CHAPTER - X

WATER HARVERSTING AND RECHARGING IN HARD ROCK AREAS

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10.0 CONCEPTUAL FRAME WORK

From a technical stand point, though hard rock areas occupy greater part of our country, but very little knowledge exists about the "vadose zone", that spans the region between ground surface and fluctuating water table. There is no much reliable information about unsaturated zone that exists over hard rock formations. As a matter of fact one would need a regional as well as large scale maps of weathering crust over hard rocks which are normally not available though sporadic pieces of information do exist through reports of survey organisations.

It is, therefore, essential to have a quantitative knowledge of the dynamics of water storage & water release mechanism from vadose zone (unsaturated zone) that is considered important in the formulation and implementation of artificial recharge works in water shortage and drought prone hard rock regions in the country.

It would be necessary therefore for any one to know first the nature, movement and occurrence of ground water in hard rocks. Some salient characteristics of occurrence of ground water in hard rock are listed below: -

Features of Occurrence of Ground Water in Hard Rocks are:

(i) Ground water reservoir (aquifer) in hard rocks are dominantly shallow
(ii) The bulk of the ground water is stored in the zone of weathering (Vadose zone)
(iii) Fractures and joints in hard rock occur as conduits for rapid transport of water as they do not provide large space for storage of ground water
(iv) The width of fractures & lineaments and weak planes narrows as depth increases
(v) Fairly limited aquifer water yield by wells and borewells in comparison to alluvial and sedimentary rock aquifer wells
(vi) Unpredictable ground water occurrence over short distances
(vii) Poor water quality in certain areas

10.1 VADOSE ZONE IN HARD ROCKS

The principle ground water reservoir in hard rocks therefore consists of two parts viz

(i) "Vadose zone" or unsaturated zone that lie between ground surface and water table; and
(ii) The phreatic or unconfined zone that lie below the water table

In view of the above idealization, about the shallow nature of occurrence of ground water, the ground water system is controlled by individual, zero order and 1st order watersheds though water movement is also expected to occur between 1st order & 2nd order basins. What is important therefore is to know the flow patterns in ground water at local levels in relation to dyke rocks and outcrop ridges. The deeper ground water below water table in zone of fractures lack substantial storage unless it is connected with thick vadose zone above or else is connected to a surface water source.

Exclusively from the issue of ground water storage, the “vadose zone” in hard rocks is extremely important, because the pore spaces in this domain undergo resaturation during infiltration and recharge and undergo desaturation under conditions of evaporation and drainage. The volume of saturation involved in the process of change in saturation in vadose zone (zone of weathering) is far large than the changes in volume of water involved in the elastic storage of water below the water table. It therefore may be noted, that the dynamic resource in ground water reservoir in the hard rock areas is governed by the “vadose zone” through which water levels fluctuate.

It is, therefore, imperative for any rechargeable scheme to have first hand information obtained/required about the water saturation and permeability of the vadose zone/weathering zone before undertaking execution of ground water recharging works. This information is very much rare in its availability. It may also be mentioned that available storage in weathered zone in hard rocks is very much linked to baseflow fluctuations in local streams.

10.2 WATER HARVESTING IN HARD ROCK REGION

The hard rocks such as basalts, granite, quartzites, limestones etc. occupy nearly 65% of the total geographical area of the country. The basaltic hard rocks form plateau region whereas granite rocks form hill ranges as inselbergs. The aquifer in hard rocks are characterized by low permeability and low specific yield. In hard rocks the framework of fracture system in which groundwater occurs is highly variable and aquifers are of heterogeneous nature.

Plateau Basalt

Basaltic rocks of Deccan occupy the most extensive tract of Western Peninsula covering large parts of the states of Maharashtra, Gujarat, Madhya Pradesh and Andhra Pradesh. Deccan basalts popularly known as Deccan Traps consists of vast pile of bedded lava flows. These lava flow beds have two district horizons, the lower one are massive and the upper are vesicular basalts. The massive part of basaltic rocks is hard and compact whereas the vesicular part is characterized by vesicles as cavities filled with secondary minerals. The massive traps are fractured and jointed at places. The weathering and fracturation of massive and vesicular basalts are favourable zones for surface and sub-surface storage.

Before embarking upon a purposeful ground water recharging programme it is imperative to understand in greater depth the vadose zone that exists between the ground surface and the fluctuating ground water levels.

By and large the hard rock areas have very limited yield by individual wells with variation in well discharge over short distances and poor quality of ground water in some areas.

Deccan Basalt Plateau

The Deccan basalt rocks have plateau like topography in West Central India. This cover about 5 lakh sq km area. These rock formations comprise many lava-flow rock beds which range in thickness from a few meters 9 to about 100 m. The plateau-like relief have two basic rock layers:

1. Angadaloided upper rock layer : Vesicular with bedded joints
2. Compact lower rock layer : Upper part with columnar & vertical joints & lower parts as massive & compact

The individual lava-flow beds are separated at places by clay zone called "Redbole horizon" which is a marker horizon that impedes the vertical infiltration of water.

A diagrammatic section through Plateau basalts having lava-flow beds is shown in fig-1, 1(a) and1(b)

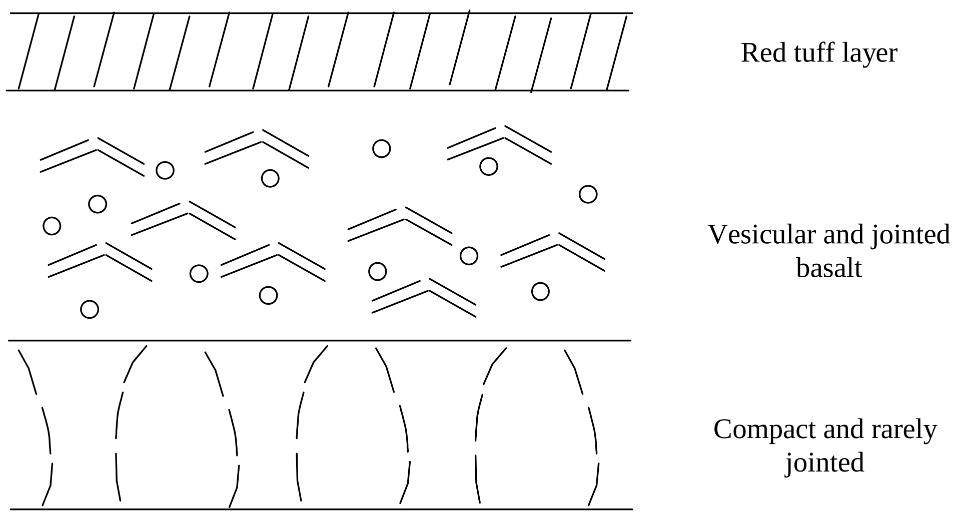


Fig.1- Basalt lava beds

Normally a basalt plateau section has repetitive sequence of alternating vesicular and compact basalt lava-flows that are horizontal bedded flows.

Weathering and Fracturation of Hard Rocks:

The fractures are only the conduit for refill and water transport rather than serving as space for storage of ground water. Therefore the vadose zone is only important as it is related to issue of storage of ground water. The fractures tend to close at depth and 100 m is approximately is the optimum depth within which potential aquifer water supplies are obtainable. Thus it is only the vadose zone which undergoes resaturation during infiltration of rain water or through other source of recharging water. This zone undergoes desaturation under drainage and evaporation. The vadose / weathered zone is important since the fracture porosity of hard rock is as small as 1% and therefore fracture zone alone is not considered productive zone unless it is connected with recharge boundary. Therefore weathered horizons play a dominant role for consideration of water circulation and recharge. The cracks in the weathered zones are often filled with concretionary material as Kankar. The recharge capability of basaltic rocks is greatly influenced by the overlaying thickness, texture and structures of the soil and their location with reference to topography and geomorphology of landscape units.

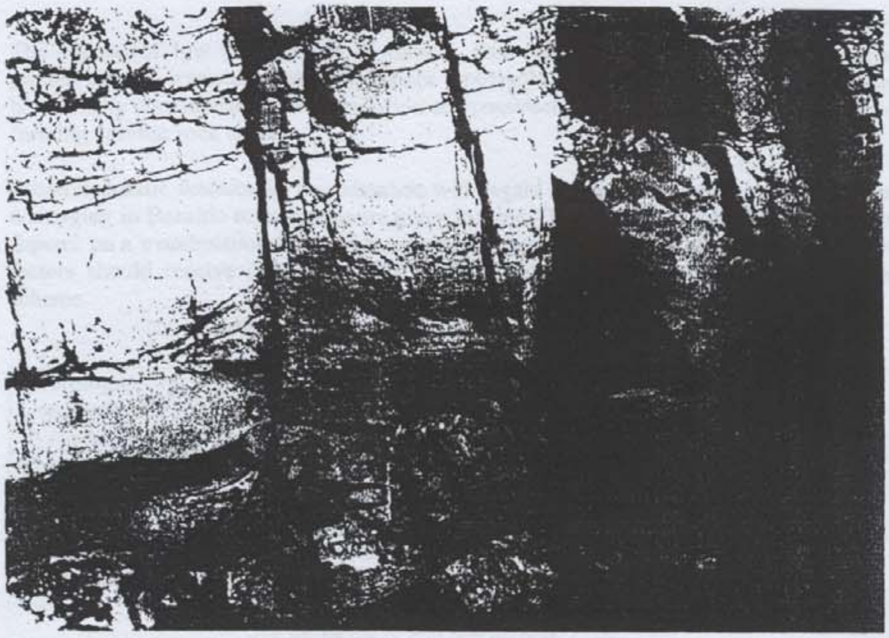


Figure – 1(a) Example of the compact lower layer of a lava sequence showing sub-vertical jointing

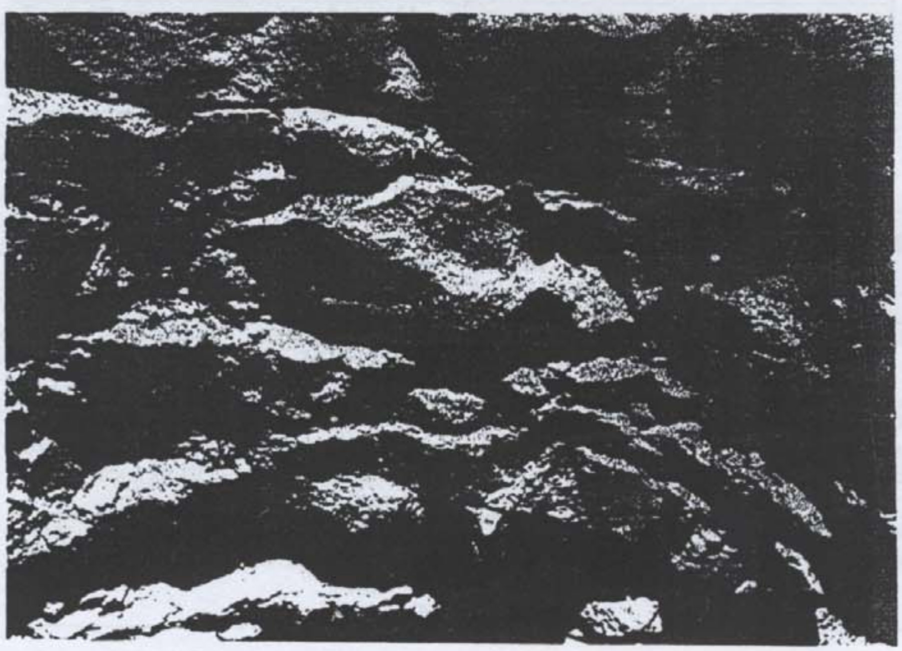


Figure – 1(b) Example of the amygdaliodal upper layer of a lava sequence showing sheet jointing

The feature of low permeability of Basalts, their multilayered occurrence, fractured and jointed natures, vesicular character besides topographic and other geological features are to be normally considered in the formulation and construction of recharging schemes in Plateau forming basaltic rock terrain.

Broad hydraulic features for consideration with regard to water harvesting and ground water recharging in Basaltic rock regions are given in table. The success of a recharge scheme will depend on a combination of various topographic and hydrologic situations. The following factors should receive consideration in the formulation of a water harvesting & recharge scheme.

Table : Topographic - Hydrogeological framework

Hydrologic Considerations	The weathered, fractured and vesicular basalts constitute most favourable hydraulic zones which need to be delineated on large scale maps.
Topography of Watershed area	The piedmont slopes constitutes the best topographic geologic environment followed by valley floors. Highly dissected slopes and plateau tops are less favourable.
Hydraulic conductivity of basaltic layers	The weathered, jointed and vesicular portions of basaltic rocks have high permeability and shall constitute favourable places in comparison to massive basalts that are less suitable for recharge and percolation.
Ground Water table and fluctuation in levels	The position of water table & its value of annual fluctuation
Thickness of Soil cover and infiltration rates.	Granular soil cover will have high infiltration rate in comparison to clay / black cotton soil that would impede infiltration and deep percolation.
Rate of Recharge	In favourable zones, fractured and vesicular basalts are expected to attain a recharge of 10 – 15% whereas in non-favourable zones, underlain by massive basalts the rates may be 2 to 3%.

Accordingly the topographic and geologic considerations that shall govern suitability of recharging works in Plateau forming Basaltic rock region are outlined below: -

Table: Framework for Topographic-Hydrogeologic Model for water harvesting & recharge

Topography	Areas / Region	Feasible Method
Plateau Area	Western Ghats	Pits, ponds and shafts
Highly dissected plateau slopes (gradients of 1 in 10 and more)	Narrow areas flanking hill ranges and ghats	Recharge shafts feasible locally.
Moderately dissected plateau, foot hills and piedmont region (gradients 1 in 10 to 1 in 100)	Areas between interbasin divides plateau and valley floors.	Recharge trenches, Nala bunds, contour bunds, percolation tanks and ground water dams.
Low lying valley areas (gradients of 1 in 100 to 1 in 500)	Valley floor of rivers (eg. Godavari, Bhima, Nira, Krishna etc. and their tributaries)	Water spreading basins and ground water dams (conservation structures)

Granite Hard Rocks:-

The weathered zone on granitic-gneissic rocks have primary porosity and permeability. The jointed and fractured character of such rocks exhibit secondary permeability determined by the fracture density and fractures frequency as well as infiltration numbers, which are the product of these to factors. The weathering process serves to enlarge the fracture and joint openings. The topography, depth of weathering and degree of fracturation and jointing have large influence on the occurrence and infiltration and recharging capabilities of such hard rocks.

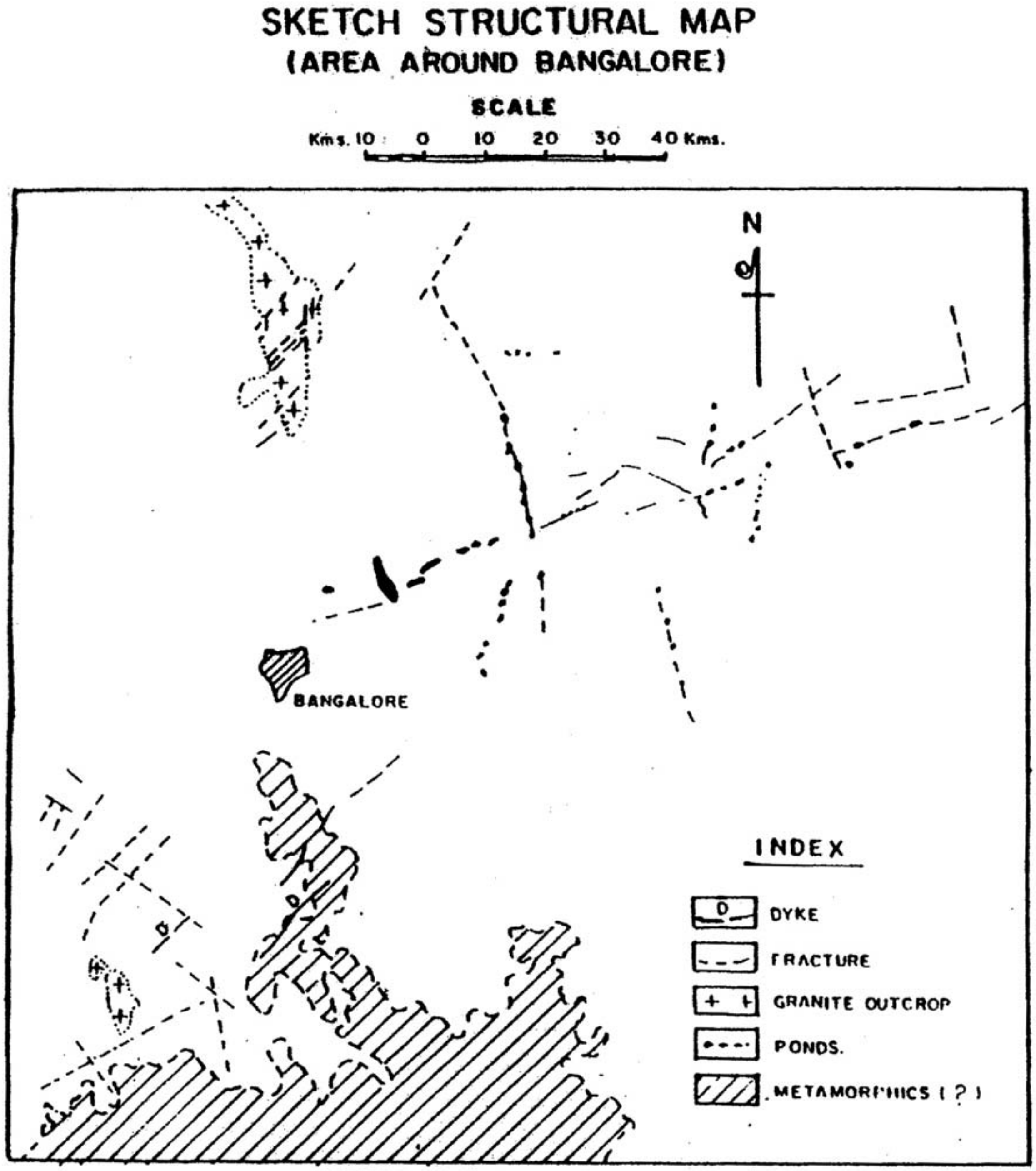
The Water-table representing top of reservoirs generally lies in disintegrated rock materials. In the lower part of the ground water aquifers, the water occurs in the interconnecting fractures by seeping through overlaying weathered material. A layer of residual soil and weathered rock lies in the fresh and massive rock in most places. The thickness of soil and weathered rock ranges from few meters to as much as 30 meters.

The watertable in such rock-terrain have a hill and valley relation that more or less confirm with surface topography although the watertable may be somewhat flatter. In such a terrain over hard rocks, a river could be the surface expression of water table in a valley but beneath a hill the watertable may be 10 to 25 meters below ground surface. The natural movement of ground water is relatively short and is almost everywhere restricted to the zone underlying the topographic slope extending from a divide to adjacent stream. Thus a good understanding of landscape units is prerequisite to understand mechanism of recharge over granite hard rocks. The aerial photos and remote sensing imagery provide imaginative overview in the identification of features and selection of areas for construction of appropriate recharging structures.

The fracture-trace mapping and satellite lineament mapping and the mapping of zones of weathering have great role in the delineation of potential sites for recharging of groundwater. The another factor which is of great relevance to the recharge mechanism in hard rock is the time and space distribution of storage. The shallow storage takes place in weathered hard rocks that occur at shallow depth. The deep storage is the state of ground water in aquifer whereas storage at or near the land surface comprises interception or detention storage on the upper part of vadose zone. The storage at the surface is in the form of ponds. A satellite based area of fracture over granite gneissic hard rock around Bangalore is shown in figure-10.1. It can be seen that the ponds have alignment along topographic depressions caused by rock fracture alignments.

From above mentioned facts it considered essential pre-requisite to conceptualise a topographic – hydrogeologic framework of a hard rock region before identifying and evaluating sites for ground water recharging and water harvesting. A generalized geologic cross-section of such a terrain shall show a phenomenon of local flow system which has its recharge area at “topographic high” in hills occupied by hard rocks and its discharge area in “topographic lows” occupied by a stream. As a rule the regional flow shall have its recharge at the basin divide and it discharge areas at the valley bottom.

The geomorphic, tectonic and geologic considerations for the sustainability of a Recharge Scheme over crystalline hard rocks are outlined below: -



INTERPRETATION (From landsat colour composite)

FIG : 10.1

S.No.	Geomorphic Conditions	Method Feasible for Recharging Hard Rocks
1.	Piedmont surface (a gently slopping plain with shallow weathered hard rock	Percolation tanks and sub-surface dyke.
2.	Burried piedmont on undulating plain having deep weathered hard rocks	Infiltration dams and percolation ponds.
B	Tectonic Features; folds & faults	Recharge methods feasible; zones of direct infiltration
1.	Lineaments and fractures intersection in topographic low areas / valleys	Sub-surface dams and percolation tanks.
2.	Area between dykes as vertical geological barriers	Check dams / percolation tanks.

10.3 GIS OVERLAYS ANALYSIS

A geographic information System (GIS) may be used as it is an automatic method to evaluate the potential of an area for recharging ground water especially over hard rock regions since most information of use is derived from high resolution satellite imaging and aerial photo interpretation. This method enables ranking the potential of an area on the basis of "Recharge Favourability Score" by using statistical relationship among factors that are assumed to be related to ground water recharge. The recharge favourability score should be evaluated as per table given below: -

Factors No.	Recharge Favourability Score	Map Scale	Source of Data
A	**Topographic Factors**		
1.	% Slope or weighted average slope.	1:25,000	Digital Terrain Model
2.	Soil factors/land surface altitude.	1:25,000	Topographic maps
3.	Weighted average soil permeability or infiltration	1:20,000	Soil Maps
B	**Geologic Factors**		
4	Lineament intersection	1:25,000	Satellite images; LISS III & PAN
	Fracture trace intersection	1:50,000	Satellite images
5.	Fracture density/Fracture frequency and infiltration numbers	1 to 2 m resolution data	High resolution Satellite data; LISS III, PAN & IKONOS imagery
C	**Geomorphological Factors**		
6	Ridge & Valley	1:25,000	Enhanced Satellite images e.g. ETM + images
	Piedmont surface buried pediment, zones of weathering	1:50,000/1:25,000	Air photos/Satellite images

D	**Hydrologic Factors**		
7	Existing surface water ponds/ tanks	1:25,000/1:50,000	Satellite images, LISS III & PAN IKONOS Images
8	Perennial character of streams, gaining and losing reaches in stream courses	High resolution images	Images / Maps / Photos
E	Factors of Saturated thickness of weathered zones	High resolution images	Satellite imagery

It is recommended to use invariably, the following remote sensing broad criteria while deciding to locate sites for recharging ground water over hard rock terrain.

1.	Detailed Geomorphological Mapping	Mapping and delineating of weathered zones and assigning of depth classes.
2.	Mapping of Fractures and lineaments	Identification of open and close fractures through digital enhancement that control stream segments.
3.	Compiling the drainage network	Joint – trellis drainage Fault – trellis drainage
4.	Mapping Dyke rocks and their orientation	As vertical geological barriers / permeability zones.
5.	Correlation of data with Aeromagnetic map of the area if available	Aero-magnetic anomalies and correlation with lineaments and faults
6.	GIS overlay Analysis	Production of area / zone maps of varying recharging possibilities.