes with large interdunal depressions. Scattered xerophytic vegetation.	Moderate to good.
DF	Dune Fields	Wind blown sand	–	Undulating terrain with sand dunes.	Poor.
PP(S)	Pediplain (sedimentary)	Mainly Jurassic sediments overlain by colluvial or alluvial cover	At places criss-crossed by fractures, faults	Thinly alluviated erosional surface developed over sedimentary rocks. Gently sloping. Sparsely vegetated, etc.	Moderate to good.
P(S)	Pediment (sedimentary)	Various sedimentary litho units	Criss-crossed by fractures, faults, etc.	Broad, gently sloping erosional surface having detritus of sedimentary rocks with thin veneer of detrital material.	Moderate.