WORKSHOP

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Hydrological Problems of Hard Rock Region

by
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1.0 Introduction

`Water is a prime natural resource, a basic human need and precious national asset. Estimation of water resources is therefore, a prime requisite for planning and development. Planning of Water resources require adequate knowledge about the region and its geology. It is a known fact that about 65% of the total land area is covered by hard rocks (fig.1). Both surface and groundwater are to be used conjunctively to meet the water requirements of the area, which often became more acute due to recurring droughts. Due to the wide distribution of hard rocks in Central and Southern India the whole behavior of the nature and hydrologic process varies from other parts of the country due to the unique nature of hard rocks, i.e., they devoid of primary porosity but have been rendered porous due to weathering and fracturing. The weathering zone is extensive within depths of 10 to 20 m but is localised down below with increase in fracture porosity. The calcareous members like clay gneisses and marbles have been subjected at places to solution.

1.1 Definition of `Hard Rock'

Among the geologist and hydrogeologist, still there is no consensus in defining the `Hard Rocks'. In general, Hard Rocks are those geological formations the drillability of which is low and the intergrannular porosity is practically absent. Larsson et al (1987) defined `hard rocks' as igneous and metamorphic, non-volcanic and non-carbonate rocks. Gustafson and Krsany (1993) accepted the same approach. yet, hydrogeologists may feel inefficiency of such definition and its limited content due to the fact that also other rock types (especially well cemented sedimentary rocks often occurring in areas built also by crystalline rocks) may be characterized by the same geological environment as crystalline rocks themselves. Moreover, it is often impossible to define exact geological boundary between `hard rocks' and some other rock types. Therefore, in many hydrogeological studies, the term `Hard Rock' is used in a wider sense but rather vaguely and not exactly defined. Recently, Gustafson (1993) proposed that the term `hard rock' might, from a groundwater exploration point of view, include all rocks without sufficient primary porosity and conductivity for feasible groundwater extraction.

1.2 Hydrology of Hard Rock Area

The main characteristic feature of Indian hydrology is the concentration of rain in major parts of the country in some months during the monsoon season. During the non-rainy months, the river flows dwindle and many of them dry up. There is a need to impound the

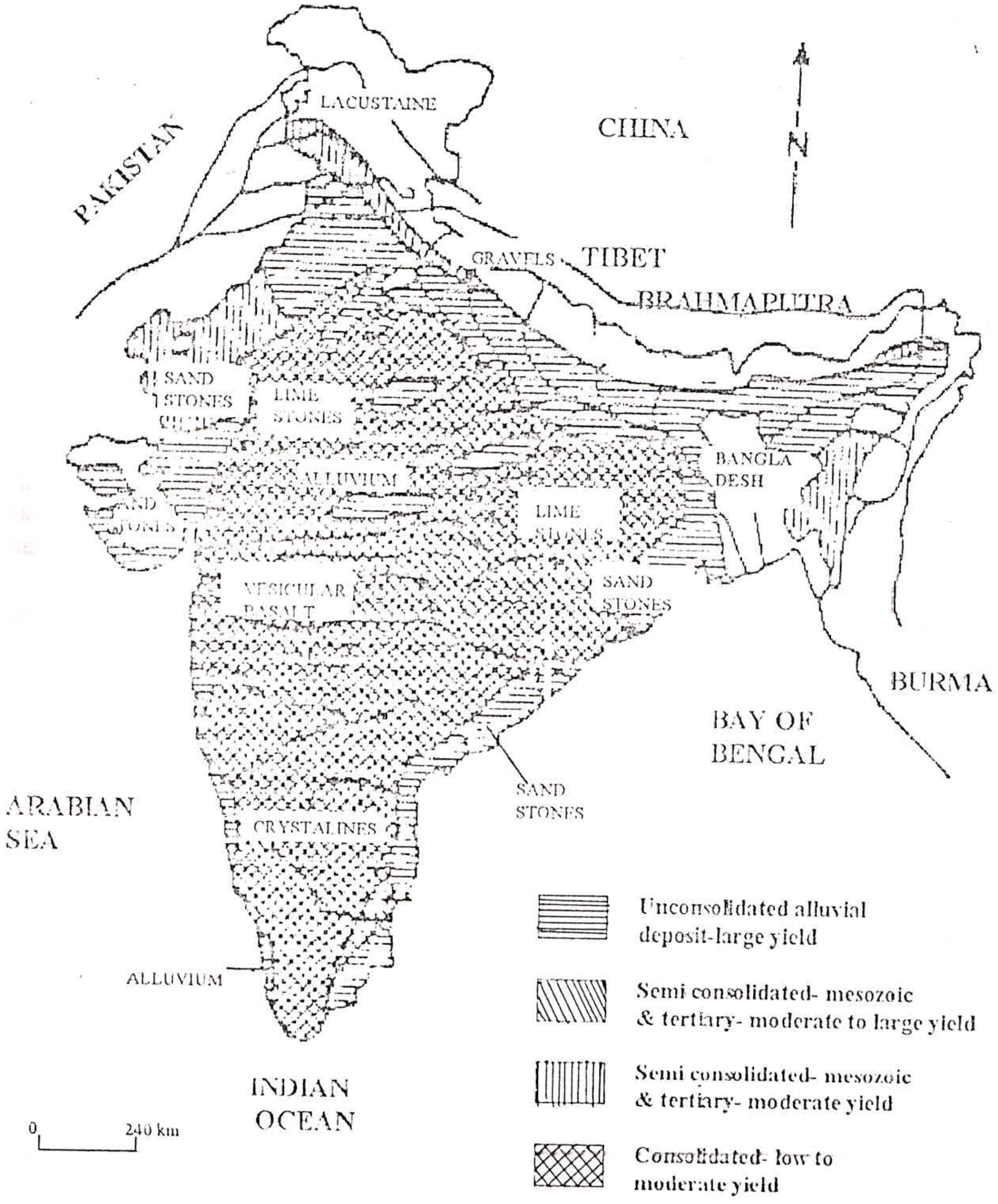

Fig. 1. Hydrogeological map of India.

water in reservoirs for subsequent controlled releases. The quantity of average annual flows of major river basins and the possibility of impounding it through reservoirs in the hills and dams in the plains, with groundwater potential and its recharge, decides the extent of irrigation.

From the distributions of annual and seasonal rainfall, it is evident that heavy rainfall is confined largely to the southwestern, eastern and the northeastern portions of the country. The central region and the Gangetic Plain lie in the zone of moderate rainfall, while the north Deccan and adjoining areas receive heavy rainfall towards the end of the monsoon season. Thus, the north Deccan and adjoining areas receive heavy rainfall towards the end of the monsoon season (Subramanyam, 1988).

The regional distribution of rainfall over the Indian subcontinent is highly uneven and shows wide variations (Hartmann and Michelsen, 1989). Thus, at one extreme it has two zones of excessive rainfall comprising the Western Ghats and the outer slopes of the Himalayas. The annual rainfall in these areas is varying form 1800 to 5000 mm. Next, in order of annual rainfall but larger in area is the belt with the annual rainfall varying between 800 and 1800 mm. The whole of Madhya Pradesh, the eastern half of Hyderabad, the Eastern Ghats and the Coastal Plains of Karnataka with a narrow belt on the summits of the Western Ghats are included in this zone (Raghavendra, 1980). The third zone is rest of peninsula having less than 750 mm of rainfall per year and in certain limited tract even as little as only 250 mm. The failure of rains is less common in those areas that have annual average rainfall 750 - 1500 mm because of lower precipitation variability (10 - 20 %). But when they occur at all they prove very destructive due to the dense population, small land holdings and the lower classes of agricultural population in those areas.

The eastern districts of Andhra Pradesh and Tamilnadu receive most of their rainfall from October to December due to severe cyclonic storms that form in the central and the southern bay of Bengal and move west or north west across the peninsula. Then it enters in the Arabian Sea and change their course northward causing heavy to very heavy rainfall along the western coastal areas. But since the rivers in this region are short and wide, the floods produced by such rains last for no more than one to two days pose little threat and do not cause much damage.Western Ghat, from which most of the southern rivers originate, is not as high as Himalayas. Moreover, the region through which these rivers flow is a table and formed by hard volcanic rocks (Deccan traps), which have withstood the rigors of sun and rain for ages. The rivers of the peninsula are of great antiquity, compared to the youthful rivers of the extra peninsula are of great antiquity, compared to the youthful rivers ;of the extrapeninsular area, and their river channels have reached the base level of the erosion. Godavari, Krishna and Cauvery are the three major rivers in this region.

Major portion of the Deccan basalt of hard rock region in India is semiarid. Due to insufficient surface water, groundwater has been an essential element in meeting domestic, agricultural and industrial demands. Two water - bearing zones can be generally identified in this hard rock area (Narasimhan, 1990; Briz-Kishore, 1993; Ranganath, 1982): The composed or weathered zone and water bearing joints and fractures. In the weathered and decomposed part of bedrock, groundwater occupies the intergranular spaces of the formation material. The yielding capacity of this zone is often limited and is seasonal in character. The groundwater flow systems are of local type, where each local system has its recharge area at a topographic high and its discharge area at a topographic low, which are adjacent to each other. The intermediate and regional groundwater flow systems do not exist because of negligible hydraulic conductivity with depth. The crystalline rocks generally do not possess original or primary openings, and fresh crystalline rocks have less than 1 per cent porosity and negligible hydraulic conductivity. The ability of crystalline rocks to store and transmit water is dependent on the development of secondary openings which were formed by fracturing and weathering. The weathered part of these crystalline rocks is of particular importance both as storage zone for groundwater and as aquifer for open wells and shallow tube wells,(Deolankar, 1990; Uhl and Joshi, 1986).

The occurrence and movement of groundwater in Deccan basalt of hard rock region are controlled by the fracture pattern. The fracture porosity forms the main criteria in defining the ground water flow system. Fractured zone generally constitute the potential aquifers and therefore the geometry of the fractured aquifer system assumed considerable importance while exploring the groundwater in hard rock terrain. Hence, the exploration, development and management of groundwater in the hard rock basaltic terrain are very important. Groundwater in these regions occurs under unconfined and semiconfined conditions. The presence of vesicles, fractures, zeolites, intertrapean redboels and tuffaceous formations give rise to varying magnitude of porosity in the basalt. The aquifer transmissivity ranges from 2 to 140 sq. m /day, the higher values which were noticed over fractured and jointed basalt. Aquifer resistivity ranges from 10 - 30 ohm m over alluvium and 20-60 ohm m over weathered basalt (Narayanpethakar et al., 1997).

The hydrology and groundwater resources in Deccan Traps have explained by many hydrologists. As per the wok done by State Department of Mines and Geology, Karnataka (1975), the black trap is hard, compact and consist of few blow hole sand is traversed by joints to shallow depth and joints had persisted only upto 10 - 15 m depth. Beyond this depth, the rock becomes more and more compact and fresh presence of such massive variety of trap was noticed approximately from 630.6 m contour and below. Weathering extended hardly 0.5 to 1.0 m depth. The depth for the water in the well varied from 2 to 10 m. While, the pink trap appealed tobe better aquifer. They are weathered to an average depth of 12 to 15 m and were having more blowholes and amygdoloidal structures which were filled by secondary minerals like zoeolites and silica. More of fractures and fissures were noticed which helps to retain water percolation, after rainfall. Pink t raps are seen at an approximate altitude of 660.6 to 675 m above M.S.L. and extended approximately upto 630 m contour. The depth of water table in such formation varied form 6 to 12 m depending upon the topography. Figure 2, shows the lithology of the wells and the geological formation of the hard rock region in general.

In the Deccan trap, the ground water occurs under water table conditions in weathered and jointed traps, and under confined conditions in the zeolitic and vesicular traps wherever they are overlain by hard traps. Depth of weathering in general varied from 2 m to 18 m. Wells ranged in depth from 3.7 to 17.8 m bgl and depth to water table ranged from 1.10 to 16.2 m bgl. The yield of dug wells ranged from 20 cu. m / day to 250 cu. m /day for the pumping period of 2 to 8 hrs. Wells in valleys nearer to nallas and in zeolitic traps yielded better. The inflow rate varies from 0.58 lpm / sq. m to 1.2 lpm / sq. m for recuperation period varies from 1380 minutes to 1175 minutes and in vesicular trap the inflow rates of 1.1 lpm / sq. m to 1.2 lpm / sq. m for recuperation period of 70 minutes and 1260 lpm. The transmissivity figures obtained by the Pappodopulos and Cooper method ranges from 21.5 sq. m /day to 150 sq. m /day. The specific capacity of the wells ranges from 2.42 to 19.13 cu. m /h/m and unit specific capacity in the range of 0.039 to 0.1995 cu. m /h/m. Deccan trap does not contribute appreciably to tube well yield, and the contained water can be tapped only by constructing large-diameter well. In most cases, this zone is entirely shut off by the lining in a tube well. The saturated fractures and joints found in the relatively unweathered bedrock at greater depths are capable of yielding a substantial quantity of water. The fractures and joints are mostly horizontal in nature and interconnected with a network of joins and fissures. The yield from these zones is not readily affected by seasonal changes. In the granite and genesis of south India, such saturated zones are normally encountered at depths ranging from 10 to 50 m. In tectonically disturbed areas, they may even occur at greater depth of 100 m or more. These saturated zones areas usually weathered and have a small vertical extent of a few tens of centimeters. The normal yield of a tube well tapping such zones is around 5.5 cu. m/h. Very low yields of about 450 -900 liters /hour are frequent where as quite large yields up to 90,000 liters /h have been reported from a few isolated tube wells. In the consolidated or fissured formation, the occurrence of ground water is restricted to weathered residue and fracture zones having secondary porosity, and the yield is above 20 cu. m /h in the Mesozoic and Paleozoic formations , while it goes down to 5-20 cu. m /h and even below 5 cu. m /h in the Precambrian and Archaean formations.

In general the groundwater potential of hard rocks is poor, through relatively high yields may be obtained in restricted locations under favourable circumstances of topography and rainfall. The zone and the frequency of openings in fractured rocks are normally restricted to shallow depth resulting in low void ratio and hydraulic conductivity. Exceptionally carbonate rocks develop solution channeling with high hydraulic conductivity and yield, particularly in zone of past and present water table fluctuations. The drainage d3eveloped in individual lava flows during intertrappean periods give rise to productive zones, under favourable conditions of topography with high conductivity and yield.

Intensive exploratory drilling in igneous and other hard rock in parts of peninsular India have showed that the openings at greater depth, becomes less pronounced and less abundant and in some cases they are not favourable for movement of ground water . Relatively higher yields from hard rocks are obtained within 40 to 50 m. Depth from surface. Optimum depth drilling beyond which is normally not warranted is about 100 meters while rock type is commonly of secondary importance to the control of weathering and structure. The geometry of the fracture or joint sets is determined by the types of the rock and the stress to which they have been subjected, besides the effect of weathering and relief which makes the void space constituting the system progressively larger on approaching the surface. The topographic conditions and the rainfall regime maintain a high level of saturation in the hard rocks. Thus topographic lows and high rainfall will offer better advantage, although latter factors are insufficient to ensure favourable conditions. Every situation must be considered in the light of the relative influence of the controlling factors. Nevertheless, the water table and the top of the flow system will show generally sympathetic relationship to the topography. The degree of sympathy will be governed by the hydraulic conductivity, the closer water table and topography relationship.

2.0 Major Hydrological Problems in Hard Rock areas

2.1 Hydrological network design for all basins in hard rock region

Network design for hard rock area requires a special attention, as the hydrological variations are quite drastic from place to place. Design criteria should include the number of data acquisition points and their locations. Hydrological data should include hydrometeorological, stream gauging, sediment gauging and ground water levels. For Hard Rock Region network design cannot be the same as other regions because the hydrological variations are quite drastic from place to place. Rao et al. (1983) have mentioned that in many cases, the network design has been done purely from the point of meeting a specific purpose. If such stations are continued thereafter, they become part of a national network.

The study of network and their design is a subject that is common to many sciences. Hydrologists have been mostly involved in the studies of linear networks, particularly for examination of stream system. Rodda (1969) stated two basic scientific problems in network design. The first is to determine how many data acquisition points are required, and second is where to locate them. The general approaches to network design have seemed to fall into two important broad categories viz. the regionalisation and system analysis approaches. The regionalisation approach deals with the distributed rather than the point values and with treated data rather than in their original form. It can be applied to the study of hydrological variables that are not easily mapped. The system analysis approach is based on the optimization of the some goal, subject to constraints imposed upon the system.

Rao (1979) by using WMO norms worked out the number of gauge and discharge station to be set up under immediate and ultimate stages for major river basin of hard rock region as shown in table. 1.

Table 1. Number of gauge and discharge station to be set up under immediate and ultimate stages for major river basin of Hard Rock Region.

Sl No.	Major River Basin	Basin Area sq. km	Types of the region	Networks as per the norms for intermediate stage	Existing Key Station	Ultimate key station
1	Godavari	3,07,840	1,07,000 hilly 2,00,840 flat	336	39	107 80
2	Krishna	2,56,390	1,56,390 hilly 1,00,000 flat	52 15	36	156
3	Pennar	54,700	Flat	9	2	22
4	Cauvery	82,270	Flat	13	7	33

However, no consensus has been yet arrived by scientific group regarding the establishment of network station for various purposes in a hard rock terrain. Therefore, it is necessary to take up such pilot studies to recommend the network design.

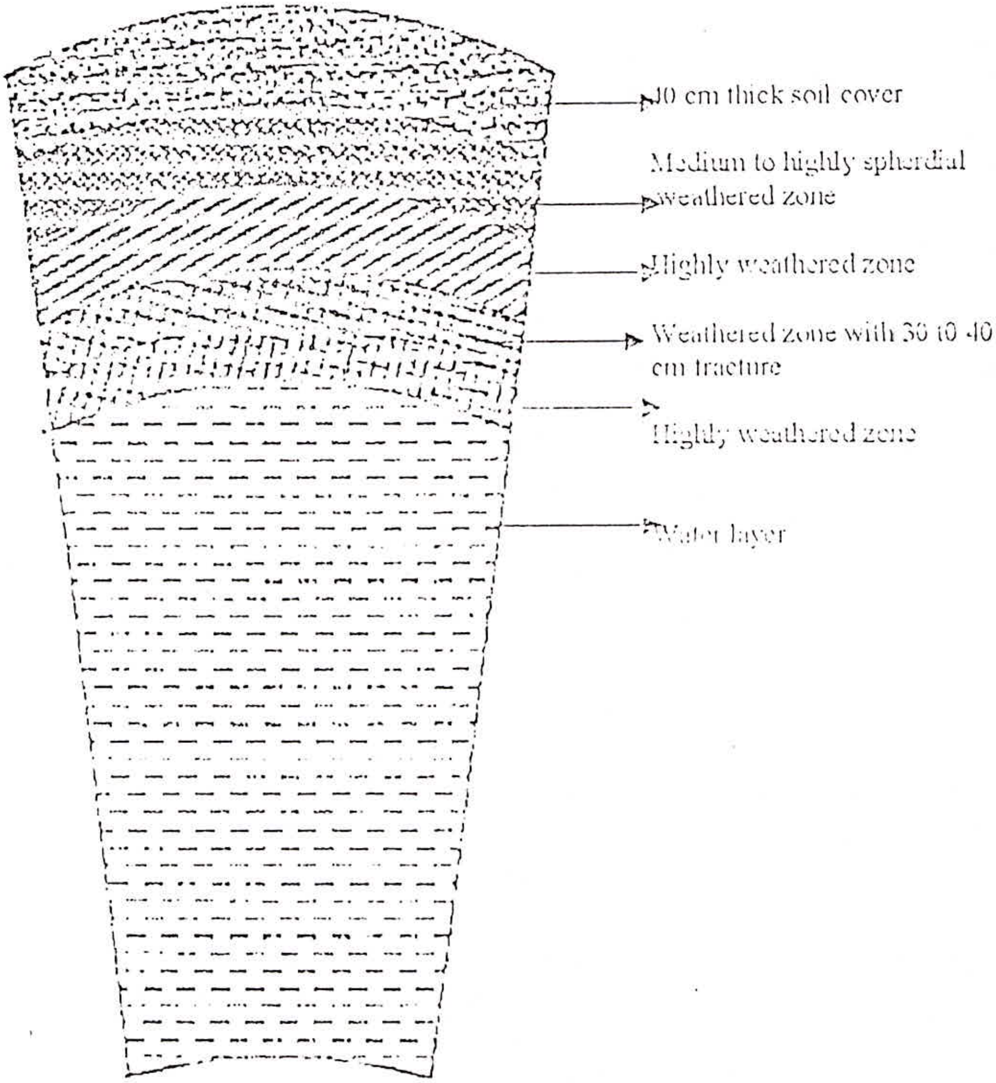

Fig. 2. Cross-Section of an Open Well.

2.2 Groundwater quality

Groundwater quality poses a serious health hazards in various parts. The major contaminants found in this region are high concentration of chloride, sulphate, sodium and bicarbonate. In addition to salinisation problem on of the most serious problem is fluoride Main problematic areas are Mundarrgi taluk of Dharwad district, Sindhanur and Sirguppa of Bellary district and Pavagada and Madhugiri of Tumkur district and Saundatti taluk in Belgaum district.

Handa (1975) reported high fluoride concentration in semi-arid and arid parts of India. especially, in Nalagonda, Anantpur, Chittor, Medak and Nadigama taluk in the Krishna district, Vishakhapatnam and Hazurabad taluk in Karim nagar district(all in Andhra pradesh) and in some parts of Tamil nadu and Karnataka. Nitrate is also a common problem in parts of Hard rock area.

However, modelling of ground water quality in a fractured media need immediate attention by the scientific community. Studies are ongoing in various parts of the country.

2.3 Failure of Open and Borewells

Failure of open and borewells in many parts of the hard rock region are common phenomenon. This problem usually arises, either because of the over abstraction in existing wells or due to the failure in identifying the exact water bearing zones. As in the hard rock region water mainly exists in fracture and joint, locating such zones and predicting the flow processes is a difficult process. Such problems are quite common in northern districts of Karnataka and in many parts of the Tamil Nadu.

In general, failure of open wells can be attributed to three distinct categories: quantitative, qualitative or both. Quality failure occurs when even though ample groundwater storage is available and it cannot be utilized for various purposes due to excessive chemical, biological and other contaminants. Quantitative failure is the outcome of the disbalance between yield and human exploitation of groundwater. Here the concept of safe yield is introduced. Safe yield is defined as the amount of water which can be taken from the aquifer indefinitely without producing an undesirable result, hydrologically it is almost the water which under normal circumstances leaves the basin as a natural base flow. Exploitable groundwater resources are closely linked with safe yield. It can be a maximum value close to the live storage, and are limited only by the technical problems of setting an adequate systems of bore wells to utilize the groundwater to the maximum value or it can be actually exploitable groundwater resources governed by technical, environmental and legal requirements on the minimum baseflow and or minimum groundwater level. Undesirable results occur when the ground water storage cannot be replenished by a natural recharge in a reasonable period of time, or when a prolonged abstraction results in the intrusion of saline water, or in deterioration of water quality. Such problems are quite common in hard rock areas due to its low infiltration and permeability characters. Studies should be taken up to explore the ideal situation for artificial recharge of ground water.

2.4 Regional Flood Formulae

The main objectives of hydrological studies of flood is to develop appropriate procedures in order to arrive a desired design variable for he particular structure tobe safe under extremes of floods without leading to over design and consequent increase in cost. One of the common methods of estimating the design flood for the design of bridges and culverts especially in small catchment is by the use of frequency analysis of annual peak flood data recorded at site under consideration. The flood frequency analysis procedures are based on general statistical and probabilistic concept and the data used in such analysis has to satisfy the criteria of homogeneity , independence, randomness and time invariance. Flood frequency analysis for a river basin site with a long record can be based almost exclusively on that record alone. Unfortunately many of the streams in small catchments have not been gauged or very scanty data are available at the site. When only short records or no records are valuable, the need for procedure for augmenting site-specific hydrologic information with regional information arises in order to improve upon or stabilize site specific estimates or to make inference at un-gauged river basin sites. The need for such procedures is particularly great in the estimation of extreme hydrologic events where a combination of limited site data and need for inference in the tails of probability distributions unite to destabilize such estimates. The regional analysis approach can provide estimate of floods for a limited data and ungagued locations, through appropriate regional multiple regression relationships of statistical parameters of the flood series and catchment characteristics. The choice of catchment, morphometric characteristics depends on the (i)Judgement of the likely predictive success of variables, and (ii) Numerical calculations of regression equations and the interpretation of their coefficients. Development of regional flood formulae is one of the important tasks in the hard rock region as there are major rivers; viz, Godavari, Krishna and Cauvery are flowing through it.

2.5 Groundwater balance

In hard rock region, there is a growing demand for the groundwater resources as the surface water resources as the surface water resources are not available adequately. Hence, there is an urgency to quantify the availability of groundwater resources required to meet the demand. The water balance technique has been extensively used to make quantitative estimates of water resources and the impact of man's activities on surface and groundwater.

The development and management of any ground water basin in a scientific manner involves the groundwater balance or hydrological balance analysis as a first step. Groundwater balance study enables the assessment of quantity of water available for development and assists in predicting the consequences of artificial changes in the regime of groundwater basin. Groundwater balance studies are effected in order to ascertain the quantity of water available for development in a region and this can be done only after identification of the various physical features of the hydrologic system involved their hydraulic characteristics and their hydraulic inter-relationship. Clearly, after the groundwater system is fully understood, the results can be combined with the data regarding the amounts of water transiting the stream network in the relevant region as well as precipitation in it in order to furnish the basis of a water balance analysis. Knowledge of water balance assists the prediction of the consequences of artificial changes in the regime of the groundwater basins. In the hard rock terrain the main problem is estimation of various components needed for water balance calculation. For the accurate determination of water balance components, a detailed field and laboratory investigations are required which in most of the time becomes difficult.

2.6 Tank studies

The tanks have existed in India from earliest times, and have been an important source of irrigation, particularly in the semiarid tropics of South India. Minor irrigation tank widely distributed in many parts of Karnataka, Tamilnadu, Andhra Pradesh and Maharashtra to meet the water requirement. Percolation tank is a common structure in the State of Maharashtra to stores surplus surface water during rainy season and recharge ground water for sustained and better yield of dug well. Although tank irrigation can be found in all parts of India, it accounts for over 30 % of the total area irrigated in Andhra Pradesh, Karnataka, and Tamil Nadu State. Among these States, the percentage of area irrigated by tanks is highest in Tamil Nadu (Palanisami and Easter, 1983).

However, the purpose of construction of tank has not been fully utilized. Therefore it is essential to take up the studies to estimate the yield and other related hydrological parameters which are typical for hard rock regions.

2.7 Reservoir sedimentation

Soil erosion and reservoir sedimentation are the threats to the water resources development in our country. One of the important aspects of planning of reservoirs is the sediment brought down by the rivers. This is particularly important in view of the fact that there are limited storage sites and, as such, it is imperative to derive ways and means to prolong the life of reservoirs and to ensure that realistic assumptions about the rate of sedimentation are made at the planning stage itself.

2.8 Hydrological aspects of drought and development of drought indices

Hydrological drought indices are concerned with the effects of rainfall deficiencies on hydrological components such as surface water, groundwater and soil moisture. The development of hydrological drought indices in the form of numerical numbers (indicative of drought) occurrences are not many, but more complex statistical and stochastic hydrologic models are found in the literature. Various researches have defined the hydrological drought e.g. Whipple (1966) defined a drought year as one in which the aggregate runoff is less than the long term average runoff. Yevjevich (1967) defined the term hydrologic drought as the "deficiency in water supply or deficiency in precipitation, effective precipitation, runoff or accumulated water in various storage capacities. Linsley et al. (1975) defined hydrologic drought a "Period during which stream flows are inadequate to supply established used under a given water management system".

Drought is reported very frequently in states like Karnataka, Maharashtra, Tamil Nadu and Andhra Pradesh. In order to assess and to quantify the severity of drought, it is essential to develop a drought index for regional estimation.

2.9 Forest Hydrology

Forests influence the various hydrological parameters viz., rainfall, interception, infiltration, soil moisture, evapotranspiration, groundwater, water yield, soil loss and floods etc. In this direction, a detailed study is required on forested catchments especially in parts of Western Ghats. Impact of Forest cover on groundwater recharge with particular reference to hard rock region is a major task before the before the forest hydrologists.

2.10 Drainage problems in black soil areas

Several types of drainage situations have been identified depending upon the type of aquifer (whether confined or unconfined) and other related field situations. In practice, the water table is lowered either by installing tiles or by digging drainage ditches or wells thorough which water can be pumped out at a specified rate. For designing a proper drainage system, it is necessary to develop simplified mathematical relations to quantify both the water flow rate and the amount towards a ditch or well. The condition may also be associated with recharge through rain or irrigation.

Drainage problem, particularly in irrigated heavy soils, is caused by over irrigation or by surface runoff resulting from excess rainfall. The solution depends mainly upon the ratio of precipitation to the rate of downward flow through the soil system consisting of poorly previous layer and the presence or absence of a pervious sub-soil. Therefore, it is necessary to develop a suitable model for estimating field drainage from heavy land. This kind of problems had been reported from black soil areas of Maharashtra and Karnataka. Due to the drainage problems in black cotton soil areas, soil salinisation and water quality problems are quite common. Waterlogging in number of canal command areas are also quite often in hard rock terrain.

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