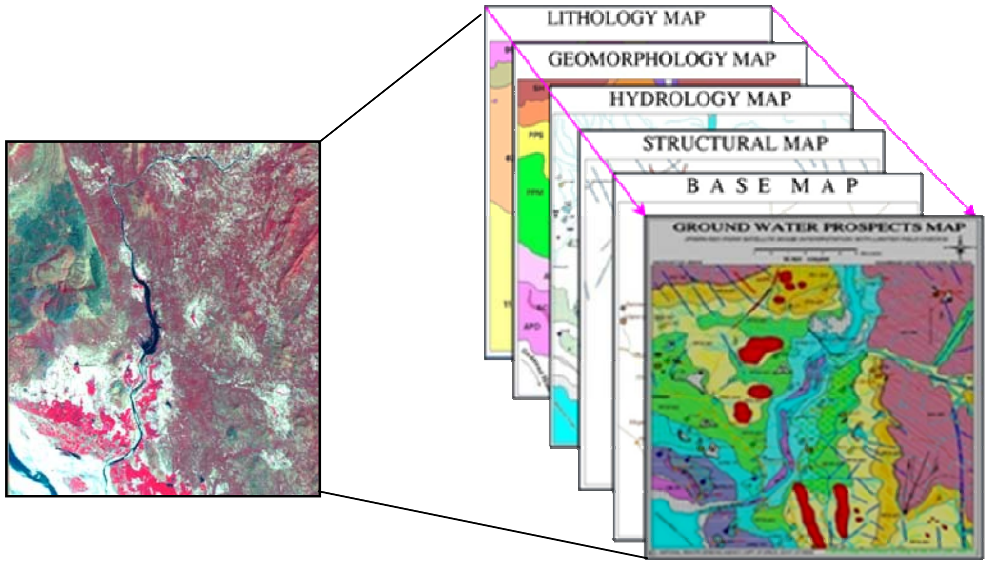
Concept of Ground Water Prospects Maps preparation using Remote Sensing and Geographic Information System for Rajiv Gandhi National Drinking Water Mission Project



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1. General ground water scenario in the country

Groundwater is a major source for all purposes of water requirements in India. More than 90% of rural and nearly 30% of urban population depend on it for drinking water. It accounts for nearly 60% of the total irrigation potential in the country, irrigating about 32.5 million hectares. The dependency on the ground water is expected to increase in future due to increase in population.

As per the estimation of Central Ground Water Board, the dynamic ground water resource, i.e. utilizable ground water resource which is meant for meeting the water requirements according to National Water Policy is about 43.2 million hectare meters. The static ground water resource also known as fossil water available in the aquifer zones below the zone of water level fluctuation is about 1081.2 million hectare meters. The dynamic resource gets replenished every year through natural recharge, so that the balance is maintained.

However, the occurrence and distribution of the ground water is not uniform throughout the country and varies significantly based on geology, rainfall and geomorphology. India is a vast country comprising of diversified geology, topography and climate. The prevalent rock formations range in age from Archaean to Recent and vary widely in composition and structure. Similarly, the variations in the landforms are also significant. They vary from the rugged mountainous terrains to the flat alluvial plains of the river valleys, coastal tracts and the aeolian deserts. The rainfall pattern also shows similar region wise variations. The topography and rainfall virtually control runoff and ground water recharge.

The high relief areas of the northern and north-eastern regions occupied by the Himalayan ranges, the hilly tracts of Rajasthan and peninsular regions with steep topographic slope, and characteristic geological set-up offer high run-off and little scope for rain water infiltration. The ground water potential in these terrains is limited to intermontane valleys.

The large alluvial tract in the Sindhu – Ganga – Brahmaputra plains extending over a distance of 2000 km from Punjab in the west to Assam in the east constitutes one of the largest and most potential ground water reservoirs in the world. The aquifer systems are extensive, thick, hydraulically interconnected and moderate to high yielding.

To the north of this tract all along the Himalayan foot hills, occur the linear belt of Bhabar piedmont deposits, and the Tarai belt down slope with characteristic auto-flowing conditions.

Almost the entire Peninsular India is occupied by a variety of hard and fissured formations, including crystallines, trappean basalt and consolidated sedimentaries (including carbonate rocks) with patches of semi-consolidated sediments in narrow intra-cratonic basins. Rugged topography, compact and fissured nature of the rock formations combine to give rise to discontinuous aquifers with limited to moderate yield potentials. The near surface weathered mantle forms the all important ground water reservoir, and the source for circulation of ground water through the underlying fracture systems. In the hard rock terrain, deep weathered pediments, low-lying valleys and abandoned river channels, generally contain adequate thickness of porous material to sustain ground water development under favourable hydro-meteorological conditions. Generally, the potential water saturated fracture systems occur down to 100 m depth, and in cases yield even up to 30 lps. The friable semi-consolidated sandstones also form moderate yielding aquifers and auto-flowing zones in these formations are not uncommon.

The coastal and deltaic tracts in the country form a narrow linear strip around the peninsula. The eastern coastal and deltaic tract and the estuarine areas of Gujarat are receptacles of thick alluvial sediments. Though highly productive aquifers occur in these tracts, salinity hazards impose quality constraints for ground water development.

The quality of ground water in both hard rock and alluvial terrains is by and large fresh and suitable for all uses. The specific conductance is generally less than 1000 μs/cm. But in coastal areas, estuarine tracts of Gujarat, Rann of Kutch and arid tracts of Rajasthan, the degree of mineralization in ground water is rather high and salinity hazards are not uncommon. The salinity hazards in ground water are also noticed in the inland areas of Punjab, Haryana, Uttar Pradesh, Rajasthan and Gujarat, generally confined to arid and semi-arid tracts.

2. Development of ground water

Ground water being a hidden resource is often developed without proper understanding of its occurrence in time and space. The total number of wells in the country has gone up from about 4 million in 1951 to more than 15 million at present, and the number of energised pump sets in the same period have grown from initially negligible to about 12 millions (Press Information Bureau, Govt. of India). Most of these wells are drilled indiscriminately based on the requirement. As a result, many a times, the wells have gone either unproductive or became failures causing financial loss to the users. In the over-exploited zones, the wells are getting dried up in due course of time. In some of the areas, the situation is so serious that there is a scarcity of water even for drinking purposes. In these areas, the ground water needs to be recharged artificially, as the natural recharge is not sufficient, to augment the resource and maintain the water table. On the other hand, the resource is not yet exploited to the optimum level in many areas in the country.

In many States, Public Health Engineering Departments (PHEDs) and Panchayath Raj Engineering Departments (PREDs) are engaged in rural drinking water supply. Potable water is provided to the rural population by these departments mainly through hand pump wells and piped water supply schemes by pumping of water from bore / tube wells and connecting to overhead tanks / ground level reservoirs. In water scarcity areas, water is also supplied to villages through tankers during summer season. These departments are having well established drilling and maintenance units supported by experienced hydrogeologists for selection of sites for drilling. However, scientific database on ground water, which facilitates identification of prospective ground water zones for systematic selection of appropriate sites for drilling, is not available in majority of the cases. They do not have enough time to select the sites by conducting systematic hydrogeological studies in the area followed by site specific investigations in the favourable zones.

3. Methods of ground water exploration

Surface investigations and subsurface investigations will be carried out for end to end exploration activity.

i. Surface investigation

a) Study of existing geological, hydrological and meteorological data – provides information on the parameters such as rock types, geological structures, landforms and recharge conditions which control the occurrence and distribution of ground water. Once these factors are precisely known, it is possible to understand the ground water regime better by visualizing the gross aquifer characteristics of the area. Based on the analysis of this data, geophysical surveys can be planned effectively.

b) Geophysical measurements – Surface based geophysical methods are used to get information on geological structure, rock type and porosity, water content and water quality. The most commonly used geophysical surveys such as 'the electrical resistivity surveying' ('profiling' and 'sounding') is most popular and well established techniques for ground water exploration to know the resistivity of the subsurface hydrogeological condition for pinpointing the locations and depths for drilling bore wells. The other exploitation methods like seismic, gravity and magnetic are very rarely used.

ii. Subsurface investigation

The subsurface investigations are comparatively expensive, but impossible to avoid if data on quality and quantity of the groundwater are desired. One or more, small diameter holes are drilled to supply information on the groundwater level and the geological substrata. The results of the drilling and sampling of material make it possible to establish a litho log with information from the different strata. It is also possible to take groundwater samples for chemical analysis. Any number of geophysical logs can be used, depending on the geological conditions, such as the spontaneous potential, resistivity logging, acoustic log and temperature logs.

The last and perhaps the most informative step in an investigation for a groundwater well is a pumping test. Pumping tests can be either short time (for information from the vicinity of the hole) or long time (for information from larger area). Geological formations have distinct physical properties that affect the flow of groundwater and determine the yield of a well. These properties include;

– Effective porosity – the percentage of interconnected space in rock and soil that can contain water.

– Hydraulic conductivity (K) – indicates how easily water moves through the aquifer.

– Transmissivity (T) – is the ability of the aquifer to transmit water (T = K * saturated thickness of aquifer).

– Storativity – the ability of a confined aquifer to take up or release water in response to a change in head resulting from recharge or extraction.

Pumping tests on water wells are the most common way to determine these hydraulic parameters of aquifers. During a pumping test, water is pumped from a well at a specific rate, and measurements are taken to determine how fast and how far the water level in the well drops (time-drawdown data). Measurements are also taken to determine how fast the water level in the well returns to normal (time-recovery data) once pumping has stopped. This data is used to determine what will happen to the aquifer if water is pumped from it at a constant rate (progressive response to steady-rate pumping), and how much water can move through the aquifer and into the well. Based on these values and the height of the water column from the top of the aquifer to the non-pumping water level (artesian pressure), a pumping rate referred to as 'Safe Yield' can be calculated. The safe yield is the pumping rate over a given time that will eventually remove enough water from the aquifer for the pumped water level to drop to the top of the aquifer at the well. Where larger volumes of water will be drawn, in addition to the production well, one or more observation wells are studied. Test holes that may have been drilled earlier can be useful as observation wells. These wells are used to obtain other data needed to calculate the storativity of the aquifer. These observation wells help give a more accurate assessment of the aquifer in terms of its capacity, geometry and flow direction. They also allow for more complex mathematical assessments with computer modelling giving a better picture of the potential for drawdown and recovery of the aquifer. Water sampling at suitable intervals for chemical analysis is done during the duration of the pumping time.

4. Need of a Scientific Data Base for the Country

So far, a comprehensive data base generated by taking all the parameters that control the occurrence and movement of ground water is not available for the country on all India basis. Such a data has been generated only for specific locations and it is fragmentary in nature. Since the data that is available is generated based on only few ground water controlling parameters, it becomes necessary to undertake complementary site-specific survey/ mapping to get more accurate picture of the site before developing ground water. Besides, conducting the geophysical surveys is quite cumbersome. Complex instruments and technical man power are required for conducting the survey. Lot of logistic support is also involved. The technology is not accessible to the common users, particularly to the private individuals who constitute the major section of ground water consumers in the country. Hence, it is not feasible to carry out these surveys at each and every place. Once the prospective zone is identified through other methods, the geophysical surveys can be conducted only to pinpoint the location for drilling the well in the prospective zone.

There is an inherent linkage between development and management of ground water resources. For an effective supply side management, it is essential to have full knowledge of hydrogeological controls which govern the yields and behaviour of ground water levels under abstraction stress. The effects of ground water development can be short term and reversible or long term and quasi-reversible which require a strong monitoring mechanism for scientific management. There is a need for scientific planning in development of ground water under different hydrogeological situations and to evolve effect management practices. Demand driven development of ground water resources by different user groups without any scientific planning and proper understanding of the behaviour of local ground water regime, leads to sharp depletion of the resources and also degradation of quality. Signals of mismanagement of ground water resources are seen in areas where ground water extraction rate has exceeded the natural recharge. Ground water management has become the foremost challenge for the Organizations dealing with ground water in India. The activities of the Organizations and policies affecting ground water need to reflect the priority issues with the overall objective to provide water security through ground water management.

Therefore, a comprehensive and a reliable scientific database on ground water for the entire country is a pre-requisite for proper management of ground water resource in the areas where it is over-exploited and for planning its optimum development and effective utilization in hitherto unexploited areas.

5. Rajiv Gandhi National Drinking Water Mission Project

I. Background

The Government of India (Department of Drinking Water Supply), through the Rajiv Gandhi National Drinking Water Mission (RGNDWM) supplements the efforts of the State Governments to accelerate the pace of coverage of drinking water supply to Non Covered (NC), Partially Covered (PC) and quality affected rural habitations with mission approach by providing Central assistance under the Accelerated Rural Water Supply Programme (ARWSP). As per the estimation of the RGNDWM, there are nearly 4.4 lakh NC and PC habitations spread over in different States of the country, as on 01-04-1998, accounting for more than 30% of the total habitations. Taking this as a serious issue, the Govt. of India has included the supply of drinking water to these habitations in a time-bound-period in the 'common minimum programme' of the central Government.

As part of supplying the drinking water to these habitations, the RGNDWM has approached the NRSC/ISRO to provide scientific data on drinking water sources (ground water source) to the non-covered (NC) and partially-covered (PC) habitations, within the radius of 1.5 km in case of plain areas and within 100m elevation in case of hilly terrain, using the satellite data in a time bound period. The NRSC / ISRO has agreed to provide the same and taken up the project on priority basis. Later it is decided to cover all the habitations including the NC and PC for creating ground water database.

The objective of the project is mainly to provide the ground water prospects information on 1:50,000 scale" by combining the information derived from satellite data with conventional ground hydrogeological surveys for entire country. The project work was commenced in the year 1999. It has been planned to implement the project work throughout the country in a phased manner. In Phase-I six states namely, Andhra Pradesh (eastern part), Chhattisgarh, Karnataka, Kerala, Madhya Pradesh & Rajasthan were covered. In Phase-II four more states namely; Gujarat, Himachal Pradesh, Jharkhand and Orissa were taken up for preparing the maps. Convinced by the overwhelming success of this project in ten states, covering nearly 50% of the country, the Ministry has extended it to the rest of the country under Phase-III & IV programme. Accordingly NRSC has completed the groundwater prospects maps for the entire country. Presently the GOI has renamed this programme as National Rural Drinking Water Programme (NRDWP).

II. Objective

The objective of the project is to prepare the ‘ground water prospects maps’, corresponding to Survey of India toposheet on 1:50,000 scale, covering all the habitations. The map has to show **a)** prospective zones for ground water occurrence **b)** tentative locations for constructing recharge structures.

The information provided in the ground water prospects maps form a suitable database for narrowing down the target zones and systematic selection of sites for drilling after conducting follow-up ground surveys to establish drinking water sources to all the non-covered and partially-covered habitations, besides providing information for selection of sites for construction of recharge structures to improve the sustainability of drinking water sources, wherever required.

III. Ground water prospects mapping – The Concept

a. Ground water controlling factors

Ground water is a part of the hydrological cycle and forms a dynamic system. It comes into existence with the process of infiltration at the surface. Then, it percolates into the ground, which comprises of different rock formations having different hydrogeological properties. The storage capacity of the rock formations depends on the porosity of the rock. In the rock formation the water moves from areas of recharge to areas of discharge under the influence of hydraulic gradients depending on the hydraulic conductivity or permeability. In other words, at a given location, the occurrence of ground water depends on the storage capacity and the rate of transmission.

However, the hydrogeological properties of aquifer developed at the time of formation of the rocks with the initial geometric shape ranging from tabular to lenticular to cylindrical undergo different changes as – a) The structural and erosional modifications change the thickness and lateral continuity of most major rock units, b) The hydrothermal alteration, contact metamorphism, digenesis, and thermal-mechanical effects modify rock-hydraulic properties to differing degrees locally, and c) The fracturing alters permeability along fault / fracture zones. These changes bring significant variations in the hydrogeological properties within the rock type thereby changing the ground water storage and transmitting abilities both horizontally and vertically.

The framework in which the ground water occurs is as varied as that of rock types, as intricate as their structural deformation and geomorphic history, and as complex as that of the balance among the lithologic, structural and geomorphic parameters. The entire column of subsurface acts as a three dimensional framework of groundwater conduits / aquifers and ground water barriers/ confining units. Finally, the ground water prospects in the unit depend on the availability of the recharge which in turn depends on the prevailing hydrological conditions. Hence, the ground water regime can be defined as a combination of four factors, i.e. 1) Lithology, 2) Landform, 3) Structure, and 4) recharge conditions. The possible combinations of variety and intricacy are virtually infinite and the ground water conditions at a given site are unique.

b. Hydrogeomorphological units

The combined units in which the Lithology, landform, structure and recharge conditions are unique are called 'hydrogeomorphic units'. They are considered as three dimensional homogenous entities with respect to hydrogeological properties and the recharge condition. In other words, they are treated as the aquifers. The ground water prospects are expected to be uniform in a hydrogeomorphic unit. However, some amount of heterogeneity may exist at micro level and it can be brought out only through large scale studies. It is basically depended on the scale of mapping. The degree of heterogeneity and the resultant variations in the ground water condition need to be accounted depending on the scale of study.

In order to study the ground water prospects of a hydrogeomorphic unit, inventory of the controlling factors i.e., rock type, landform, structure, and recharge condition, by which the hydrogeomorphic unit is made up of, has to be done and their hydrogeological characteristics need to be evaluated.

c. Relevance of Satellite Data

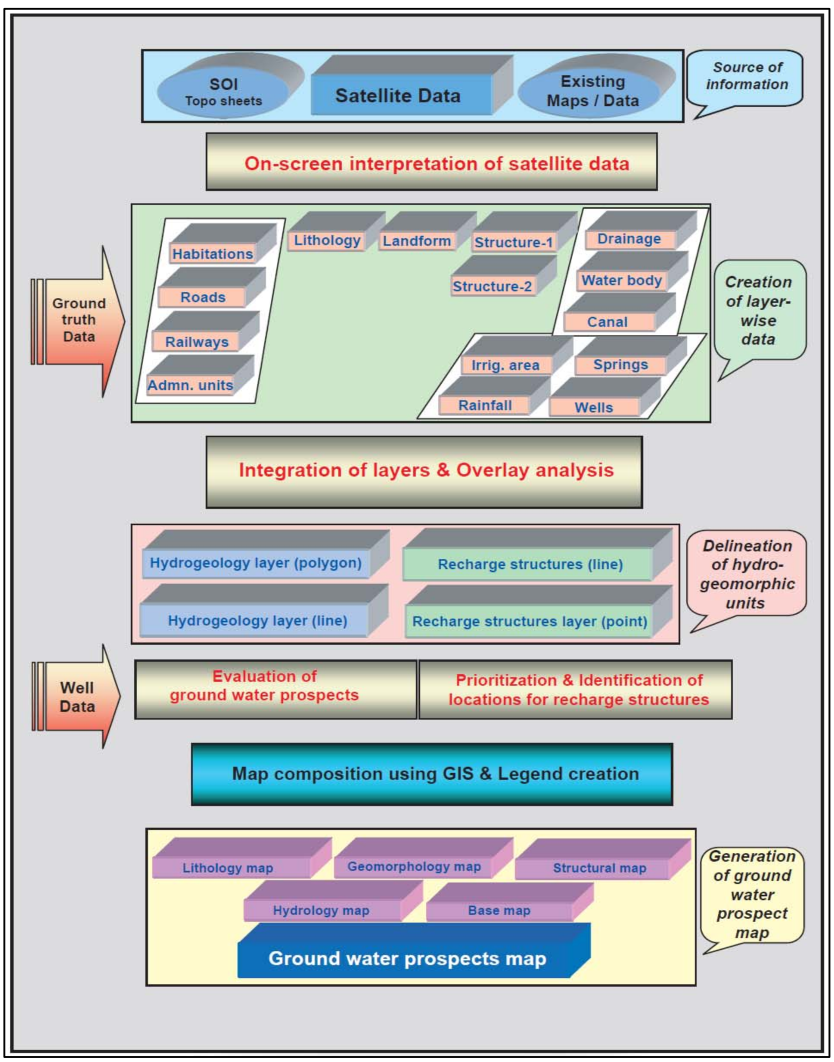
The hydrogeomorphic unit is evolved from the original rock formation due to structural, geomorphological and hydrological processes. These processes and the resultant changes are manifested on the surface. Satellite imagery is the best data base where the information pertaining to all these parameters is available in an integrated environment. Based on the interpretation of satellite imagery in conjunction with limited ground truth information, the extraction and mapping of spatial distribution of the rock formations, landforms, structural network and hydrological conditions can be done accurately. They can be better studied and understood in association with each other. This is not possible through conventional ground surveys. Apart from this it takes lot of time and energy there by becoming the ground water survey costly. The geology maps showing rock types and major structures prepared by Geological Survey of India are being used for gross estimation of the resource and its distribution. Particularly, the data on the land forms, geological structures and recharge conditions are not at all available.

For example, an area occupied by granite gneisses intruded by dolerite dykes and cut across by a number of faults and lineaments, it is possible to draw conclusions on – the dolerite dykes act as barrier for movement of groundwater, whereas the lineaments/faults which cut across them act as conduits for groundwater movement. The weathered zones within the granite gneisses contain limited quantities of groundwater. The water bodies (tanks) which are seen on the imagery as black patches not only provide irrigation facility in the area but also contribute for recharge to groundwater. Thus, by providing appropriate hydrogeological information the satellite data facilitate proper identification and mapping of prospective groundwater zones. The satellite data by providing spatial distribution of irrigated crop land as bright red patches are not only useful in calculating where and how much of groundwater is being tapped for irrigation but also in classifying the entire area into over-developed, under-developed, optimally developed and undeveloped zones, indicating the status of groundwater development. Analysis of multispectral high resolution data clearly depict minor faults and lineaments indicated by slips/offsets and gaps and in the dyke ridges. These faults/lineaments act as conduits for movement of water below the ground and form the prospective groundwater zone. With the help of field boundaries, cart tracks, stream courses and other reference points, these zones can be more accurately demarcated on the ground. In addition, some minor fractures originating from these major faults/lineaments, and passing through water bodies (tanks) which also form potential sources for tapping drinking water to the nearby village could be delineated.

IV. Methodology of ground water prospects mapping

The methodology has been developed keeping in view the concept discussed above. It is basically a systematic procedure evolved to prepare a ground water prospects map using satellite data and GIS techniques in conjunction with limited field work. Various steps involved in the preparation of ground water prospects maps are furnished as a flow chart in Fig.1. The total methodology can be divided into two main parts. The first part deals with the delineation of hydrogeomorphic units considering parameters influencing the hydro geological properties. It consists of a) creation of individual thematic layers on lithology, geomorphology, structures, hydrology along with base map details based on the visual interpretation of satellite data in conjunction with limited field / existing data, and b) derivation of hydrogeomorphic units by integrating the thematic data. The second part deals with the evaluation of hydrogeomorphic units based on hydrogeological characteristics of controllingparameters. It consists of a) estimation of ground water prospects by taking into account the well observatory data, and b) identification of suitable locations for constructing recharge structures along with prioritization of the units. The data thus created at different stages is organised into a digital data base as per the standards and specifications furnished in chapter-6. The database consists of 1) basic data as different layers 2) individual thematic maps for all the four parameters and for base map details and 3) integrated ground water prospects map as a final output.

Fig-1

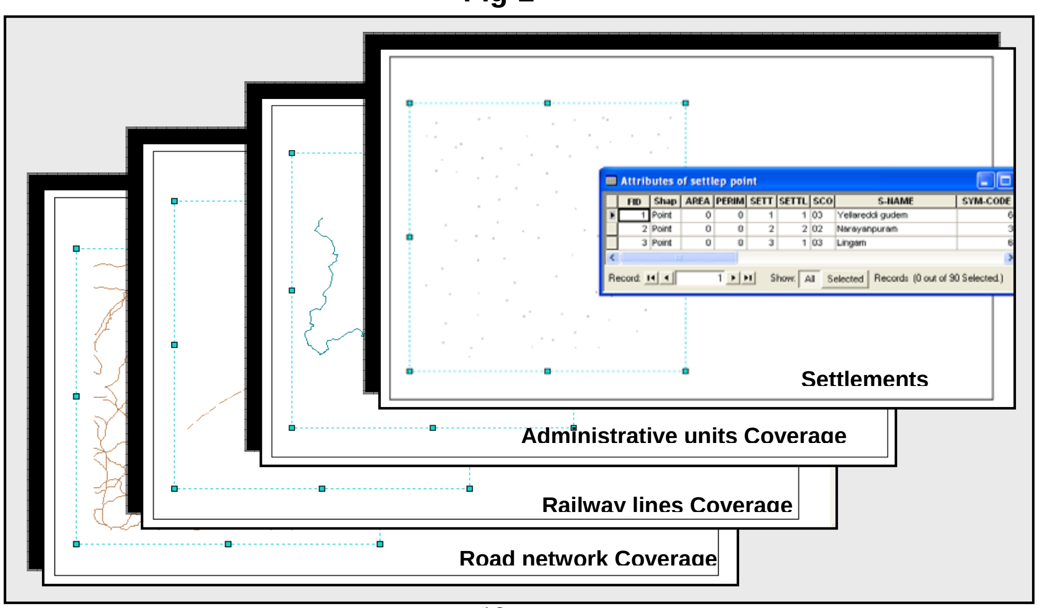


a. Concept of Thematic layers for mapping

As the occurrence and movement of ground water is a function of lithological, structural, geomorphical and hydrological parameters, each parameter exercises its control over the quality and quantity of ground water. Hence, a complete data on the parametres is a pre-requisite to understand the ground water regime and map the prospects properly. Missing of one element also leads to erroneous conclusions. To make sure that all the relevant data pertaining to each and every parameter are systematically studied and considered, it is proposed to generate the data on every parameter of all the five themes as a separate layer in an orderly manner. Different parameters in each theme that are to be considered for mapping are identified. Accordingly, all the rock formations, geological structures, landforms and recharge conditions occurring in the country are classified in to various types and an exclusive classification system for each of these themes has been evolved for this purpose. All the layers should be prepared in such a way that the contents in each map in all the four sides should match with the contents of the adjacent map layer in all respects. Finally, it should be possible to generate a seamless mosaic for the entire state/country.

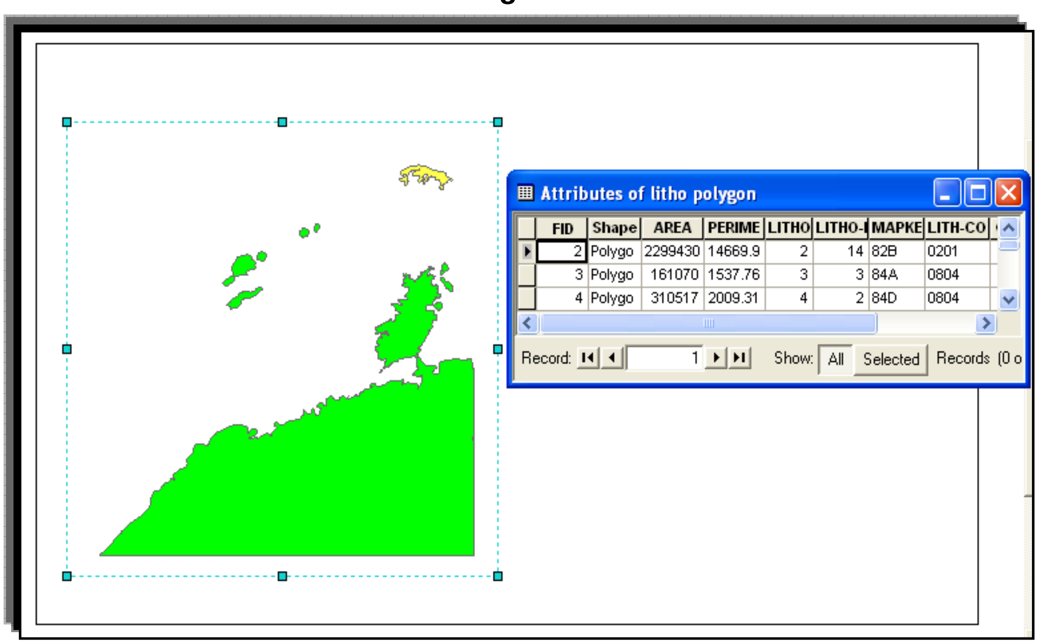
Base map layers: It consists of four categories of information in four separate layers **(fig-2)**. They are – a) Administrative units (maps covering areas that form a part of single administrative unit may not have this coverage) b) Settlements, c) Road network, d) Railway lines (maps covering areas where railway lines are not present may not have this coverage). Total number of coverage may vary depending on the study area. The administrative units are mapped as polygon coverage, the settlements are mapped as point coverage, the road net work and railway lines are mapped as separate line coverages.

Fig-2



Lithology layer: All the rock formations occurring in the study area are mapped in a single layer are represented as polygon features and are annotated with respective numeric codes as per the RGNDWM rock types classification system **(fig-3)**. While preparing the lithology layer based on the interpretation of satellite imagery, the existing geological / hydrogeological maps and literature need to be consulted. It helps in understanding general geological setting of the area and different rocks types that occur or likely to occur in the area. Where previous maps and literature are not available and differentiation of rock types is very difficult / not possible, a reconnaissance field visit will be useful. With this "priori knowledge", the satellite imagery has to be studied to correlate the different image characteristics with different rock types. Where contrasting rock types are occurring, the boundaries can be seen very clearly on the satellite imagery with different colours / tones or landforms. In other cases, complementary evidences have to be considered to demarcate the boundaries between different rock types. Where previous geological maps on 1:50,000 scale are available, the same may be considered. However, the maps need to be modified / edited and updated incorporating additional details that can be interpreted from satellite imagery.

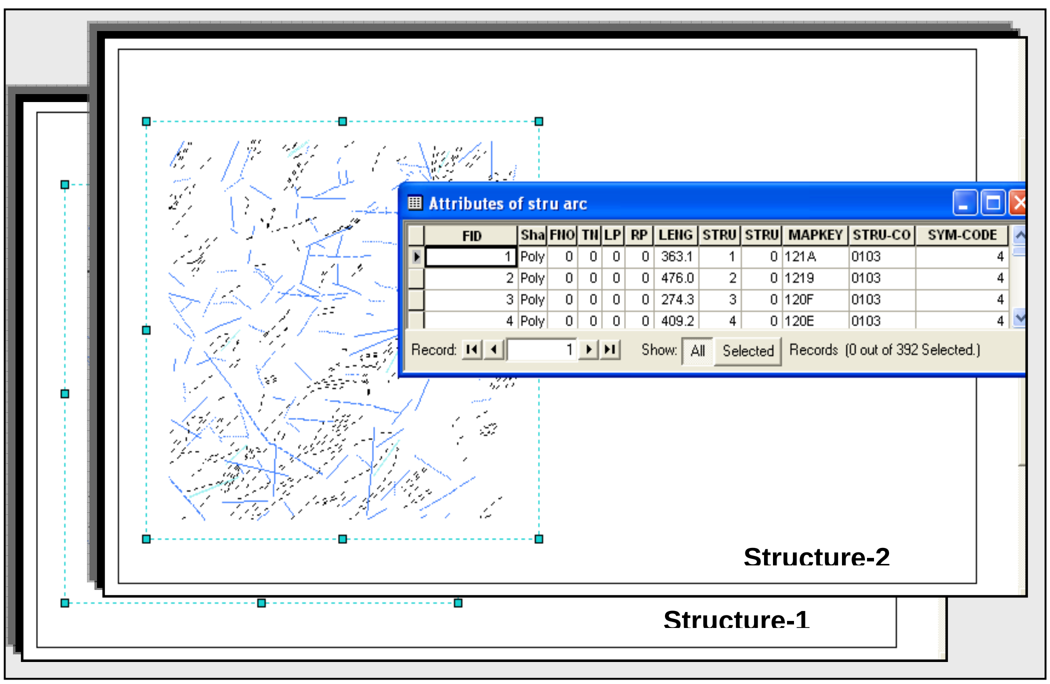
Fig-3



Structural layers: The geological structures occurring in the area are treated as two major categories for mapping- i) faults, shear zones, thrusts, fractures, dykes, veins, etc., which occupy an area acting as conduits and barriers for the movement of ground water and ii) the structural elements such as bedding, schistocity / foliation, folds, etc., which can be represented as attributes to either litho unit or landform. Both the categories are to be mapped however, as two separate layers. The structures are represented as line features and are marked as per the designed line symbols. Maps covering the alluvial plains, deltaic plains, etc, may not have these coverages. **(Fig-4)**

In hilly terrains/Himalayan terrain as 'thrusts' form the major discontinuities, all the thrusts need to be mapped. They can be mapped as two classes – 1) Thrust, and 2) Thrust (inferred). The relation between the structural discontinuities (faults/shear zones/thrusts/fractures) and occurrence of springs/seepage zones have to be studied to infer the control of such discontinuities on ground water occurrence and flow. This information along with the zone of influence of major thrusts/faults from ground water point of view has to be provided in the 'remarks' column of the legend against appropriate unit(s). The thrust/fault zone, wherever mappable and having bearing on ground water occurrence are to be delineated as separate units (as a polygon), and listed in the legend at the appropriate place.

Fig-4

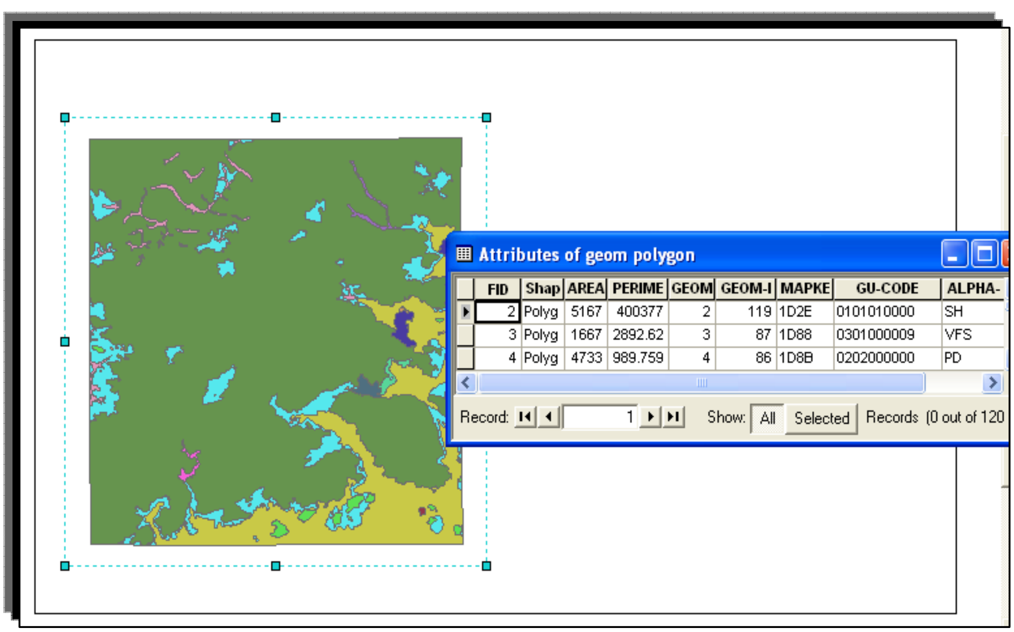


Geomorphology layer: All the landforms / geomorphic units occurring in the study area are mapped as a single layer **(fig-5)**. They are represented as polygon features in the layer and are annotated with alphabetic codes as classification system. For demarcating the geomorphic units the toposheets may be consulted to comprehend the relief variations and other topographic features. While preparing the geomorphology layer, the litho-unit/rock type has to be considered as base unit and each rock type is to be classified into different geomorphic units / landforms so that the final geomorphological layer is prepared showing assemblage of different landforms corresponding to each rock type. Sometimes a single geomorphic unit / landform may exits in one lithologic unit and vice versa. It is to be noted that wherever the lithological and geomorphological boundaries are common, they should be made co-terminus.

The geomorphic units/ landforms which are further classified into shallow, moderate and deep categories based on their depth of weathering, thickness of deposited material, etc have to be verified on the ground by observing the nala / stream cuttings, well sections, etc. However, the contacts between shallow, moderate and deep categories are to be treated as gradational.

Apart from dissection in the hills, slope-form also plays an important role in ground water occurrence and flow in the hilly/ mountainous terrain. Therefore, the hills with concave slope, especially in the lower reaches, have to be delineated as separate units wherever possible, e.g. 'highly dissected structural hills with concave slope (SHHc),' 'moderately dissected denudational hills with concave slope (DHMc),' etc. In hilly terrains, since 'mountain' terminology is not used in the geomorphic classification system, a note need to be included in the layer and in the corresponding ground water prospects map at the bottom of the upper part of the legend that 'the area forms part of the (local name of the range) Himalayan mountain range.'

Fig-5



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2	Polyg	5167	400377	2	119	1D2E	0101010000	SH
3	Polyg	1667	2892.62	3	87	1D88	0301000009	VFS
4	Polyg	4733	989.759	4	86	1D8B	0202000000	PD

Hydrology layers: There are 7 items to be considered for mapping in hydrology theme **(fig-6)**. They are – 1) Drainage, 2) Water bodies, 3) Canals, 4) Rainfall data, 5) Irrigated areas, 6) Springs, 7) Wells. The drainage is represented as line as well as polygon features, the water spread area of the water bodies is represented as polygon features whereas the bunds are marked as line features, the canals are represented as line features, the rain fall data is considered in the form of rain gauge station with average amount of rainfall and marked as point feature, the irrigated area as polygon feature, the springs and wells are represented as point features. Each item is mapped as separate layer using appropriate symbols and colours. The number of layers may vary depending on the availability of items in the study area.

In the drainage layer, all the rivers/streams (entire drainage up to first order streams) both perennial and ephemeral are to be mapped. In case of hilly areas and highly dissected terrain where drainage density is very high, some first order streams can be omitted to reduce the clumsiness in the map. The total drainage from toposheet may be taken first and then some of the 1^{st} $_{order}$ drainage may be omitted over the hills and high relief areas, but none of the 2^{nd} $_{order}$ streams should be omitted. Along major rivers and streams where changes in the river / stream courses are more common, necessary corrections in the drainage courses may be made by referring the satellite image. Hanging drainages lines, if any, should be connected using image control.

In alluvial terrain, the ephemeral and perennial streams are to be shown separately with different symbols. In hilly terrains, the snow-covered areas as seen on the satellite image (preferably of lean period) have to be demarcated and shown in geomorphological layer. In the final ground water prospects map, in the 'map unit' column of the legend, such areas will be represented as SC, and in the 'remarks' column, it will be written as "it acts as recharge zone." No ground water structures required to be suggested in this unit. Satellite image is the primary source of data for mapping water bodies. However, the boundary of water spread area has to be taken from SOI toposheet and to be used for delineating perennial and ephemeral catagories. Canal network is to be mapped basicallyfrom SOI toposheet. But the new canals constructed recently have to be map using the imagery. Maps available with Irrigation Departments can also be consulted.

Initially, a pre-field irrigated area layer has to be prepared based on visual interpretation of the satellite image. Subsequently, during the field surveys, necessary information on the surface and ground water irrigated areas, cropping pattern, command areas, etc. have to be collected and incorporated for preparing the final irrigated area layer.

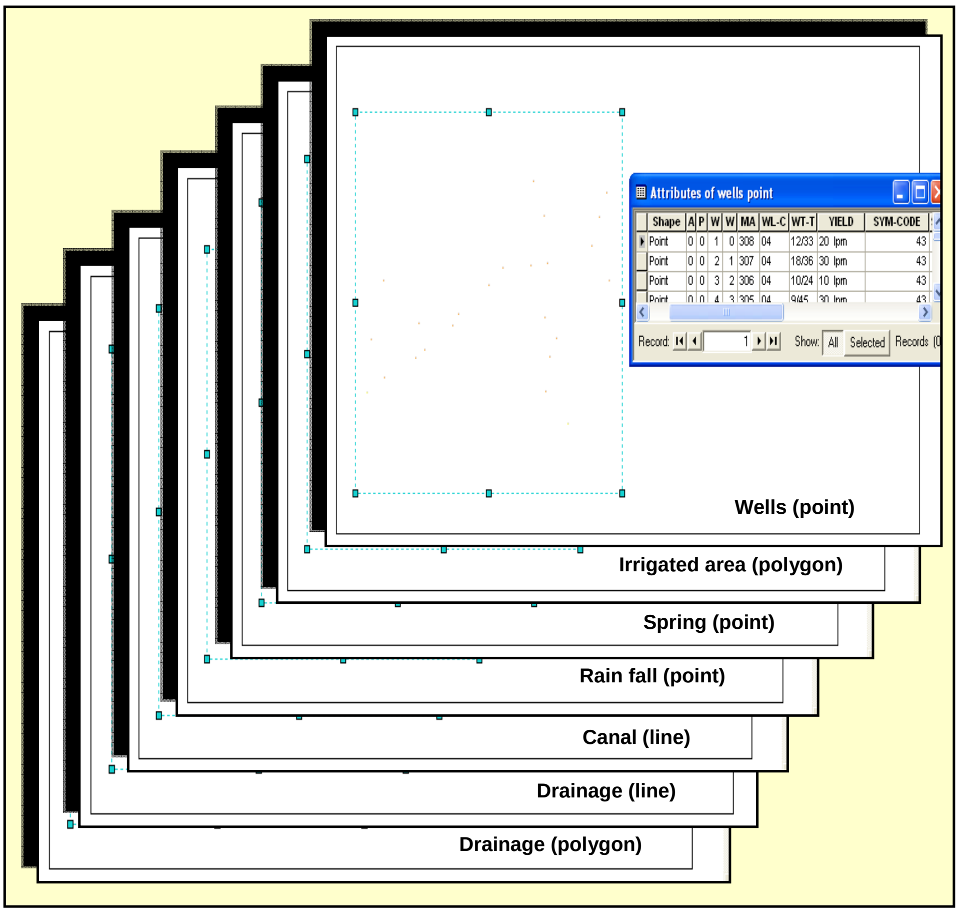
Location of rain gauge stations in the study area and the average annual rainfall in mm are to be recorded in rainfall data layer. In case of the absence of rain gauge stations in the study area, the average annual rainfall of the region can be taken into account. Source of rainfall data should be either IMD or District Gazetteer.

The well data layer is to be prepared based on entirely the field work. In each map (Full map covering about 700 Sq. km), a minimum of 80-100 wells have to be observed and represented on the map. These observation wells should be selected in such a way, that they are properly distributed throughout the map covering all the map units. At least 2-3 wells should be observed in each unit so that the ground water prospects of each unit can be evaluated judiciously. In case, if wells are totally absent in a particular unit, then it should be mentioned in the legend against the corresponding map unit as “No Wells”. But, before mentioning the same, one should make himself sure about the absence of wells in that unit. The details pertaining to the wells to be collected in the field include – type of well, depth to water table, water table fluctuation (i.e. pre- and post-monsoon water tables), yield, total depth of well, type of subsurface formations and any other related information. This information can be collected partly by observing the wells and partly by discussing with well owners, neighbours, villagers, Gram Panchayat representatives etc. In addition to the above, the data on the observation wells (water table fluctuations) and the pump test data, drillers log, if any available with the State and Central Govt. Depts., are to be collected and used for preparation of well data layer. While selecting the wells for observation, preference should be given in the following order:

1. Irrigation bore / tube wells
2. Water supply bore / tube wells
3. Irrigation dug wells
4. Hand-pump wells (drinking water)
5. Dug-wells community water supply
6. Dug-wells individual house

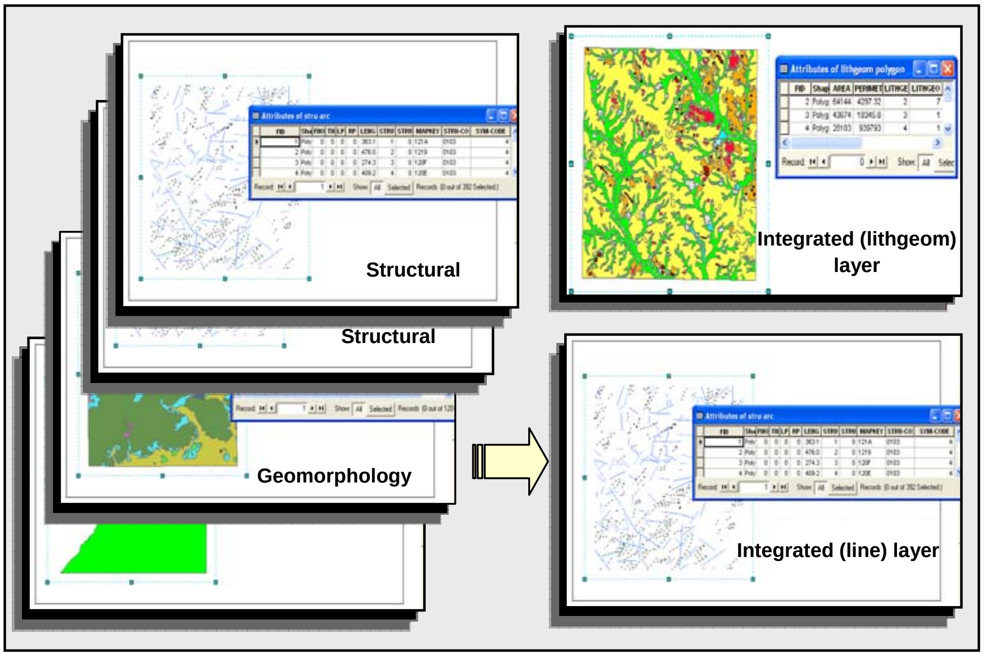
Further, preference should be given to the wells located outside the village since, they will not clash with the village symbol while representing on the map.

Fig-6



b. Delineation of Hydro-geomorphic Units

All the thematic layers thus created are integrated in GIS environment by superimposing the layers one over the other. Then the layers are subjected to overlay analysis. The data pertaining to hydrogeological properties present in each layer as the attribute data is also processed simultaneously. The entire process of integration is carried out in two steps. In the first step, the lithology, geomorphology and structural layers are integrated. During the process of integration, the boundaries of geomorphic units and rock types should be made co-terminus by adjusting the boundaries to avoid sliver polygons. From this exercise two types of units-1. Lithology-landform controlled units 2. Structure controlled units are derived as shown below.



Lithology-landform controlled units: These units are derived basically from the integration of lithology and geomorphology layers and the rock type and land form are unique in each unit. The geological structures such as bedding, schistocity / foliation, folding etc. are treated as structural character of the rock and is taken into account in the rock type itself. The primary porosity and permeability of the rock formations and the secondary porosity and permeability developed due to geomorphic process / landform genesis control the occurrence and movement of ground water in these units. A derivative layer comprising of all these units as polygons has to be generated. The polygon features are annotated with alphanumeric codes, e.g. PPS-71, PPD-81, UPM-32, etc. wherein the alphabetic code represents the geomorphic content and the numeric code represents the lithological content.

Evaluation of aquifer material: The integrated lithology-landform units are treated as homogenous areas with respect to hydrogeological properties and can be considered as aquifers. However, in order to take the depth wise character of the aquifer into account, the geological strata disposed in the subsurface at different levels has to be evaluated considering the porosity and permeability.

Accordingly the aquifer material can be classified into six categories as indicated below:

Loose Sediments (LS)	Mainly Quaternary formations comprising of unconsolidated sediments represented by coastal, deltaic, aeolian, alluvial and flood plains.
Permeable Rock (PR)	The semi-consolidated sediments and vesicular volcanic rocks having primary porosity and permeability.
Weathered Rock (WR)	Mainly weathered zones in hard rocks where the occurrence and movement of ground water is controlled by the depth of weathering.
Fractured Rock (FR)	The fractured zones in the hard rocks which generally act as conduits for movement of ground water.
Fissured Rock (FIR)	The hard rocks like gneisses, schists, slates, quartzites, limestones, etc having jointing, bedding, cleavage and other weak planes which impart limited porosity and permeability to the rock.
Impervious Rock (IR)	Massive Rocks without significant porosity and permeability like massive granite, dolerite dyke, etc which act as barrier for ground water movement.

Mostly, the layered rock formations such as sedimentaries, Deccan traps and alluvial deposits are characterized by the presence of multi-aquifer systems, because of the inter-layering of different permeability horizons. Generally, shallow aquifers occur under unconfined condition, and deeper aquifers occur under either semi-confined or confined conditions. In order to increase the productivity of wells, multiple (more than one) permeable horizons (aquifers) of different thickness are tapped through slotted pipes.

In such cases, however, the yield and other parameters of each individual aquifer are seldom known and the information available in the drillers logs or from the user is the cumulative effect of all the aquifers tapped.

Structure controlled units: The weak zones such as faults, thrusts, shear zones, fractures etc., and the linear intrusives such as dykes, quartz veins, etc.form as structure controlled units. Irrespective of rock type and landform, they act as conduits and barriers for ground water movement The line features are represented with different colours as indicated in Annexure III. The aquifer material of the structure controlled units with respect to hydrogeological properties is considered as uniform throughout the length and depth of the unit. However, depending on the intensity of the weak zones, they have to be classified as minor and major categories. Since the weak zones and intrusives are already mapped as type 1 structures in structural layer 1, the same can be converted into structure controlled hydrogeomorphic unit (line) layer.

Assessment of Recharge Conditions

In the second step, the hydrogeomorphology layers (both polygon and line feature layers) are integrated with hydrology layers. As a result the hydrological features occurring in each hydrogeomorphic unit gets delineated. The study and analysis of the integrated data facilitates evaluation of the unit in terms of the potential of the aquifer material for the occurence and movement of groundwater, amount of the water available for recharge and the actual recharge taken place.

The main sources of recharge to the aquifer / hydrogeomorphic unit are rainfall, water bodies, return flow from the irrigation, etc. The amount of water available has to be taken in to account for assessing the recharge condition from all these sources. However, the total available water may not percolate in to the ground. It depends on the infiltration capacity of the soil and the hydrogeological properties of the underlying rock formations. Hence, the actual recharge is assessed not only based on the water available from different sources but also the hdrogeological properties of geological material. The recharge conditions are classified as excellent, very good, good, moderate, limited, poor or nil as per the classification system. Depth of the water levels and their fluctuation observed from the wells located in the geomorphic unit also indicates the recharge conditions prevailing in the unit. Deeper water levels and high fluctuation indicates the poor recharge condition and vice versa.

c. Estimation of Ground water prospects

Then each hydrogeomorphic unit has to be has to be estimated for its ground water prospects. The ground water prospects of lithology-landform controlled units are estimated based on the analysis of hydrogeological characteristics of all the parameters controlling the occurrence and movement of ground water in conjunction with the observation well data collected during the feild work. The ground water prospects of the aquifers are estimated in terms of type of wells suitable, depth range of wells that can be drilled and expected yield range. In addition, the success rate of wells, water quality and ground water irrigated area are also estimated. The ground water prospects of structure controlled units, however, are considered as anomolous with reference to surrounding lithology-landform controlled units. The fault/fracture zones generally acts as conduits for movement of ground water. The yields are significantly higher and wells are likely to be sustainable for longer duration. The linear intrusive units generally acts as barriers for ground water movement. But the fractured portions may form as good aquifers and give high yields.

Types of wells suitable: Based on this criteria given below a suitable type of well has to be suggested in each hydrogeomorphic unit.

Dug Well (DW)	Where, the water table is very shallow and/or aquifers with low transmissivities are present (weathered, fissured/clayey formations).
Bore Well (BW)	Where, the water table is deep and/or a thick column of weathered / fractured rocks or semi-consolidated rocks with fairly good transmissivities are present.
Tube Well (TW)	Where, loose or collapsible unconsolidated and semi-consolidated sediments with fairly good transmissivities are present.
Dug-cum-Bore Well (DBW)	Where, the water table is at moderate depth, having semi-confined aquifers and the formation is not collapsible.
Dug-cum-Tube Well (DTW)	Same as above (DBW), but where the formation is loose and collapsible requiring slotted casing.
Ring Well (RW)	Same as DW, but where loose and collapsible formation is present.

Depth Range of wells: The depth range of the wells is estimated based on the depth to water table, the water table fluctuation, the depth at which the productive acquifer occurs. The depth ranges of wells can be classified into 3 categories i.e. less than 30m, 30 to 80 m, more than 80 m. Appropriate depth range suitable to the hydrogeomorphic unit can be suggested.

Expected Yield range: Initially, considering the hydrogeological characteristics of the controlling factors, the potential yield of the hydrogeomorphic unit is evaluated. Then the yields of the existing wells located in the unit are to be considered for calibration. While doing so 1) the average yield of the wells is to be taken in to account, 2) the wells with abnormally low and abnormally high yields should be avoided (where abnormally high yields are noticed in the hard rocks i.e. >200 lpm, the reasons also should be verified and possibility of its occurrence on fracture zones may be checked by examining the satellite imagery. If any fracture /

lineament is inferred on the satellite data, some more wells should be observed along such zone to confirm the existence of fracture and represent the same on the map as 'confirmed fracture' with appropriate line symbol). Finally, based on the correlation study, the expected yield range of wells in lpm or cu.m/ day has to be estimated for each unit. A more porous and pervious rock cannot give lower yield than a less porous and pervious rocks. Similarly, a shallow weathered zone on the same rock cannot give high yield than deeply weathered zone.

For estimating the approximate yield range of a hydrogeomorphic unit, right at the observation well, a chart showing the diameter of the discharge pipe verses yield is provided below. Similarly, a procedure for estimating the yield of a dug well is also provided. In those hydrogeomorphic units, where no observation wells are available, a tentative yield range has to be given

1. Depth of the well
2. Diameter of the well / Length & Breadth of the well
3. Depth to water level
4. Quantity of water available in the well
5. Delivery pipe size: 1", 1½", 2", 2½", 3" etc.
6. Pumping (draw down) time:
7. Recuperation time : 6 hrs, 12 hrs, 24 hrs
8. Optimum yield of the well

$$= \frac{\text{Discharge x Pumping time}}{\text{Pumping time + recuperation time}}$$

purely based on hydrogeological considerations.

Water flow	Approximate Yield Ranges (in lpm)		
	2" Dia pipe	$2^{1/2}$" Dia pipe	3" Dia pipe
Half (½) delivery (Half pipe)	10-50	15-75	22-112
Three-fourth (¾) delivery (three-fourth pipe)	50-75	75-112	112-168
Full delivery (full pipe)	75-100	112-150	168-225
Full pipe with pressure up to 1ft distance	100-150	150-225	225-337
Full pipe with pressure up to 2ft distance	150-200	225-300	337-450
Full pipe with pressure up to 3ft distance	200-250	300-375	450-560

While inferring the ground water prospects, in a hydrogeomorphic unit where in a shallow as well as a deeper aquifers occur, the 'type of wells suitable,' 'depth range of wells' and yield range of wells' are to be suggested for both the aquifers. However, the depth and yield of more productive aquifer has to be reflected on the map. In the legend, firstly theprospects of shallow aquifer has to be mentioned followed by that of deeper aquifer. For example:

Type of wells suitable	*Depth range of wells (suggested, in metres)*	*Yield range of wells (expected, in lpm or m^3/day)*
DW	20-25 m	50-100 *m^3/day*
TW	100-150 m	800-1500 lpm

In the remarks column, the depth range(s) of granular zones likely to be encountered will be given based on the existing lithologs, wherever available. The discharge of the wells in the hilly/ mountainous terrain normally is low. It ranges between 10-50 lpm and falls in any of the following 3 classes as shown in Annexure VI

- 10-20 lpm (pink colour)
- 20-30 lpm (brown colour)
- 30-50 lpm (orange colour)

Further, since in mountainous/hilly terrain, pump tests data are not available and ground water development is mainly through bore wells fitted with hand pumps, the discharge of wells and yields of aquifer are to be taken as synonymous for practical purposes for inferring the ground water prospects of a map unit. This can be mentioned as a general note in the map legend.

Success rate of wells / Homogeneity of the map unit: The success rate of wells varies from unit to unit depending on the homogeneity in the aquifer. Therefore, after careful analysis of the controlling factors and the well observation data, the success rate of wells (very high, high, moderate, low or poor) has to be estimated for each unit based on the homogeneity in the aquifer. For example, homogeneity in the aquifer and success rate of wells is very high in well sorted semi-consolidated formations like sandstones, whereas they are low/poor in hard rocks (fissured rocks) without fractures and significant weathering. While fixing the success rate of wells, the yield ranges of thewells suggested in the unit has also to be taken in to account.

Water Quality: The ground water quality, i.e. Potable (P) or Non-Potable (NP) is also evaluated for each unit. This information is provided mainly based on the existing maps / information, ground truth data and to some extent from the study of the composition of the aquifer material. Wherever the water is non-potable, the reasons for non-potability (e.g. high TDS, high fluoride, high nitrate content, etc.) are to be given.

In alluvial terrain, for the aquifers having non-potable ground water quality, while inferring the prospects, i.e. in the 'type of wells suitable,' 'depth range of wells' and yield range of wells' columns, only the aquifer (depth-wise: shallow/ moderate/ deep) yielding the potable water has to be considered. The aquifer yielding the non-potable ground water, however, can be mentioned in the 'remarks' column of the legend. If all the aquifers (i.e. shallow / moderate / deep) yield non-potable ground water, then appropriate measures in the 'water harvesting / recharge structures suitable' and in the 'remarks' column have to be mentioned.

Ground water irrigated area: The extent of ground water irrigated area is estimated for each unit to understand the status of ground water exploitation and the stress on the ground water regime.

Selection of Sites for artificial recharge Structures

In order to improve the ground water condition, particularly the sustainability of both drinking as well as irrigation wells in the hydrogeomorphic unit, sufficient recharge is essential. In case the natural recharge is not sufficient, it has to be met through artificial recharge. Many a times the sites for constructing recharge structures are selected based on administrative grounds. As a result proper recharge doesn't take place leading to wastage of money. To provide the user a scientifically appropriate location for constructing artificial recharge structures, each hydrogeomorphic unit is evaluated for its recharge potential.

Accordingly, the types of recharge structures that are suitable in each hydrogeomorphic unit are to be identified. The tentative locations for their construction are also to be suggested. The prioritization of the hydrogeomorphic units in to different priority zones for taking up for construction activity has to be made. Incorporating all this data to layers (line, point) have to be created.

Types of recharge structures: The following categories of recharge structures are considered for suggesting in each hydrogeomorphic unit –

i. Percolation Tank (PT)
ii. Check Dam (CD)
iii. Nala Bund (NB)
iv. Invert Well (i.e. Recharge Wells) (IW)
v. Desilting of Tank (DT)

vi. Recharge Pit (RP)
vii. Subsurface Dyke (SD)

Some of the similar type of terrain specific recharge structures like Storage Tank (ST) in hilly terrain and ‘Recharge Shaft (RS)’ in alluvial terrain can also be considered. Soil Conservation Measures (SCM) and In-situ water harvesting can be recommended wherever applicable and can be mentioned as a footnote of the legend. Locations for one or more than one type of the recharge structures are identified in each hydrogeomorphic unit based on the following criteria.

Criteria for site selection: In general, the locations for recharge structures are to be identified about 200-300 m upstream of the problem habitations. They have to be located mainly on 1st to 3rd order streams and at the most up to the initial stages of 4th order stream. No recharge structure is located on major streams / rivers occupying large area and forming polygons. The criteria for selection of tentative locations for various recharge structures is given below.

Check Dam: On the 1st and 2nd order streams along the foot hill zones and in the areas with 0-5% slope.

Percolation Tank: On the 1st to 3rd order streams located in the plains and valleys having sufficient weathered zone / loose material / fractures.

Nala Bund: On the 1st to 4th order streams flowing through the plains and valleys where acquisition of land for inundation of large areas is not possible. In this case, limited water will be stored in the river bed for some time which increases recharge.

Invert Well / recharge Well: In the areas where transmissivity of the upper strata is poor, e.g. in shales underlain by sandstones, in buried pediplains with top soil having low permeability, in Deccan Traps where vesicular basalt is overlain by massive basalt or thick black cotton soil or impervious zone.

Desilting of Tanks: The desilting is recommended in small tanks which are partially silted up. Siltation in the tanks is found by study of the image and ground truth.

Recharge Pit: Around the habitations where drainage does not exist, e.g. water divide areas, hill / plateau tops, etc. The Recharge pits are preferred in the existing tanks also.

Subsurface dyke: To improve the subsurface storage in unsaturated zones eg. vesicular / weathored / fractured basalt, lateritic terrain etc. where the ground water seepage as base flow is significant.

Accordingly, in each hydrogeomorphic unit, the suitable types of recharge structures have to be identified and shown on the map layer as well as in the legend with appropriate symbals and abbreviations.

Prioritization of units: As mentioned earlier, the priority in which the hydrogeomorphic unit is to be considered for taking up construction of recharge structures also found to be an important issue based on the nature of the unit and cost – benefit analysis. In view of this, different priority categories are identified and all the hydrogeomorphic units showing the recharge structures suitable in that unit have to be assessed in terms of priority.

Priority categories: The following categories of priorities are identified and considered for the prioritization.

i. Very High Priority
ii. High priority
iii. Moderate Priority
iv. Low Priority
v. No Priority
vi. Not required.

Criteria for prioritization: The prioritization of hydrogeomorphic units for constructing recharge structures should be based on the following criteria.

i. Presence of villages with drinking water scarcity (mainly due to the decline in water table)
ii. Status of ground water development
iii. Areas where ground water levels are declining fast
iv. Areas where water quality problem exists
v. Where recharge is poor/limited due to unfavourable hydro-geological conditions

For example, in the hydrogeomorphic units where drinking water sources have dried up or water levels are declining fast or more number of drinking water scarcity villages are located or percentage of ground water irrigated area is very high or quality problem is reported (which can be improved by dilution through recharge), 'Very High Priority' can be indicated. Similarly, the units, which are mainly covered under forests or inhabited or shallow water table having good to excellent recharge from canal commands and surface water bodies and rivers etc, are to be given ‘No Priority’. The remaining units can be given the ‘High Priority’ / ‘Moderate Priority / Low Priority. For the zones, which are not suitable for recharge structures, it should be indicated as ‘Not required’. The priority in which the hydrogeomorphic unit is classified can be indicated by mentioning as Low Priority, Moderate Priority, High Priority, Very High Priority and Not required.

d. Generation of ground water prospects map

Based on the integration of the thematic data, a comprehensive ground water prospects map showing all the above mentioned information has to be prepared. The map has to be generated in such a way that – a) the information pertaining to the factors controlling the occurrence and movement of ground water i.e lithology, geomorphology, geological structures and recharge conditions is presented as different layers and forms a base, b) the distribution of hydrogeomorphic units i.e the aquifers is shown as the derivative of these four factors and c) the ground water prospects which is in the form of type, depth and yield range of the recommended wells are to be provided as the outcome of the analysis of hydrogeological characteristics of the hydrogeomorphic units.

Map layouts: In order to generate the outputs – individual thematic maps as well as the integrated ground water prospects map – with common standards, fixed map layouts have been created. The map lay outs have the provision for the title, map area, legend area, etc. The map templates are provided to the partnership institutions along with the methodology manual.

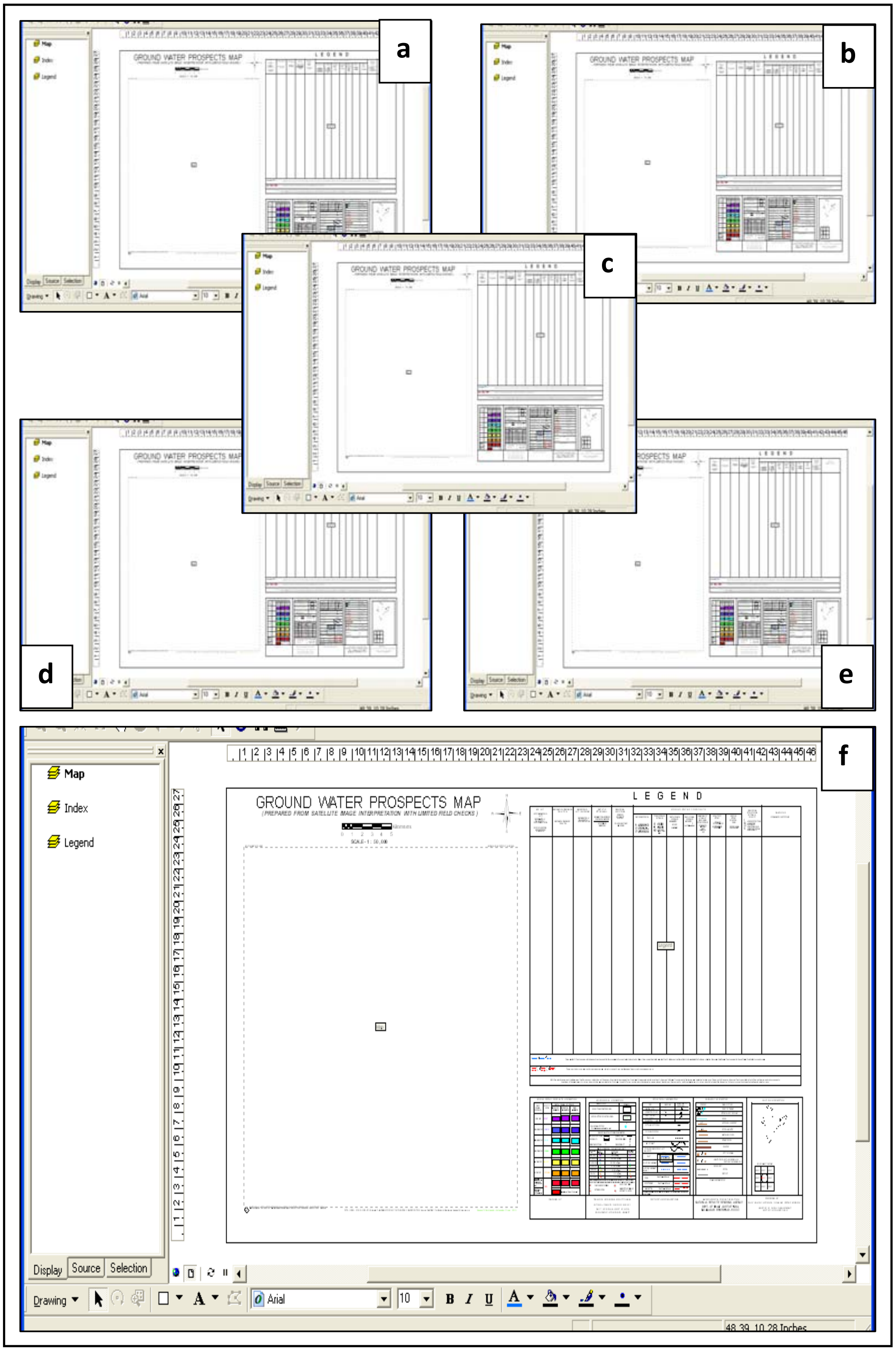
Map composition: In order to create the maps, first of all, the relevant map templates have to be opened. Then the coverages / layers have to be called in to the layout as per the requirement of contents. The five individual thematic maps are prepared by considering the coverages / layers along with associated symbol libraries that are relevant to that particular thematic map. The layers have to be opened in the corresponding template and have to be given the symbol codes and all legend information also. With this the Arc-Map MXD files can also be generated along with 18 coverage files. Once all the input files are ready, then use the Ground Water Prospects Map template and start map composition. For creating the ground water prospects maps, all the 18 in put layers except the lithology, geomorphology and structure-2 and their symbol libraries are required. The layers have to be called in a sequential order and the Lithgeom layer has to be called to the template in the last so that all the the map contents are properly represented.

Once the map is ready, then call symbol codes for each layer and assign the symbols according to the standards. Again add the Labels also for each layer.

The rock types are annotated with numeric codes, where as the landforms are with alphabetic codes. The geological structures are shown with different types of lines and the hydrological details are with different symbols. The hydrogeomorphic units are coloured with different hatching patterns based on their yield and depth ranges. For this purpose, VIBGYOR colour scheme with seven colours, i.e. violet to red, are used for depicting different yield ranges. Within each yield range, 3 hatching patterns are used for depicting the depth range of wells. Thus, a hydrogeomorphic unit showing one of the three hatching patterns in a particular colour (from violet to red) indicates the expected yield range and suggested depth range of the wells. For example, a unit with horizontal hatching in blue colour indicates that the expected yield range in that unit is 200-400 lpm and the depth range of the well is <30 m. The inselbergs, linear ridges, dykes, etc which act as run-off zones/ barriers for ground water movement, are indicated with solid red colour, and the hills (SH, DH and RH) and dissected plateaus where the prospects are limited to valley portions only are indicated with red hatching.

In addition to the above, the rivers / streams and perennial water bodies / tanks are shown in light cyan colour and roads, railways and settlements are shown in brown colour. All the faults, fractures / lineaments which mainly act as conduits for ground water movement are represented with blue colour. Similarly, the quartz reefs / quartzite bands, pegmatite veins, dykes, shear zones, etc which mainly act as barriers for ground water movement are shown with red colour. The dykes which act as carrier for ground water movement will also be shown with blue colour lines, same as fractures / lineaments.

Once this part is over, then create legend for the Lithgeom layer by inserting the legend from menu. According to Stratigraphic sequence make corresponding legend rows and start filling up the legend columns. Similarly fill the Map Index and other details also. Now the final Ground Water Prospects Map is ready. Save the file with the corresponding map sheet number


a
b
c
d
e
f
GROUND WATER PROSPECTS MAP
L E G E N D
Map
Index
Legend
Display
Source
Selection
Drawing
Arial
48.39 10.28 Inches

e. Creation of Legend

Since no separate report has to be prepared for each map, an exhaustive self explanatory legend has been designed containing two parts. The upper part of the legend provides map unit-wise ground water prospect information. The lower part provides the symbology details about the base map, hydrological and geological information, colour scheme for representing the yield range and depth range of wells, location map, toposheet index, administrative index and other reference information. The format of the legend is fixed to maintain the standards and uniformity. The details to be furnished in the upper and the lower parts of the legend are discussed below:

Upper part

The upper part of the legend, which is meant for showing the unit-wise ground water prospects, is divided into 14 columns. The information that is to be provided in each column is furnished hereunder. However, for structure controlled hydrogeomorphic units, the ground water prospects are to be given in a single row as a statement of inference.

Column-1: Map Unit

In this column, the information about hydrogeomorphic unit has to be furnished with alphanumeric code, where the alphabetic code represents geomorphic unit and numeric code represents lithological unit and both are separated by a dash (e.g. DH-91, PPM-91, etc). Further, the box has to be filled with colour hatching. The colour represents the yield range of wells and hatching pattern indicates the depth range of wells. While arranging all the hydrogeomorphic units in the legend, the geological sequence should be followed. Within the rock types, the geomorphic units have to be arranged as per the relief (i.e. starting from valleys and plains on the top to hills at the bottom).

In case of Deccan trap, the flow numbers should be added as third digit to the lithologic code. The flow no. or range of flow nos. separated by a dash should be kept in brackets and placed after the lithologic code.

Column-2: Geological sequence / Rock Type

In this column, the lithologic units / rock types are to be indicated following the geological sequence (stratigraphy). This column is sub-divided into 2 sub-columns. In the first subcolumn, name of the Super group / Group has to be given vertically (with geological sandstone, Peninsular Gneiss etc). The code no. appropriate to each can be given in the brackets after the rock type. The names of the rock types are to be given in capital letters.

In case of Deccan Traps, write Deccan Traps vertically with capital letters. In sub-column 2, the list of flows with heading Basalt Flows should be given. For each flow no., type of flow (e.g. massive, vesicular, unclassified group, etc) has to be written in 1st line in capital letters and its elevation range (in m MSL) to be given in 2nd line in small letters. Note that the list of flows should also include intertrappeans. In between two flows, line separator is not required. However, between Mesa / Butte (M/B) unit and the rest of the units in Deccan Traps, line separator is required. Further, for this unit, in place of no. and type of flow, it should be written as On Different Flows in capital letters.

Column-3: Geomorphic Unit / Landform

In this column, the name of geomorphic unit / landform has to be given followed by alphabetic codes in brackets, e.g. Valley Fill – Shallow (VFS), Bajada – Shallow (BJS). All the geomorphic units / landforms within a given rock type have to be arranged as per the relief, i.e. starting from valleys and plains on the top and hills at the bottom. In case of Deccan Trap, the name of geomorphic unit / landform should be given in the 1st line and the elevation range for each unit has to be given in second line.

Column-4: Depth to Water Table and No. of Wells Observed

In this column, information collected from field work on depth to the water level of summer season / pre-monsoon period (minimum to maximum range in metres) along with the number of wells observed are to be given. In the units where no wells are present, it has to be mentioned as “No Wells”. Where, wells are not observed, it has to be mentioned as “Wells Not Observed”.

Column-5: Recharge conditions

In this column, the recharge conditions generalised for each hydrogeomorphic unit have to be given based on the water availability from rainfall and other sources, and hydrogeomorphic conditions. The recharge conditions have to be categorised as excellent, very good, good, moderate, limited, poor or nil.

Column-6: Aquifer material

In this column, the nature of aquifer material has to be indicated for each hydrogeomorphic unit. The aquifer material can be one of the 6 categories based on their material content. The abbreviation of the appropriate category is to be indicated. Where, more than one category is to be indicated, it should be shown as LS + WR or WR + FIR as the case may be.

Column-7: Types of Wells Suitable

In this column, type of well suitable for that particular hydrogeomorphic unit has to be given. If in a particular map unit, more than one type of wells is suitable, they can be mentioned in this column in two separate lines giving depth range, yield range and other particulars separately for each type of well.

Column-8: Depth Range of Wells (Suggested)

In this column, the optimum depth range of wells in metres has to be indicated. Though colour scheme-wise the depth range of wells is classified into 3 categories i.e. <30, 30-80 mtr, >80mtr, actual depth range of wells like 40-55 mtr, 70-80mtr, 90-110mtr should be given depending on the situation.

Column-9: Yield Range of Wells (Expected)

In this column, the tentative yield range of the wells has to be given in liters per minute (lpm) for bore/tube wells or in cubic meters (cu m) per day for dug wells.

Column-10: Homogeneity in the Aquifer and Success Rate of Wells

In this column, the success rate of wells has to be indicated in the form of very high, high, moderate, low or poor based on the homogeneity in the aquifer.

Column-11: Water Quality

In this column, the ground water quality, i.e. Potable (P) or Non-Potable (NP) has to be mentioned for each unit. Wherever the water is non-potable, the reasons for non-potability (e.g. high TDS, high fluoride, high nitrate content, brackishness, etc) have to be given in this column.

Column-12: Ground Water Irrigated area

In this column, for each hydrogeomorphic unit, the extent of ground water irrigated area (range in %) has to be indicated in terms of 5-10%, <5%, >30% etc.

Column-13: Recharge Structures Suitable / Priority

In this column, the type of recharge structure suitable and priority for taking up recharge structures has to be indicated. In addition to the above, wherever Very High, High Priority, No Priority or Not Suitable is to be given in column no.13 and that should be justified in column no. 14 giving reason.

For example:

- Very high priority for recharge structures, since ground water exploitation is very high / wells dry up during summer.
- No priority for recharge structures, since mainly occupied by forest and no

habitation.

- Recharge structures not suitable, since mainly gullied / ravenous area, etc.

Column-14: Problems / Limitations / Remarks

In this column, the problems / limitations with reference to ground water prospects, e.g. caving and collapsing of wells, high failure rate, quality / potability etc. other relevant information have to be given. In the sedimentary and volcanic formations where the ground water prospects are better in the underlying rock type, such things also have to be indicated in this remarks column, which particular zone / stratigraphic unit form the aquifer may also be indicated there. Because of space constraint, it should be indicated in telegraphic language with minimum number of words and preference may be given to such information, which has not been clarified in any other columns of the legend. In case of Deccan Trap, mention should be made in telegraphic language about the following aspects, wherever applicable –

➢ Wherever the basalt flow exposed at the surface is not forming an aquifer, mention should be made of the underlying flows or intertrappean beds, if any, which form / likely to form aquifers along with their elevation range (in m MSL).

➢ Basis for suggesting the depth and yield range of wells should be given. For example, in a unit if no wells are existing or observed, it should be mentioned as 'Prospects are inferred as no wells are available'. Similarly, it can be mentioned that 'Vesicular zone / potential aquifer encountered at … m MSL in few/ …. wells, which needs to be explored / exploited.

➢ In case of units like Mesa / Butte, etc which are given solid red colour, it should be written as 'Run-off zone; Not suitable for ground water development.'

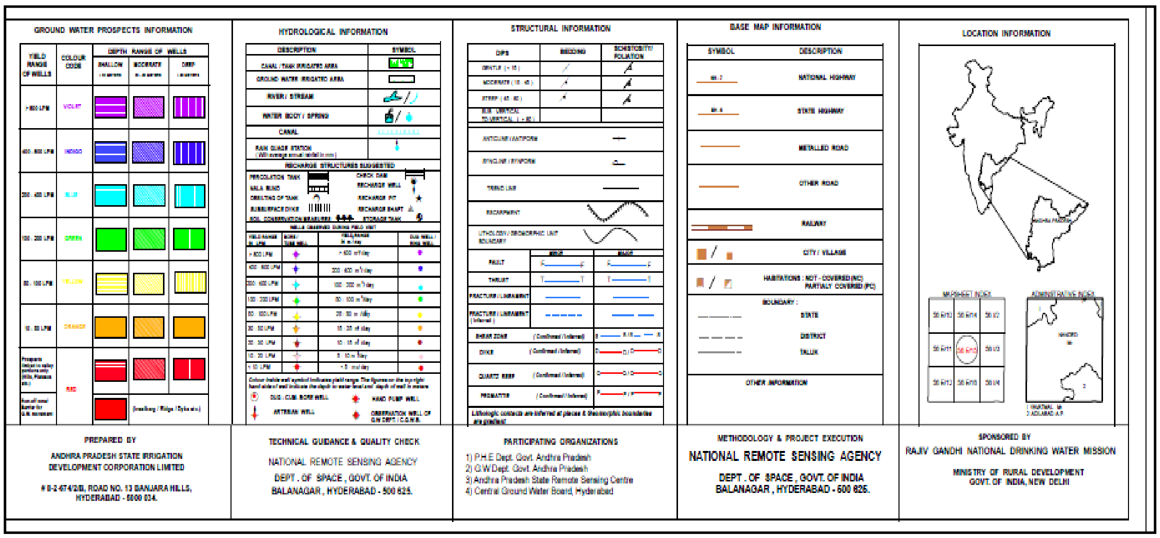
➢ For the units like Highly Dissected Plateau, which is given red hatching, it should be written as 'Mainly run-off zone; Prospects limited to valley portions only.' In such cases nothing should be written in 4_{th}-13_{th} columns and a dash has to be given.

➢ For the units, which are mainly occupied by forest and / or inhabited, the same may be mentioned in the remarks column.

In alluvial terrain, if the area is affected by 'water-logging', then the suitable measures to arrest water-logging can be recommended in the 'remarks' column. The type(s) of aquifer(s), i.e. unconfined / semi-confined / confined, can also be mentioned in the 'remarks' column, wherever possible.

Lower Part The lower part of the legend comprises of different symbols used the map to represent the base map details, structural, hydrological and ground water prospects information, location map, toposheet index, administrative index, data used, etc. Most part of it is fixed; however, the following details which vary from map to map are to be given in each map.

- Data used (details of satellite imagery, toposheet, geological maps consulted, etc.)
- Name of the author and organization in box
- Location map, toposheet and administrative index as per format shown in
- Any other information in the box provided



V. Classification Systems

There are different types of rock formations, land forms, geological structures and recharge conditions in the country. They are classified in to different types mainly based on the composition, form, origin, or association, etc. And each type is identified and labelled by that particular property based on which it is classified. Basically, all these classifications are made by different workers for different purposes.

The properties that are important for ground water study are primarily the porosity and permeability, or in other words, the texture of a geological material, the conduciveness of a landform with respect to recharge and discharge and the source of water for the recharge, etc. In view of this, it is difficult to use the existing schemes as it is and evaluate them for the properties that are relevant to ground water. Using the existing classification leads to erroneous interpretation of ground water condition due to confusion. Therefore, an attempt is made to classify the rock types, land forms, geological structures and recharge conditions based on the hydrogeological properties considering various terrain provinces.

a. Lithology

The geological classification of different rock types which is mainly based on their origin and mineral composition does not provide sufficient information for hydrogeological studies. In ground water studies, texture of the rocks is more important as it defines the water holding and transmitting capacity of the rocks vis-a-vis the aquifer characteristics. Considering this, a separate lithologic classification system has been evolved, wherein all the rocks having similar or matching hydrogeological characteristics are grouped together. Thus, mainly based on the texture of the rocks (primary / secondary porosity and permeability resulting from inter-granular pore spaces, bedding, cleavage, schistosity, foliation, etc), a two stage lithological classification system has been evolved**.(Table-1)**

In this classification, all the rock types have been classified into 9 rock groups. Under each group, several lithologic units that are likely to occur have been identified. For the sake of easy representation on the maps, numeric codes have been assigned to different rock groups and rock types / lithologic units. In the numerical code number of the rock type / lithologic unit, the first digit represents the rock group and the second digit represents the lithologic unit. In a given area, if more than one similar lithologic unit occurs at different stratigraphic positions, a third digit can be added to the code number for further differentiation. Efforts have been made to include all possible variations in lithologic units in each rock group. Further, provision has also been kept to include additional units, wherever required. However, this should be done judiciously after fully satisfying that such variations are not covered in the existing litho-units and creating an additional unit is absolutely essential.

In case of Deccan Traps, the textural characteristics of individual basalt flows and their vertical disposition (or stratigraphy) exercise significant control on the movement and occurrence of ground water. In view of this, mapping of individual basalt flows, which are of generally 10-30 m thickness having horizontal to sub-horizontal dips, has been considered essential. However, in case of Mesa, Butte and Highly Dissected Plateaus, which mainly acts as run-off zones, instead of delineating individual basalt flows, all of them may be clubbed together and mapped as ‘Group of Flows’.

b. Geological Structures

In the hard rock areas, geological structures exercise definite control on the aquifer characteristics of different rock types, as the structurally weak planes act as conduits for movement and occurrence of ground water, thereby introducing an element of directional variation in hydraulic conductivity. The geological structures that can be identified on satellite imagery can be divided into two categories: (i) primary structuresassociated with specific rock types and (ii) secondary structures-which cut, deform and otherwise affect the rock units themselves. Both these primary and secondary geological structures have been classified into the following 8 categories to facilitate systematic mapping based on satellite imagery interpretation with limited field checks. All these structures like – i) bedding, ii) schistosity / foliation, iii) faults, iv) fractures / lineaments, v) fractures / lineaments (inferred), vi) shear zones, vii) folds and viii) trend lines are represented on the map with different line symbols. **(Table-2)**

c. Geomorphology

The earth's surface can be classified into different geomorphic units / landforms based on their physiographic expression, origin, material content and climatic conditions, etc. Different types of geomorphological maps can be prepared giving emphasis to some of these factors. Hence, the geomorphological maps vary greatly depending on the purpose for which they are prepared, i.e. terrain evaluation, land resource mapping, soil classification, watershed prioritization, ground water studies, etc. A number of terms are available in the geomorphic literature for describing a variety of landforms, but all of them may not exercise definite control on the ground water regime. In view of this, a systematic classification of geomorphic units / landforms **(Table-3)** wherein the individual geomorphic unit / landform has definite bearing on the ground water regime has become necessary to follow in this project. In this classification, all the geomorphic units / landforms have been broadly classified into 3 major physiographic zones, (1) Hills & Plateaus, (2) Piedmont Zones and (3) Plains. In each of these zones, a number of geomorphic units / landforms which are possible to occur have been included. The details provided in this classification are commensurate with the scale of mapping, i.e. 1:50,000 scale. However, depending on the ground realities, additional landforms can also be included. Further, it may be mentioned here that much of the geomorphic terminology used in this classification system have been taken from the existing geomorphic literature. But, these terms are used more liberally to cover additional landforms which were not originally intended for. Thus, the names of landforms given in this classification system are not used in their strict sense. Their usage has been extended to cover a variety of landforms. For example, the terms pediment and pediplain were originally used to represent rockcut surfaces / plains formed mainly by massive rocks in arid and semi-arid climatic zones; whereas, these terms are used here to represent all gently undulating plains formed on all rock formations (including sedimentary and volcanic rocks) in all climatic zones.

d. Recharge

Recharge is the most important factor in ground water studies. If sufficient recharge is not there, the most favourable aquifer zones will also go dry. Hence, it is essential to pay sufficient attention to study the recharge conditions before evaluating the ground water prospects of each unit. As already mentioned earlier, the hydrological information derived from satellite imagery in conjunction with ground hydrological data will be quite useful in proper evaluation of recharge conditions. The recharge conditions are classified in to seven categories **(Table-4)** considering the perennial / ephemeral nature of water bodies, rivers, streams and canals, amount of rainfall, the extent of recharging area and the hydrogeological conditions.

In the ground water prospects map, the recharge conditions also are given in the legend for each hydrogeomorphic unit along with rock type and landform. This not only helps in proper evaluation of ground water prospects but is also useful for selection of sites for planning recharge structures in different units to improve the sustainability of drinking water sources.

VI. Scope and limitations of ground water prospects maps

Scope

- Ground water prospects maps may be used by the field Officers of the departments concerned in the respective states to select the sites at appropriate places
- It helps mainly in identification of prospective locations for narrowing down target zones for follow-up detailed hydrogeological and geophysical surveys at appropriate places for drilling.
- These maps are the good inputs for aquifer mapping.
- One of the input for resource estimation for future ground water development for the given area.
- The maps are prepared based on the availability recharge conditions i.e rainfall, depth to water table, availability of water in the water bodies during the period of the mapping. Hence depth and yield will vary.

- VIBGYOR colours scheme is maintained for indicating yield and hatching pattern for depth. In does not mean that entire polygon gives the same yield but it varies within the unit due to heterogeneity. Hence sometimes yield may go one step up or down. It is because of rain fall variations.
- Maps help in identifying the ground water exploitation areas (through ground water irrigated patches) for addressing the suitable recharge structures for improving the ground water levels.

Limitations

1. Pin pointing bore / tube well points (41/2" & 61/2" dia) may not be accurate.

Reasons

- Scale of mapping (1:50,000 scale)
- Accuracy of map: The accuracy of the map is around 100 meters (which includes satellite data accuracy and other mapping errors).
- Heterogeneity of the terrain: These maps are generated with limited field checks hence in many cases the hydrogeomorphic units are extrapolated with the help of satellite image features.

Recommendations

- Ground survey to estimate the detailed hydrogeological conditions
- Ground geophysical survey (electrical resistivity)
- Up scaling keeping the map as base to assess the micro level changes

2. Depth variations

Reasons

- Dynamic hydrological conditions
- Varying subsurface condition.

Recommendations

- Deeper depths to tap the multi layer aquifer system
- Drilling of the well near to the fracture system

3. Yield variations

Reasons

- Depletion of water table due to scanty rainfall
- Porosity and permeability variations within the unit

Recommendations

- Implementation of recharge structure at the time of development of well
- Detailed ground geophysical survey

4. Variations in estimated success rate

Reasons

- Non availability of well information.

- Inaccessibility of the terrain

Recommendations

- Drilling within the network of the fractures.

5. Low yields/poor yields along the fracture areas

Reasons

- Heterogeneity within the fracture aquifers.

Recommendations

- Drilling within the intersection of the fractures and confirmed fractures with proper survey

Capacity Building

Geologists of the partnership institutions were trained in the preparation of the ground water prospects maps based on the interpretation of satellite data with limited ground truth information. After submitting the maps to the concerned state departments, conducted training workshops at the respective state centres for the usage of the ground water prospects maps effectively on the ground for the selection of the sites for drilling and identification of recharge structures at proper locations with field demonstrations.

Name of the state	Place	Duration of training	No. Officers Trained
Andhra Pradesh	Hyderabad	23-28 July 2001	15
		16-20 Oct, 2001	12
		17 -18 June 2010	36
		23-24 Feb 2012	23
		17-18 Jan 2013	60
		06-07 Mar 2013	35
Assam	Guwahati	Jan 19 - 29, 2010	60
		14 Dec 2012 (For All NE States)	55
Chattisgarh	Marwalu	26th May, 2002	55
	Raipur	3-4 Feb, 2003	70
		01-02 April, 2010	40
Gujarat	Gandhinagar	18-19 Mar 2005	50
		15-16 Jul, 2010	42
Himachal Pradesh	Shimla	16-17 Jul, 2004	50
		22-23, Jul, 2010	40
	Sundernagar	19-20 Jul, 2004	50
	Dharmasala	22-23 Jul, 2004	50

Jharkhand	Dhanbad	4-5th Aug, 2003	35
	Ranchi	27-28 Apr, 2004	28
		12-13, Aug, 2010	69
	Dumka	30 Apr – 01 May 2004	22
Karnataka	Bangalore	19-22 Sept, 2001	40
		05-06, October 2010	50
		30-31 Jan 2013	55
		13-14 Feb 2013	
Kerala	Thiruvanantapuram	21-22 Nov, 2002	63
		14 July, 2004	47
		22-23 Dec 2010	30
Madhya Pradesh	Indore	12-14 July 2002	32
	Bhopal	08-09 Jul, 2010	45
Maharashtra	Nagpur (RRSC-C)	6-7 Feb 2013	30
		5-6 Sep 2013	55
Orissa	Bhubaneswar	23rd Jun 2004	36
		15-16 Dec 2006	65
		25 - 26 Jun 2010	45
		17-18 Jun 2013	55
Rajasthan	Jodhpur	6th Nov. 2001	42
		29-30, Jul , 2010	36
		20-21 Feb 2013	45
Uttarakhand	Dehradun	05-06 Aug 2010	55
Uttar Pradesh (Bundelkhand Region)	Jhansi	18 – 20, Aug 2010	60
West Bengal	Kolkata(RRSC-E)	30-31 Jan 2013	25
Arunachal Pradesh	Itanagar	22-23 September, 2013	80
All NE States except Arunacha Pradesh	Imphal	16-17, December	75
		Total no. of Officers Trained	1963

Feedback on usage of Maps

It is reported that more than 90% success rate of wells has been achieved in all the States by using the ground water prospects maps for selecting the drilling sites. Many recharge structures have also been constructed using the information provided in these maps. The state-wise details of the wells drilled along with success rate and the no. of recharge structures constructed are furnished hereunder.

State	No. of wells drilled and success rate 2005-10	No. of wells drilled & Success rate 2010-11	No. of wells drilled & success rate 2011-12	No. of wells drilled & success rate 2012-13 to till date	Recharge Structures constructed		
					2005-10	2010-11	2011-13
Andhra Pradesh	43827 (93%)	1415 (88%)	--	--	2279	08	--
Chhattisgarh	33413 (92%)	13642 (85%)	--	--	327	--	--
Karnataka	47951 (95%)	224 (90%)	--	--	2589	14	--
Kerala	7979 (92%)	--	--	--	26	--	--
Madhya Pradesh	22006 (90%)	--	--	--	3361	--	--
Rajasthan	104082 (95%)	--	1644 (85%)	5400 (85%)	320	--	--
Gujarat	13380 (95%)	8862 (92%)	--	--	155	--	--
Orissa	292 (92%)	--	--	--	--	--	--
Assam	--	157 (100%)	--	--	--	147	--
Maharashtra	--	--	--	813 (80%)	--	--	1070
Total	272930	24300	1644	1327	9057	169	1070

- Total number of wells drilled from 2005 to till date : 3,00,201
- Total number of recharge structures constructed from 2005 to till date: 10296

Mode of Execution

Precision geo-coded images of LISS-III sensor data of IRS series of satellites (1C/1D/P6) with LCC projection have been used as the input for preparation of the ground water prospects maps. In order to prepare the maps with common standards and quality, technical guidelines consisting of methodology, mapping procedure, mapping and quality standards, etc have been formulated. During the process several experts from Dept. of Space, ISRO, Central Ground Water Board, State Ground Water Depts. and Universities were consulted and their views and suggestions were incorporated. The maps are prepared in association with various partnership institutions which include different DOS Centres, State Remote Sensing Centres, State / Central Government Departments, Private organizations, and Universities/Research organizations. Experts from different DOS centre and from Central Ground Water Board (CGWB) were involved in quality checking of the maps. The final ground water prospects maps were supplied to the concerned State Government Departments dealing with Drinking Water Supply in the respective states.

Phase number	States covered	Number of maps	Year of completion
Phase-I	1. Andhra Pradesh (Eastern part), 2. Karnataka 3. Kerala 4.Chattishgarh 5.Madhya Pradesh 6. Rajasthan	1654	1999-2002
Phase-II	1.Gujarat 2.Himachal Pradesh 3. Jharkhand 4. Orissa	724	2002-2007
Phase-III A and B	**Phase-III A** 1. Andhra Pradesh (remaining part), 2.Assam 3.Jammu and Kashmir, 4.Maharashtra 5.Punjab 6.Uttarakhand **Phase-IIIB** 1. Arunachal Pradesh 2. Haryana 3. Uttar Pradesh (part) 4. West Bengal (Part)	1290 339	2007-2010

Phase-IV	1. Uttar Pradesh (remaining part), 2. West Bengal (remaining part), 3. Bihar 4. Delhi 5. Goa 6. Puducherry 7. Tamilnadu **<u>NEstates</u>** 8. Manipur 9. Meghalaya 10. Mizoram 11.Nagaland 12. Sikkim 13.Tripura **<u>Union Territories</u>** **1.** Andaman & Nicobar Islands 2. Chandigarh 3. Daman &Diu 4. Dadra & Nagar Haveli 5. Lakshdweep Islands	891	Completed in July 2014

Table-1

Classification of rock types / lithologic units

Code No.	Rock Group	Code No.	Rock Type / Lithologic Unit
1	UNCONSOLIDATED SEDIMENTS	11	Alluvium – sand/silt dominant
		12	Alluvium – clay dominant
		13	Alluvium – sand/silt & clay alternating beds
		14	Colluvium – clay/silt dominant
		15	Colluvium – pebble/cobble dominant
		16	Eolian sand / silt
		17	Loess
		18	Alluvium – Gravel dominant
		19	——————-
2	RESIDUAL CAPPINGS	21	Laterite (ferricrete)
		22	Bauxite (alecrete)
		23	Kankar (calcrete)
		24	Chert (silcrete)
		25	Detrital laterite / bauxite
		26	———————
3	DECCAN TRAPS & INTER-TRAPPEANS	31	Inter-/Infra-trappean sand / clay beds
		32	Tuffacious basalt
		33	Vesicular basalt
		34	Amygdaloidal basalt
		35	Massive basalt
		36	Columnar basalt
		37	Red / green bole
		38	Unclassified basalt
		39	——————-
4	OTHER VOLCANICS & META-VOLCANICS	41	Basalt / meta basalt
		42	Rhyolite / meta rhyolite
		43	Dacite / meta dacite
		44	Andesite / meta andesite
		45	Undifferentiated meta basics
		46	Ophiolite / Ophiolite melange
		47	——————-
5	SEMI-CONSOLIDATED SEDIMENTS	51	Sandstone / pebble bed / conglomerate
		52	Shaly sandstone
		53	Sandstone with shale / coal bands
		54	Sandy shale
		55	Shale with sandstone / limestone bands
		56	Shale / coal / lignite
		57	Limestone / shell limestone
		58	Limestone with shale bands
		59	Cemented assorted mixture of gravel, sand, silt & clay
6	CONSOLIDATED	61	Thin bedded / flaggy sandstone / quartzite

	SEDIMENTS	62	Thick bedded / massive sandstone/ quartzite
		63	Thin bedded / flaggy limestone / dolomite
		64	Thick bedded / massive limestone/ dolomite
		65	Shaly limestone
		66	Shale with limestone/sandstone bands/ lenses
		67	Shale
		68	Conglomerate
		69	Cavernous limestone
7	PLUTONIC ROCKS	71 72	Alkaline rocks Basic rocks
		73	Ultrabasic / ultramafic rocks
		74	———————
8	GNEISS-GRANITOID COMPLEX / CHARNOKITE KHONDALITE / COMPLEX / MIGMATITE COMPLEX /	81	Granites / Acidic rocks
		82	Migmatite / migmatite complex
		83	Granitoid gneiss / gneissic granitoid granitoid complex
		84	Charnockite
		85	Khondalite
		86	Charnockite-Khondalite complex
		87	———————
9	METAMORPHIC ROCKS	91	Gneiss
		92	Schist
		93	Phyllite
		94	Slate
		95	Quartzite
		96	Calc-gneiss / calc-schist
		97	Marble / crystalline limestone
		98	Undifferentiated meta sedimentaries
		99	Undifferentiated Metamorphics
	INTRUSIVES	Q Q	Quartz reef
		P P	Pegmatite / aplite vein
		D D	Basic dyke
			Basic sill

Note: This classification is based on texture of the rocks. In the map legend, the rock types are listed as per the geological sequence indicating their type name like Barakar sandstone, Peninsular gneiss etc. giving the appropriate code number from this table. In case of unconsolidated sediments where they are shallow (less than 10 m thick), the rock type occurring below such sediments is considered. In case of residual cappings, the underlying rock type is indicated in the map legend. Quartz reef, pegmatite, basic dyke may also be marked as polygon features, wherever required.

Table-2

Classification geological structures

Structure	Category
1. Bedding	Horizontal to sub-horizontal (0-10 dip)
	Gentle (< 10 dip)
	Moderate (10-45 dip)
	Steep (45-80 dip)
	Vertical to sub-vertical (> 80 dip)
2. Schistosity / Foliation	Horizontal to sub-horizontal (0-10 dip)
	Gentle (< 10 dip)
	Moderate (10-45 dip)
	Steep (45-80 dip)
	Vertical to sub-vertical (> 80 dip)
3. Fault	Minor (< 3 km length)
	Major (> 3 km length)
4. Fracture / Lineament	Minor (< 3 km length)
	Major (> 3 km length)
5. Fracture / Lineament (inferred)	Minor (< 3 km length)
	Major (> 3 km length)
6. Thrust	Thrust Minor (< 3 km length)
	Thrust Major (> 3 km length)
7. Folds	Anticline/Antiform – non plunging
	Anticline/antiform – plunging
	Anticline/antiform – doubly plunging
	Syncline/synform – non plunging
	Syncline/synform – plunging
	Syncline/synform – doubly plunging
8. Shear zone	Minor (< 3 km length)
	Major (> 3 km length)
9. Trend line	

Table-3

Classification geomorphic units/landforms

Physiography		Geomorphic Unit / Landform		Code
I. Hills & Plateau				
	Hills			
		Structural Hills		SH
			Less dissected	SHL
			Less dissected-Concave slopes	SHLc
			Moderately dissected	SHM
			Moderately dissected-Concave slopes	SHMc
			Highly Dissected	SHH
			Highly dissected-Concave slopes	SHHc
		Denudational Hills		DH
			Less dissected	DHL
			Less dissected-Concave slopes	DHLc
			Moderately dissected	DHM
			Moderately dissected-Concave slopes	DHMc
			Highly Dissected	DHH
			Highly dissected-Concave slopes	DHHc
		Residual Hills		RH
		Inselberg		I
	Plateaus			
		Upper Plateau		UP
			Undissected	UPU
			Moderately Dissected	UPM
			Highly Dissected	UPH
			Weathered	UPW
			Weathered-Canal command	UPC
		Middle Plateau		MP
			Undissected	MPU
			Moderately Dissected	MPM
			Highly Dissected	MPH
			Weathered	MPW
			Weathered-Canal command	MPC
		Lower Plateau		LP
			Undissected	LPU
			Moderately Dissected	LPM
			Highly Dissected	LPH
			Weathered	LPW
			Weathered-Canal command	LPC

Physiography	Geomorphic Unit / Landform			Code
		Plateau (in case of Deccan traps)		
			Undissected	PLU
			Slightly Dissected	PLS
			Moderately Dissected	PLM
			Highly Dissected	PLH
			Weathered	PLW
			Weathered-Canal command	PLC
	Other landforms common to Hills & Plateaus			
			Linear/curvilinear ridge	LR/CR
			Cuesta	C
			Hogback	HG
			Mesa	M
			Butte	B
			Inselberg	I
			Sheet rock	SR
			Residual mound	RM
			Hill top-weathered	HTW
			Outer Fringe of Plateau	OFP
			Escarpment slope	ES
			Hill Slope/Denudational Slope	HS/DS
			Fracture/Fault Line Valley	FV
			Intermountain Valley	IV
			Valley	V
			Deglaciated Valley	DV
			Hanging Valley	HV
			Valley slope	VS
			Valley flat	VT
			Valley Fill – Shallow	VFS
			Valley Fill–Moderate	VFM
			Valley Fill – Deep	VFD
			Old Slided Mass	OSM
			Resent Slided Mass	RSM
			Moraine Complex	MC
			Sink Hole	SK
II. Piedmont Zone				
	Piedmont Slope			PS
	Pediment			PD
	Pediment-Inselberg-Complex			PIC
	Piedmont Alluvium			PA
		Shallow		PAS
		Moderate		PAM

Physiography		Geomorphic Unit / Landform		Code
		Deep		PAD
		Gullied		PAG
		Ravinous		PAR
		Dissected		DPA
	Bazada			BJ
		Shallow		BJS
		Moderate		BJM
		Deep		BJD
		Gullied		BJG
		Ravinous		BJR
		Dissected		DBJ
			Linear / Curvilinear Ridge	LR/CR
			Cuesta	C
			Hogback	HG
			Mesa	M
			Butte	B
			Inselberg	I
			Talus Cone	TC
			Alluvial Fan	AF
			Alluvial Fan-Upper/Proximal	AFU
			Alluvial Fan-Lower/Distal	AFL
			Fracture/Fault Line Valley	FV
			Valley	V
			Valley Fill-Shallow	VFS
			Valley Fill-Moderate	VFM
			Valley Fill-Deep	VFD
III. Plains				
	Pediplain			
		Weathered Pediplain		PP
			Shallow	PPS
			Moderate	PPM
			Deep	PPD
			Gullied	PPG
			Ravinous	PPR
			Dissected	DPP
			Under Canal Command	PPC
		Buried Pediplain		BP
			Shallow	BPS
			Moderate	BPM
			Deep	BPD

Physiography		Geomorphic Unit / Landform		Code
			Gullied	BPG
			Ravinous	BPR
			Dissected	DBP
			Under Canal Command	BPC
	Striped Plain			SP
		Shallow Basement		SPS
		Moderate Basement		SPM
		Deep Basement		SPD
		Gullied		SPG
		Ravinous		SPR
		Dissected		DSP
		Under Canal Command		SPC
	Lateritic Plain			LP
		Shallow Basement		LPS
		Moderate Basement		LPM
		Deep Basement		LPD
		Gullied		LPG
		Ravinous		LPR
		Dissected		DLP
		Under Canal Command		LPC
	Other landforms common to Pedi plain & Stripped plain			
			Linear/Curvilinear Ridge	LR/CR
			Cuesta	C
			Hogback	HG
			Mesa	M
			Butte	B
			Inselberg	I
			Residual mound	RM
			Sheet rock	SR
			Fracture/Fault Line Valley	FV
			Valley	V
			Valley Fill – Shallow	VFS
			Valley Fill – Moderate	VFM
			Valley Fill – Deep	VFD
	Alluvial Plain			AP
			Shallow	APS
			Moderate	APM
			Deep	APD
			Gullied	APG
			Ravinous	APR

Physiography		Geomorphic Unit / Landform		Code
			Dissected	DAP
			Under Canl Command	APC
		Alluvial Plain – Older / Upper		APO
			Shallow	AOS
			Moderate	AOM
			Deep	AOD
			Gullied	AOG
			Ravinous	AOR
			Dissected	DAO
			Under Canal Command	AOC
		Alluvial Plain Younger / Lower		APY
			Shallow	AYS
			Moderate	A
			Deep	AYD
			Gullied	AYG
			Ravinous	AYR
			Dissected	DAY
			Under Canal Command	AYC
	Flood Plain			FP
			Shallow	FPS
			Moderate	FPM
			Deep	FPD
			Gullied	FPG
			Ravinous	FPR
			Dissected	DFP
			Under Canal Command	FPC
	Deltaic Plain			DP
			Shallow	DPS
			Moderate	DPM
			Deep	DPD
			Gullied	DPG
			Ravinous	DPR
			Dissected	DPd
			Under Canal Command	DPC
	Other landforms common to Alluvial plain, Flood plain & Deltaic plain			
			Channel Bar	CB
			Point Bar	PB
			Natural Levee	NL
			River Terrace	RT
			RiverTerrace-Younger/Upper	RTY

Physiography		Geomorphic Unit / Landform		Code
			River Terrace-Intermediate	RTI
			River Terrace-Older/Lower	RTO
			Back swamp	BS
			Cut-off Meander	CM
			Oxbow/Serpentine Lake	OL
			Meander Scar	MS
			Palaeochannel	PC
			Abandoned channel	AC
			Buried Channel	BC
			Migrated River course	MR
	Coastal Plain			CP
			Shallow	CPS
			Moderate	CPM
			Deep	CPD
			Gullied	CPG
			Ravinous	CPR
			Dissected	DCP
			Under Canal Command	CPC
		Coastal Plain – Older		CPO
			Shallow	COS
			Moderate	COM
			Deep	COD
			Gullied	COG
			Ravinous	COR
			Dissected	DCO
			Under Canal Command	COC
		Coastal Plain – Younger		CPY
			Shallow	CYS
			Moderate	CYM
			Deep	CYD
			Gullied	CYG
			Ravinous	CYR
			Dissected	DCY
			Under Canal Command	CYC
		Other land forms common to Coastal plain		
			Beach	BH
			Beach Ridge	BR
			Palaeo Beach Ridge	PBR
			Beach Ridge&Swale Complex	BSC
			Palaeo Beach Ridge &Swale Complex	PBS

Physiography		Geomorphic Unit / Landform		Code
			Swale	SW
			Offshore bar	OB
			Spit	ST
			Mud Flat	MF
			Mud Flat Older	MFO
			Mud Flat Younger	MFY
			Tidal Flat	TF
			Salt flat	SF
			Lagoon	LG
			Channel Island	CI
			Offshore island	OI
			Reef island	RI
			Palaeochannel	PC
			Buried Channel	BC
	Eolian Plain			EP
			Shallow	EPS
			Moderate	EPM
			Deep	EPD
			Gullied	EPG
			Ravinous	EPR
			Dissected	DEP
			Under Canal Command	EPC
		Other land forms common to Eolian plain		
			Sand Dune	SD
			Stabilised Dune	STD
			Dune Complex	DC
			Interdunal Depression	ID
			Interdunal Flat	IF
			Playa	PL
			Desert Pavement	DPV
			Loess Plain	LP
			Palaeochannel	PC
			Buried Channel	BC

Note: 1. In case of Plateau, the elevation range (in metres) is given in the parenthesis along with the unit name [e.g. Upper Plateau – Undissected (UPU) – (400-500 m)] in the legend.

2. The gullied, ravenous, dissected and canal command areas within the Plains and Plateaus can be separately mapped by adding G, R, T and C, respectively as the third digit to the alphabetic code of the geomorphic unit, wherever applicable.

For example: Alluvial Plain – Gullied — APG
Alluvial Plain – under Canal Command — APC
Pediplain – Dissected — PPT
Pediplain – under Canal Command — PPC

Table-4

Classification of recharge conditions

Category	Recharge condition
Excellent	Recharge from continuously irrigated canal commands, permanent water bodies, perennial rivers / streams, etc., (continuous recharge throughout the year – shallow water table conditions)
Very good	Recharge from temporarily / seasonally irrigated canal commands, seasonal / ephemeral water bodies / streams (recharge for part of the year).
Good	Having large recharge area with high rainfall and favourable Lithological – structural – landform conditions for sufficient recharge.
Moderate	Limited recharge area and moderate rainfall or seepage from other sources or limited by unfavourable Lithological – structural – landform conditions
Limited	High relief areas occupying large areas with heavy runoff, very limited recharge only along narrow valleys.
Poor	Very limited recharge area / poor rainfall / shadowed by ground water barriers like linear ridges, dolerite dykes etc.
Nil	No recharge from any source

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