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HYDROLOGICAL PROBLEMS OF HARD ROCK REGION
(A State - of - Art Report)

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (UTTARANCHAL)

PREFACE

During last three to four decades, there have been considerable developments in different fields of the hydrological sciences. Physiographically, India as a whole can be divided into three distinct features; (i) The mountainous region of the Himalayas the extra-peninsula, (ii) The great Indus-Ganga-Brahmaputra plains and (iii) The triangular plateau of the peninsula. The hydrogeological framework of India has been divided into three major categories, namely; the areas underlain by unconsolidated formation, the areas underlain by semiconsolidated formation and the areas underlain by the consolidated formations. Almost the entire peninsular region is occupied by the consolidated formations ranging in age from Archean to Tertiary. The Archeans generally include the schistose formations of the Dharwar systems, gneiss, charnockites etc., while the Precambrians include the Cuddapahs and the Vindhyans.Consolidated formation involves the hard rock terrain also. Eventhough, there is no exact definition what does hard rock mean, it is generally understood by all geologists that hard rock are crystaline, i.e. igneous and metamorphic rocks. Hard rocks (crystalline rocks) such as granites, gneisses, basalt, and indurated pre-Cambrian sediments cover approximately 75 per cent of the total area of the India. Considering the wide distribution of hard rock in Southern parts of the country and the erratic hydrological behaviour of the hard rock terrain, National Institute of Hydrology established a regional centre to tackle the hydrological problems associated with the hard rock areas of the country.

During various meeting of the Regional Co-ordination Committee, which comprises of the field engineers from different State/Central Government organisations within the region, an urgent need has been felt to discuss about the various hydrological problems on the suitable platform, which leads to identification of thrust areas for research. Keeping, this view, it is decided to prepare the status report on the hydrological problems such as Hydrological Network Design, Groundwater Quality, Failure of the Open and Bore Wells, Regional Flood Formulae, groundwater balance studies, tank studies, Reservoir Sedimentation, Hydrological aspects of drought, Forest hydrology and Drainage problems of Black soil of the hard rock terrain etc.

In this report, the literature related with the problems were collected from various States and Central Government organisations as well as Universities. This report has been prepared by Mr. Dilip G. Durbude, Scientist 'B, Regional Centre National Instituite of Hydrology, Belgaum. I am sure that this document would prove to be very good reference source for academic community as well as field engineers dealing the above problems in the hard rock region.

(K.S. RAMASASTRI)
DIRECTOR

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1. Introduction

1.1 What Does "Hard Rock" Mean?

It is well known that no general agreement has been reached among hydrogeologists about, which types of rocks should be considered for "hard rock" from hydrological point of view. Even though there is no exact definition what does hard rock means, it is generally understood by geologists that hard rocks are crystalline, i.e. igneous and metamorphic rocks. Some hydrogeologists took over this concept also. e. g. Larsson et. al. (1987) defined "hard rocks" as igneous and metamorphic, non-volcanic and non-carbonate rocks. Gustafson and Krasny (1993) accepted the same approach. Yet, hydrogeologists may feel insufficiency 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 characterised by the same hydrogeological 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 Gustafsson (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.

It is obvious, that from the hydrogeological viewpoint, hard rocks should incorporate also part of "other rocks". Regions built up by crystalline and highly cemented sedimentary rocks are often characteristic by a great variety of petrographical rock types: there are magmatic rocks from granites to basic rocks, metamorphic rocks such as different types of gneisses, migmatites, mica schists, phyllites, granulites etc., and shales, graywackes, quartzites, sandstones and conglomerates as the principal representatives of sedimentary rocks. From the differences in petrographic composition of rocks and their different way of weathering and fissuring also differences in hydrogeological properties have often been considered and expected. Hydrogeological environment controlling groundwater occurrence and movement is determined by its internal character (its anatomy - type and distribution of porosity) which consequentially determines the spatial arrangement - geometry (horizontal extension and thickness) of hydrogeological bodies (aquifers and aquitards). However, the type of hydrogeological environment is almost or entirely independent of these geological features. This is particularly the case of "hard rock" environment.

Objective comparison of prevailing transmissivity magnitude of particular crystalline and highly cemented sedimentary rocks indicated certain differences in distinct areas. The majority of statistical samples of transmissivity values treated during the hydrological mapping programs were classified by low transmissivity (IV) class, i.e. prevailing transmissivity ranging from 1 to 10 m^2/d with moderate to large transmissivity variation (Krasny, 1993). Therefore, crystalline (igneous and metamorphic) rocks and sedimentary highly cemented and/or folded rocks belong to the same type of hydrogeological environment. These can be characterised by a regionally extended "aquifer" in the near-surface (sub-superficial) zone of rocks occurring more or less conformably to the land surface regardless its lithological (petrographical) composition.

There are obvious indications that some thin-bedded highly cemented sediments as for instance shales or siltstones are of similar average permeability or may even be better permeable than some heavy-bedded well cemented sandstones (or quartzites) which till now have often been traditionally regarded better permeable in general. This is e.g. the case of some Flash regions and Permocarboniferous basins. In these areas results of regional hydrogeological studies have not confirmed higher prevailing permeability and transmissivity of sandstones by comparison with shales and siltstones (Krasny, Kullman, Vrana et al. 1987, Krasny 1976). That means the occurrence of the near-surface aquifer of prevailing fissure porosity as in "hard rocks".

Following these considerations hydrogeological hardrock environment (sometimes designated as "hydrogeological massif") can be characterised by three decisive features as defined by Krasny (1996b):

- Upper or weathered zone [formed by regolith, talus and/or Quaternary deposits where intergranular (interstitial) porosity prevails]. The usual thickness is some meters but under special conditions this zone may reach even many decades of meters
- Middle or fissured zone [formed by more or less regularly (from the regional point of view) fissured bedrock with prevailing fracture porosity] The usual thickness is some tens of meters
- Lower or massive zone [formed mainly by a massive bedrock with usually isolated deep-seated faults or fault zones]. Sometimes mineral and thermal water ascends along them.

The above mentioned upper and middle zones in hardrock environment form together the principal regionally extended "near-surface" aquifer occurring more of less conformably to the land surface. The thickness and character of this composite and heterogeneous aquifer, however, changes from place to place particularly in relation to petrography of respective rocks and their tectonic deformations (faulting and fissuring), character of their weathering and, morphological and climatic conditions. The thickness of this aquifer usually reaches up to a few or more tens of meters. Permeability decreases in general downwards. It is just this aquifer which is decisive for the magnitude of regional groundwater runoff and, consequently, natural groundwater resources formation. The near-surface aquifer usually enables better groundwater abstraction possibilities as well.

At the end conclusion can be drawn that from a hydrogeological point of view to a "hardrock" environment ("hydrogeological massif") should belong crystalline (igneous and metamorphic) rocks and sedimentary highly cemented and/or folded rocks. As often in natural sciences, however, it is difficult to define the exact boundary between different types of rocks.

1.2 Hard Rock Regions in India

Physiographically, India has the following three distinct features;

(1) The mountainous region of the Himalayas- the extra peninsula

(2) The great Indus-Ganga-Brahmaputra plains and

(3) The triangular plateau of the peninsula.

The extrapeninsular and peninsular regions are unlike to each other in every respect. The peninsular region has more or less remained, from the dawn of the geological history, a solid mass with no marine sedimentation during the Cambrian. The extrapeninsular region had continuous marine sedimentation almost throughout its history from the Cambrian period (Krishnan 1975). The peninsular shield is essentially made up of an Archean basement complex of Gneiss, Granitoids, Charnockitites etc., metasedimentary and metabasic rocks of Dharwar system, followed by rocks of Cuddapah and Vindhyan systems. Deccan traps of large thickness occupy the west-central part of the shield. The Gondwana rocks occupy the rift systems in the peninsular shield. Relic mountains and flat and shallow valleys

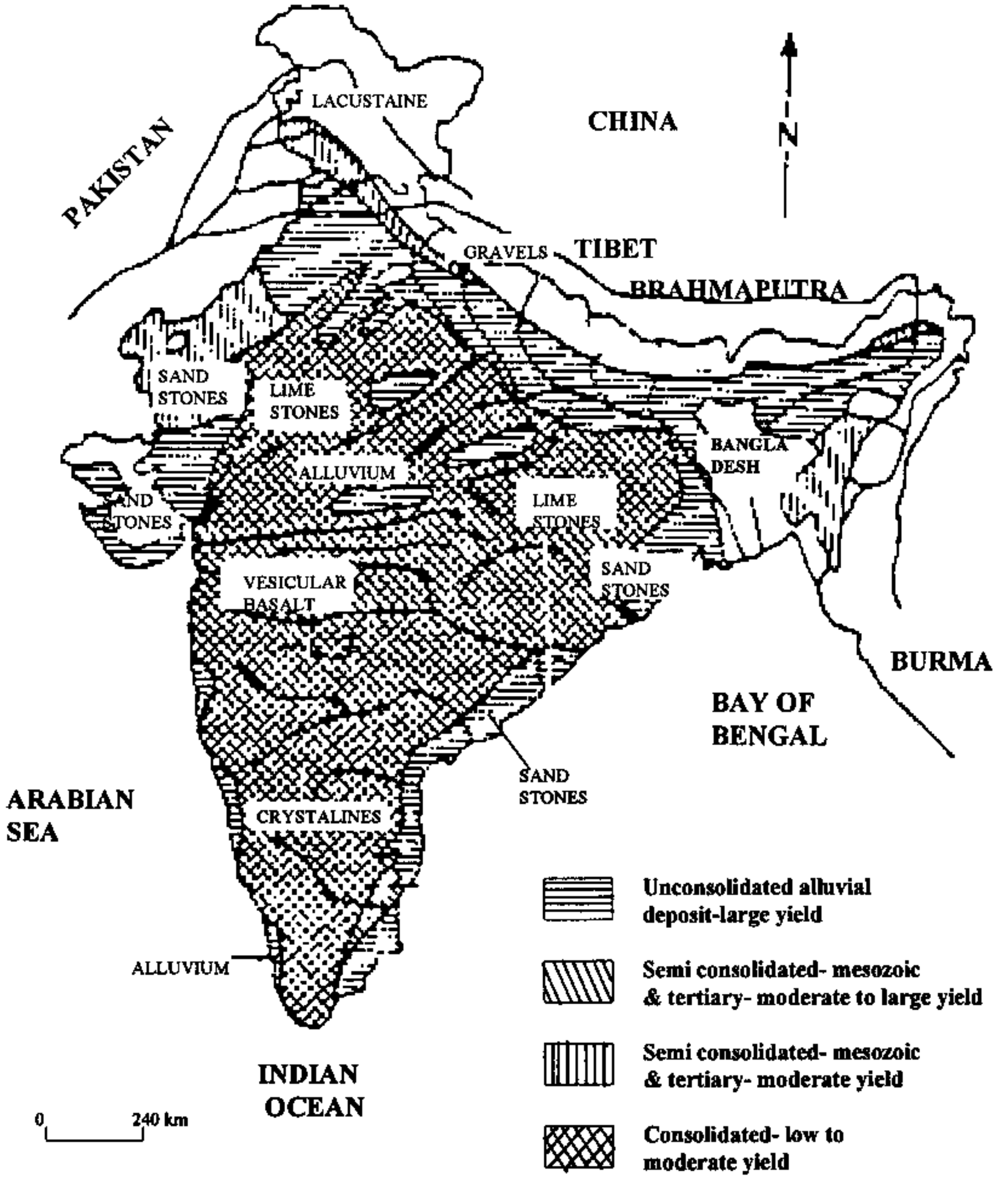

Fig. 1. Hydrogeological map of India.

characterize the peninsular region in contrast to the lofty mountains, deep valleys, and torrential rivers marking the extrapeninsular region.

In India, groundwater has also been exploited substantially during the past few decades for irrigation. Most of the ground water utilization in India is from shallow aquifer zones at depths less than 100m. Based on the mode of occurrences and availability, ground water is mainly governed by geological formation, the nature and extent of aquifer bodies and hydrogeoligcal properties in relation to ground water flow characteristics. Thus, the hydrogeological (Chaturvedi 1982, Ranganath 1982) framework of India has been divided into three major categories (fig.1): (1) the areas underlain by unconsolidated formation; (2) the areas underlain by semiconsolidated formation; and (3) the areas underlain by the consolidated formations.

The unconsolidated and semiconsolidated formations are porous formation, the consolidated formation are characterised as fissured (Narasimhan, 1990). Almost the entire peninsular region is occupied by the consolidated formations ranging in age from Archean to Tertiary. The Archeans generally include the schistose formations of the Dharwar systems, gneiss, charnockites etc., while the Precambrians include the Cuddapahs and the Vindhyans. The Deccan traps range in age from Upper Mesozoic to Lower Tertiary and are well jointed, fissured, vesicular, and massive. The sedimentaries and metasedimentaries belong to Cenozoic, Mesozoic and upper Precambrians systems and are composed of sandstone, limestones, shales, slates, quartzites, etc. Hard rocks (crystalline rocks) such as granites, gneisses, basalt, and indurated pre-Cambrian sediments cover approximately 75 per cent of the total area of the Indian subcontinent. The area covered under Hard Rock Region includes Karnataka, Parts of Andhra Pradesh, Tamil Nadu, Madhya Pradesh and Maharashtra.

The Deccan Traps cover 85 per cent of the area of the state of Maharashtra. Two main types of basalt occur-the compact or nonvesicular basalt without gas cavities, and the amygdaloidal basalt with gas cavities filled with secondary mineral. All basalt is non-porous and can hold water only in open divisional planes. The only divisional planes in the basalt of Maharashtra are contraction joints. These are present in compact basalt and they can store large quantities of groundwater when the pattern of jointing is for a proper delineation of area suitable for groundwater development (Karmakar et. al., 1997).

In Karnataka State the Dharwar schist belt exposed in northern part of Dharwad district consist of schistone greywacke overlain by varigated shale (Bhat and Hegde, 1997). Dharwars are the complex series of crystalline schists, quartzites, conglomerates, limestones, and agrillaceous sediments with volcanic flow, pyroclastic debris, basic silts and other minor intrusives. The main rock types are hornblende schists associated with phyllites, quartzite, actinolite schists and pyroxene bearing gneisses. Peninsular gneisses are mostly migmatitic, biotite gneisses and gneissio granites. The rock unit encountered in the area of Ilkal of Bijapur district dominantly consist of pink granites, dyke rocks, metavolcanics, schistose rocks, banded iron formations and granitic gneiss. The granitic gneisses form one of the major lithounit of the area, and are exposed in the form of tors and pediments. Unclassified crystalline hard rock complex has been found in the area of Peddavagu river basin in Ranga Reddy district of Andhra Pradesh. Different type of granitoid rocks constitutes the basin, which is traversed by numerous dolerite dykes and veins of quartz, feldspar, pegmatite and epidote. Lineaments control weathering and fracturing (Venkat Reddy and Raju, 1997).

Tamil Nadu comprises various geological formations ranging in age from the Archean to recent. The crystalline rocks of the Archean age like grinites, gneisses, charnockites and associated intrusives are of specific interest for groundwater development Pink and Grey grinites are exposed in South Arcot, Coimbatore, Madurai and Tiruneveli districts. Hard rocks comprising of granites, gneisses, basalts and consolidated sedimentary rocks (Sand stone and limestone) occupy major portions of Andhra Pradesh also.

2. Hydrology of Hard Rock

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 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 from 1800 to 5000 mm. Next, in order of annual rainfall but larger in area is the belt with the annual rainfall varying between 808 and 1800 mm. The whole of Madhya Pradesh, the eastern half of Hyderbad, 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 the 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 Tamil Nadu 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 enteres 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 rigours of sun and rain for ages. The rivers of the 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-Kishor, 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 don't 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 besalt of hard rock region are controlled by the fracture pattern. The fracture porosity forms the main criteria in defining the ground water flow systems. 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, intertrappean red-boles and tuffaceous formations give rise to a varying magnitude of porosity in the basalt. The aquifer transmissivity ranges from 2 to 140 sq. m/day, the higher values of 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 work done by State department of Mines and Geology, Karnataka (1975), the black trap is hard, compact and consists of few blowholes and is traversed by joints to shallow depth and joints had persisted only upto 10 to 15m depth. Beyond this depth, the rock becomes more and more compact and fresh presence of such massive variety of trap was noticed approximately from 630.6m contour and below. Weathering extended hardly 0.5 to 1.0m depth. The depth for the water in the well varied from 2 to 10m. While, the pink trap appeared to be better aquifer. They are weathered to an average depth of 12 to 15m and were having more blowholes and amygdoloidal structures which, were filled by secondary minerals like zeolites and silica. More of fractures and fissures were noticed which helps to retain water percolation, after rainfall. Pink traps are seen at an approximate altitude of 660.6 to 675m above M.S.L. and extended approximately upto 630m contour. The depth of water table in such formation varied from 6 to 12m depending upon the topography. Figure 2 shows the lithology of the wells and the geological formation of the hard rock region in general, (extracted from the report on failure of open well by Majumdar et al., 1997).

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 2m to 18m. Wells ranged in depth from 3.7 to 17.8m bgl and depth to water table ranged from 1.10 to 16.2m bgl. The yield of dug wells ranged from 20 m^3/day to 250 m^3/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/m^2 to 1.2 lpm/m^2 for recuperation period varies from 1380 minutes to 1175 minutes and in vesicular tarp the inflow rates of 1.1 lpm/m^2 to 1.2 lpm/m^2 for recuperation period of 70 minutes and 1260 lpm. The transmissivity figures obtained by the

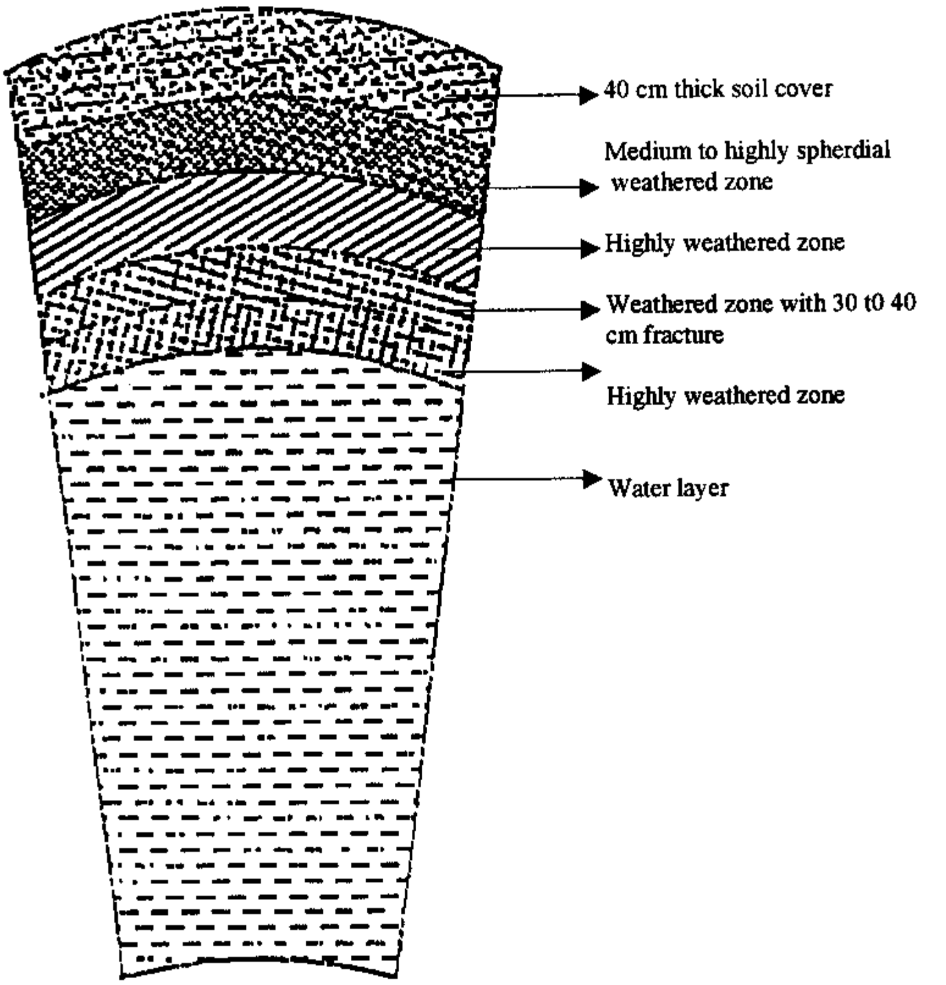

Fig. 2 Ground Lithogy of Hard rock region

papadopulos and Cooper method ranges from 21.5 m^2/day to 150 m^2/day. The specific capacity of the wells ranges from 2.42 to 19.13 m^3/h/m and unit specific capacity in the range of 0.039 to 0.1995 m^3/h/m. Deccan trap doesn't contribute appreciably to tube well yield, and the contained water can tapped only by constructing large-diameter wells. 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 joints and fissures. The yield from these zones is not readily affected by seasonal changes. In the granite and gneiss 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 are 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 m^3/h. Very low yields of about 450-900 liters/hour are frequent, whereas 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 groundwater is restricted to weathered residue and fracture zones having secondary porosity, and the yield is above 20 m^3 / h in the Mesozoic and Paleozoic formations, while it goes down to 5-20 m^3 /h and even below 5 m^3 /h in the Precambrian and Archean formations.

In general the groundwater potential of hard rocks is poor, though relatively high yields may be obtained in restricted locations under favourable circumstances of topography and rainfall. The size 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 zones of past and present water table fluctuations. The drainage developed 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 it 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 condition 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.

3. Hydrological Problems of Hard Rock Region

India is the seventh largest country in the world with diverse climates, topography, geology, soil types, land cover and land use pattern. The water resources of India are enormous but they are unevenly distributed in several terms: seasonally, regionally, basinwise, cultivator class-wise and cropwise. Due to the lack of national water resource budgeting and planning, famine in vast tracts of western and southern peninsula plateau region and floods in northern and eastern India ravage the lives of millions of Indian farmers and result in crop losses running into several tens of millions of rupees year after years. Famine, especially scarcity of drinking water is causing havoc in hard rock region i.e. Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu (Katchwana, 1981). An overview of India's total available water resources reveals that they are much below the natural capacity and technical feasibility.

Drought in a semiarid area of hard rock region is due to low rainfall and low irrigation in dry regions. Around 87 talukas in 12 districts of Maharashtra, covering one third of the state's cultivated area, and 88 talukas in Karnataka spreading to two thirds of state's cultivated areas, classified as drought prone are today the hot bed of drinking water and fodder shortages (Desarda 1987). Creating and utilising irrigation potential is the major policy issue form the point of view of the highest possible exploitation, maximum utilization, and salvaging of drought areas from crop damage and depletion of cattle. Of the basic water resources of 185 million (mn) ha/m, 105 are usable; after meeting the domestic and industrial demands, 77mn ha/m is left for irrigation i.e. just 20 per cent of the water yields from rain. Viewed in terms of the irrigable land area, it is 113.5 mn ha/ m or nearly 60 per cent of the gross cropped area. However, there is a regionwise difference in the ultimate potential. The percentage of the gross cropped area, that can be ultimately irrigated, varies from 17 per ecnt in Himachal Pradesh to 85 per cent in Punjab. The ultimate potential of the four states of the dry region from surface sources is not more than 35 per ecnt. The variations have also been noted among the states with respect to the percentage of the potential tapped so far. In the case of Karnataka, Maharashtra and Andhra Pradesh, half of the potential remains untapped (Chatterjee 1967). In the face of the famine, under which large parts of Andhra Pradesh, Maharashtra, Karnataka and Gujarat are reeling currently, the importance of developing protective irrigation cannot be overemphasized. Indeed, it a vital necessity.

Contamination of natural water is a serious problem posing the humanity during the past several years. This is related directly or indirectly to various anthropogenic activities. As more groundwater extraction systems are installed, sufficient attention has to be given to the geochemical reaction that occur both naturally and as a result of human activities, before adequate groundwater recovery can be designed and implemented. The groundwater occurring in the shallow aquifers contain fluoride in many places, the concentration of which varies and people use this water for drinking. This is creating a serious dental problem among the children of the rural folk.

All above variation in the geomorphological features as well as geohydrological differences makes a variety of hydrological problems in this heterogeneous physiological unit of peninsula. To take care of these problems of this regions, the scientist/ researchers have to develop an understanding of the specific problems of this area and conduct hydrological studies of interest to this region using new and modern techniques. The following hydrological problems /studies have been identified in this hard rock regions,

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.

2. Groundwater quality of hard rock region

Groundwater quality poses a serious health hazards in various parts of hard rock région. The major contaminants founds in this region are high concentration of fluoride, chloride, sulphate, sodium and bicarbonate.

3. Failure of Open and Borewells in hard rock region

Failure of open and borewells in many parts of the hard rock region are common phenomenons. 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.

4. Regional Flood Formulae

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.

5. Groundwater balance

In hard rock region, there is a growing demand for the groundwater 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.

6. Tank studies

Minor irrigation tanks are widely distributed in many parts of Karnataka, Tamil Nadu, Andhra Pradesh and Maharashtra to meet the water requirement. However, the purpose of construction of tanks 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.

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.

8. Hydrological aspects of drought and development of drought indices.

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.

9. Forest Hydrology

Forests influence the various hydrological parameters viz., rainfall, interception, infiltration, soil moisture, evapo-transpiration, 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.

10. Drainage problems in black soil areas

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.

3.1 Hydrological network design for all basins in hard rock region

Network design enters into most aspects of hydrology. For economic and optimum utilization of water resources, a determination of extent and availability of surface and ground water is the first requisite and this in term requires adequate hydrological and hydrometeorological data. Long term hydrological and meteorological data provide the basis for all hydrological studies and determine the major aspect of hydrological and hydraulic design of water utilization projects. Inspite of considerable effort in the pursuit of hydrological knowledge, there is still remains uncertainty in aspects of hydrologic cycle. Quantification of any hydrologic resource or process can be performed only with limited accuracy, and thus plans for hydrologic control and development must make provisions for this lack of information. In fact there is no substitute for hydrologic information.

Hydrologic network serves an important and fundamental role in the scientific management of water resources. Ideally the network should themselves be designed as scientifically as possible. The definition of a network for hydrological data acquisition is a matter of some controversy. It is clear that the network should satisfy the demands by the principal users of hydrological data for scientific and practical purposes. According to Rodda (1969), a 'Hydrological network' is a program for systematically acquiring information, processing and disseminating it in a like manner. This description of network is somewhat akin to Langebein's definition 'A network is an organized system for the collection of information of a specific kind. Its component parts must be related to one another; i.e. each station, point or region of observation must fill one or more definite niches in either space or time'. Thus the definition of a network for hydrological data acquisition is a matter of some controversy. One way of avoiding controversy might be to employ a definition similar to suggest for hydrological data. Following that example, 'a hydrological network is one which provides data commonly used by the hydrologist.

The ideal network design would incorporate knowledge concerning the physical and stochastic nature of the hydrologic processes into a framework that accounts for the effects that the data will have on future water resources decisions. It should be stressed that network design is an iterative process. Any design should be reevaluated and updated periodically. The data that are collected change the designer's perception of the use of the data. The information flow from an associated network may change because of changes in the network. Also, a better technique design may become available.

Hydrological data should include, hydrometeorological, stream gauging, sediment gauging and ground water level monitoring. For Hard Rock Region network design requires a special attention, as 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) mentions 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. Some of the approaches and methods used for the network design of some major and minor rivers of hard rock region is discussed below,

3.1.1. Raingauge network design

A network of Raingauge stations is intended to serve one or more of the purposes such as water supply, hydropower generation, irrigation, flood control etc. The setting up of Raingauge networks is a long-term process. The purpose of data collection and the level of information required changes as the level of development of the region changes. for example, the information required for design and construction purposes would be more than that for mere inventory purposes; and would be certainly much more for operation and management purposes such as reservoir regulation, flood control and flood forecasting.

Raingauge networks are generally set up for,

i) Climatological or water balance studies

ii) Flood forecasting

iii) Weather modification evaluation

Due to lack of scientific norms, many network densities are being decided on empirical and subjective consideration. The Indian Standard Institute (ISI 4987-1968) suggested that one Raingauge upto 500 km^2 might be sufficient in non-orographic regions. In regions of moderate elevation (upto 1000m above sea level) the network density might be one Raingauge for 250 km^2 to 400 km^2. In predominantly hilly areas and areas of heavy rainfall, the density recommended was for 130 km^2.

Further, in 1972, ISI with Indian Meteorological Department had recommended a simple formula based on Rycroft (1949),

$$N = (C_v / p)^2$$

Where, N is the number of Raingauge, C_v is the coefficient of variation of the rainfall of existing Raingauges and p is the percentage permissible or desired error of accuracy.

The World Meteorological Organization in 1974 has recommended the minimum network densities for general hydrometeorological practices, which is given as follows,

(i) For flat regions of temperature, mediterranean and tropical zones-one station for 600-900 km^2

(ii) For mountainous regions of temperate, Mediterranean and tropical zones-one station for 100-250 km^2

(iii) For arid and polar regions-one stations for 1500-10000 km^2 depending on feasibility

Karmegam and Kulandaiswamy (1975) have been critically reviewed the available method viz., Benton method, Rational method, Ahuja's methods etc. of determining the required number of Raingauges for a drainage basin and the rational method is proposed to determine the number of gauges for a given basin. Adequacy of the existing network for six of the river basins of Tamil Nadu has been investigated using various methods. The analysis was based on i) annual mean rainfall and ii) monthly mean rainfall. The existing network in the basin considered compare well with Benton's method. However, they are inadequate when compare with Raingauges obtained by all the other methods. The rational method is recommended for the design of any Raingauge network. A modification of Ahuja's method of distributing the required number of gauges over the basin has been suggested taking into account the depth of rainfall to be measured and is applied to one of the six basins to distribute the gauges designed by the rational method.

Jones et al. (1979) and Bastin et al. (1984) have used the optimal estimation approach. Jones et.al. used this approach for preparation of maps of root mean square error of point interpolation for suggesting procedures for determining the accuracy of estimation of areal rainfall for any shape of area and any configuration of gauges. While, Bastin et al. used an optimal estimation approach for the real time estimation of areal average rainfall. For this purpose, the rainfall has been modeled as a two dimensional random variable. The variance was minimised by using the Kriging technique. It was shown that the method could be used for optimal selection of the Raingauge locations in a basin. Further, in 1981 Mooley and Ismail used the same optimum estimation approach to determine the network density required for the various limits of tolerable error in the areal estimates of monthly, seasonal and annual rainfall for different size areas in Vidarbha region of Maharashtra State. Rao et al. (1982) studied the Raingauge network design for Wainganga Basin, a sub-basin of Godavari River in Maharashtra State. A computer programmes for the estimation of areal rainfall on the basis of Stepwise Multiple Regression technique was used. This study concluded that the prediction equation on the basis of multiple correlation coefficient is capable of estimating the areal rainfall which is quite comparable to that computed by arithmetic mean method by taking all the station into consideration. This method determines an objective manner, the relative importance of each station in terms of multiple correlation coefficient so that most important stations may be retained in the network and the least important ones can be discarded. It can be very effective in identifying important Raingauge stations in each catchment so that their proper maintenance, recording and quick reporting of rainfall data can be ensured for flood forecasting purposes.

Since hydrologic information almost always is measured in a parameter specific sense, i.e. the information is inversely related to the error of estimation of one or more hydrologic parameters. For computing the error in estimation of areal rainfall, Kagan (1966) had suggested a procedure, which could be used as a criterion for determining the optimum network density of Raingauges as given in Appendix I. In 1986, Mehra had also used the Kagan's technique for determining the Raingauge network for 'Purna catchment' in Tapi basin.

The same technique of harmonic analysis and the concepts of distributed linear systems had been applied by Eagleson (1967) to the problem of optimum density of rainfall networks for flood forecasting purposes. Specification of network density for the study of long term catchment average rainfall was accomplished by consideration the long term point rainfall as a homogeneous random variable to be sampled spatially. The incorporation of the catchment dynamics into the design of flood forecasting networks reduces the number of gauges needed when compared with those obtained by mere consideration of precipitation variability.

Venkateswara Rao et al. (1988) studied raingauge network of Sarada river basin. There was only 4 rain gauge station in Sarada river basin prior to the year 1985 and were located in the plain areas. Seven more rain gauges are installed as per the ISI optimum network standards at various locations in the basin considering topography, monsoon and other climatic conditions. About 20mm variation of rainfall is observed between the old and new rain gauge networks. Two years of data variation proved the importance of optimum rain gauge network in estimating the water resources potential of the basin.

3.1.2. **Stream gauge network design**

General W.M.O. consideration concerning streamgauging station network defines three categories of hydrological networks (WMO Guide, 1976), as follows

Category (a) For flat regions of temperature, mediterranean and tropical zones where the drainage area is in between 3,000 to 5,000 km^2, the minimum stream gauge density recommended as one station for 1,000-2,500 km^2. But the countries where it is difficult to achieve due to lack of development of communication facilities, or for other economic reasons, the density of the stream-gauging network may be reduced to one station for 3,000 to 10,000 km^2.

Category (b) For mountainous regions of temperate, Mediterranean and tropical zones, the drainage area where the catchment area is 1000 km^2, one station for 300-1000 km^2.

(iii) For arid and polar regions, one stations for 1500-10000 km^2 depending on feasibility.

Though WMO norms provide useful guidelines for general network design but it does not consider the effect of man's development activities in the river basins. Benson's study indicates the likely course of action for dealing with network design problems considering the parameters such as population, per capita income. Area of land and water, relief, mean annual precipitation, surface water withdrawals, average annual growth in population, integrated area, precipitation range areally of mean annual precipitation and number of hydroelectric plants. Appropriate methodologies would have to be developed for specific regions of the country considering climatic factors, physiographic factors, population and other indices of water resource developemnt.

Rao (1979) mentions about existence of very few gauge and discharge sites in India prior to 1947. It was only during the second half of the century that observation sites were set up on large scale. For immediate implementation of network, the norms given by the WMO have been modified as below:

(a) Flat areas: One station for (3,000+10,000)/2 or 6500 km^2

(b) Hilly areas: One station for (1,000+5,000)/2 or 3000 km^2

(c) Arid zones: One station for 30,000 km^2

Using these modified norms and WMO norms, Rao (1979) 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 table1.

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 (km^2)	Types of the region	Networks as per the norms for intermediate stage	Existing Key station	Ultimate key station
1.	Godavari	307,840	107,000 hilly	36	39	107
			200,840 flat	3		80
2.	Krishna	256,390	156,390 hilly	52	36	156
			100,000 flat	15		40
3.	Pennar	54,700	Flat	9	2	22
4.	Cauvery	82,270	Flat	13	7	33

There are different types of network of stream gauging stations such as minimum, saturation and optimum network. In 1981, Rao et al. applied the physical- statistical method combine with the zonal characteristic approach to Krishna basin, which is one of the principal river basins of India. The stream gauge network of Krishna basin is arrived at by considering the criterion of reliability of interpolation of stream flow data at intermediate locations and examination of its adequacy for long term and short term requirements. Stream gauge network of Krishna basin has been evolved for different sets of conditions of variability and relative errors. In this approach, the catchment has been divided into various zones based on similarity of climate, topography etc., which are regarded as homogeneous areas, and network norms are derived for each of such zones. For determination of stream gauge network in Krishna basin the criterion of reliability of interpolation of stream flow data at intermediate location and examination of its adequacy for long term and short term requirement in respect of water resource assessment has been followed. It has been mentioned that the following three types of errors are possible in the estimate of average flow at a point on a stream;

(1) Interpolation errors

(2) Sampling errors

(3) Measurement errors

Two aspects mentioned above have been considered and the general principles adopted for the analysis are as given below.

(a) Determination of minimum area, which is not subject to, furthers interpolation.

(b) Consideration of linear gradient in mean annual run-off.

(c) Correlation of annual flows per unit distance between centers of drainage areas.

An optimum size of the gauging area per station is computed which will lie in between the gradient and correlation functions. This physical-statistical method while determining the basic required network stipulates the level of errors and variabilities for which the network is valid. The regional approach, in which the catchment could be divided into zones of similar climatic characteristics peculiar to the basin, is used for delineating those areas.

The parameters used for dividing the catchment into similar climatic zones are computed as per Koppen's classification. From these limiting values it was shown that the

Krishna basin falls broadly into two climatic zones. They are, (a) Tropical rainy with dry season (AW), (b) Warm temperature rainy (CW).

It has been recommended three variables, which can be used to supplement the above classification, for determining homogeneity:
(i) Uniformity of spatial variation of rainfall in the area
(ii) The distribution of coefficient of variation of rainfall
(iii) The gradient of streamflow along the river

Krishna basin is not prone to very large to year fluctuations of rainfall. The stream gauge network appears to be quite sensitive to the value of the stream gauge flow gradient chosen. The actual variation of streamflow with distance in Krishna catchment was studied and the area with uniform gradient of flow with Marukonda was chosen as part of this study. The steps includes in the physical-statistical method are given in Appendix II.

Further, Seth and Kumar in 1988, applied physical statistical method combined with zonal characteristics approach suggested by Karasseff (1972) and found that this method satisfies the condition with regard to spatial variation of normal stream flows and interpolation of stream flow data at intermediate points for a individual year. It considers the coefficient of variations of annual mean flows at the respective sites, correlation coefficient between them, streamlength between two gauging sites and permissible relative error.

3.2 Ground water Quality

Groundwater is an important source of water supply in many regions due to rapid growth of the world's population, which is placing an increasing demand upon fresh water supplies. Use of aquifers as operating reservoirs will require an understanding of water quality problems created by recharge of surface water into aquifers, underground waste disposal and infiltration of pollutants from surface sources into aquifers. In India the contribution of groundwater to irrigated agriculture is about 50 per cent and it meets a major part of drinking and industrial needs (Prasad, 1995). The problem of pollution in groundwater is much less as compared to surface water but still, it is not free from the menace of pollution. Based on physiographic and hydrological considerations, attempts have been made during the last 40 to 50 years to delineate different groundwater provinces in India (Auden, 1940; Taylor, 1959; Chatterjee, 1967; Mithal, 1969; Handa, 1964, 1975, 1984). It must however, be pointed out that quality of groundwater in the phreatic zone is not constant but varies considerably from time to time. Furthermore, in any one area, groundwater of different quality may occur due to local differences in geology etc. In general, water quality is describes whether or not the surrounding environment endangered by pollutants in the water.

In nearly every corner of the globe, men is making increasing demands upon his surroundings and thereby altering his own natural environment and that of the other organisms living with him on the earth. The demands are increasing not only because of the rapid growth of the human population but also due to increase in the living standard. The intensive use of natural resources and the large production of wastes in modern society often pose a threat to groundwater quality can take place over large areas from plane or diffuse sources like deep percolation from intensively farmed fields, garbage disposal sites, cemeteries, mine spoils, oil spills or other accidental entry of pollutants into the underground environment. A third possibility is contamination by line source of poor quality water, like seepage from polluted streams. Because ground water tends to move very slowly, therefore many years may elapse between start of pollution and its reflection in a well. For the same reason, many years may be required to rehabilitate contaminated aquifers after the source of pollution has been eliminated. This long delay can force abandonment of wells and may require costly development of alternate water supplies. Prevention of contamination thus is the best way for protecting ground water quality. Slow movement of groundwater, however, is a favourable factor when the contaminants are degradable (biological, bacteriological or radioactive contaminants) with time. In these cases long underground detention times may result in essentially complete removal of the undesired substances. On the other hand, slow movement causes long contact with the subsurface minerals, most of which are soluble in water and may cause natural degradation of subsurface water. Contaminated groundwater generally show increased levels of Cl^-, SO_4^{2-}, and Na^+ ions. Depending upon the redox potential, high level of nitrate or ammonia may also be present. Elevated nitrate levels upto 50-100 mg/L are not exceptional in contaminated ground water (Csaki and Endredi, 1981; Zoetman et. al., 1981).

Groundwater pollution is a modification of physical, chemical and biological properties of water, restricting or preventing its use in the various applications where it normally plays a part. In case of groundwater, it is usually traced back to four main origins:

1) Industrial pollution through used waters, which contains chemical, compounds and traces an elements like the breaking of a pipeline.
2) Domestic pollution through, rain infiltration through sanitary landfills, accidents like the breaking of septic tanks.
3) Agricultural pollution through irrigation water or rain carrying away fertilizers, minerals, salts, herbicides and pesticides.
4) Environmental pollution mainly through seawater intruding in coastal aquifers.

There are many sources that contribute contaminants to the groundwater zone. The major sources which contribute to the pollution problem are (i) land disposal of solid wastes (mostly garbage and industrial waste), (ii) Sewage disposal on land, (iii) Agricultural activities (iv) Petroleum leakage and spills, (v) Deep well disposal of liquid wastes and (vi) Urban runoff and polluted surface water.

Already groundwater pollution is noticed in patches all over the country especially in low-lying areas and in sandy soil formations. The following table shows the ground water pollution in the hard rock region of India.

Table 2. **Ground water pollution in Hard Rock Region**

Sl. No.	Pollutant	State	Places of occurrences (Districts)
1.	Fluoride	Andhra Pradesh	Krishna, Anatpur, Nellor, Chittoor,Cuddapah, Guntur and Nalgonda
		Tamil Nadu	Chengalpett, Madurai
2.	Salinity(Inland)	Maharashtra	Amravati, Akola
3.	Nitrate	Andhra Pradesh	Vishakapatnam, E. Godavari, Krishna, Prakasam, Nellure, Chittoor,Anatpur, Cuddapah, Kurnool, Khaman and Nalgonda
		Karnataka	Bidar, Gulbarga, Bijapur
		Maharashtra	Jalna, Beed, Nanded, Latur,Osmanabad, Solapur, Satara, Sangali and Kolhapur
		Tamil Nadu	Coimbatore, Periyar and Salem
3.	Chloride	Karnataka	Dharwar, Belgaum
		Maharashtra	Solapur, Satara, Amaravati, Akola and Buldana
4.	Zinc	Andhra Pradesh	Hyderabad, Osmania University campus

Groundwater quality poses a serious health hazards in various parts. Excessive salinity in drinking water is undesirable because of objectionable tastes and the laxative effect associated with sulphate. Groundwater generally contains higher dissolved solids concentrations than surface water of the same locality. Most of the minerals present in greater amounts are those which contribute to hardness (Calcium and Magnesium) and alkalinity

(Bicarbonate, Carbonate and Hydroxide). This is due to the largely increased amounts of carbon dioxide in the groundwater.

The quality of groundwater varies from place to place as well as from strata to strata. It may also vary with seasonal changes. Water down from strata at a particular time of the year may be unsuitable where as it may good enough at other times of the year. Groundwater quality problem can be understood only by the regular monitoring of quality of water. Status of research on groundwater quality in hard rock region is discussed below.

The major contaminants in the hard rock regions are high fluoride concentration noticed in several places like in Mundagiri taluk of Dharwad district, Sindhnur and Sirguppa of Bellary district and Pavagada and Mudhugiri of Tumkur district, all in Karnataka State, (Majumdar and Seethapathi, 1996). High fluoride water pollution is found in many parts of the semiarid to arid parts of India (Handa, 1975) e.g., in the Nalgonda, Anatapur, Chittor, Medak, Nandigama taluk in the Krinshna district, Vishakhapatnam and Hazurabad taluk in Karimnagar (all in Andhra Pradesh) and in some parts of Tamil Nadu and Karnataka with high concentration of fluoride are found (Sarma and Swamy, 1981,1983 and Prakash and others, 1989). The highest value of fluoride was recorded in Bankapatti, where concentration upto 17-20 mg/litre have been found. Fluorite ($Ca F_2$) is the most common fluoride bearing mineral and occurs either as an igneous, metamorphic or detrital mineral. The occurrence and distribution of fluoride in the shallow aquifer in the upper reaches of Pennar Basin were studied by Raju and Ramesan (1983). Twenty-six water samples were collected in clean one-litter polythene bottles from 24 villages falling in parts of Kalyandurg and Dharmavaram taluks during January 1981. pH, HCO_3^-, Cl^-, Ca^{++}, Mg^{++}, Na^+, K^+ and specific conductivity were determined on these samples as per the standard analytical methods. Fluoride was determined using ion specific electrode. Many places were found to contain fluoride beyond the toxic limits, the highest value observed being more than 7 mg/l). Further, Tamta (1994) has observed high concentration of fluoride in groundwater (1.5 mg/l) at number of network stations in the northern districts table land and eastern districts plateau of Karnataka state comprising district of Gulberga, Bijapur, Raichur, Bellary, Chitradurga, Tumkur, Kolar, Shimoga, Dharwar and Belgaum. Groundwater high in fluoride concentration are observed carrying sodium as a predominant cation and also found oversaturated with respect to calcite suggesting adequate residence of groundwater with the calcium-sodium clays and fluoride bearing minerals. Groundwater samples analyzed from Bidar, Mysore and Banglore districts, though exhibit oversaturation with respect to calcite, yet are depleted in fluoride concentration (< 1.0 mg/l) suggesting lack of fluoride bearing minerals in the aquifer. Groundwater samples from Malnad region-comprising districts of North Kanara, Chickmanglur, are generally low in fluoride concentration (< 1.0 mg/l) and also exhibit undersaturation with respect to calcite. Infact, fluoridation of groundwater at number of network stations is required in this area as a measure towards oral health and hygiene for public water supplies. From the groundwater data of network stations (may 1988-91) and also hydrochemical data of undated exploratory bore wells (1987-92), it is concluded that the replacement of calcium ions from solution involving solution-precipitation reactions and ion-exchange processes resulting in disequilibrium of fluoride (CaF2) mineral solubility causing accrementition of fluoride in groundwater. It also concluded that there is a need for documentation of fluosis, and carries cases in high and low fluoride content groundwater areas. Fluoride concentration in groundwater samples from bore wells and dug wells varies between < 1 PPM to 5 PPM in Kudligi taluk. The fluoride concentration is attributed to the geological cause. Though the rock type is same, in general over the entire taluk, the fluoride distribution in groundwater is found to be heterogeneous. The popullistic sample survey revealed the prevalence of dental hupoplasia in over 80% of the region. Consumption of fluoride rich groundwater and climate are the main cause for the observed disease.

Suresh et al. (1983) studied the groundwater quality of Hemavathy river basin, a sub-basin of Cauvery in Karnataka. He found the significant variation of SO_4, Cl, NO_3 and Na constituent. The NO_3 concentration around Hassan and Arkagud zones in the basin may be due to lithology and large-scale cultivation of groundwater and other nitrogen fixing plants. The high concentration of Na is due to highly alkaline nature of soil. The high Cl content surrounding Hassan is mainly due to local lithological and soil characters. The sodium adsorption ratio (SAR) for waters of the basin range from 0.06 to 6.00 with an average of 1.4, indicating that the quality is excellent for agricultural purpose.

Suryaprakasa Rao and Venkateshwar Rao (1988) were conducted detailed ground water exploration studies in the Godavari Basin. The studies include aerial photographs, hydrological data collection and electrical resistivity survey. Resistivity surveys were carried out across the buried river courses identified from the aerial photographs at a number of locations to delineate the thickness and quality of the aquifer, mostly K-type and Q-type resistivity curves are obtained. High resistivity in the K-type curve indicated sandy aquifer with potable water. Resistivity of the fresh water sandy aquifer ranges between 15 and 35 ohm-m. Geo-botanical indicator, like pandanus and termite mounds are also considered for the location of potable water sources.

Paliwal (1991) studied the groundwater quality of hard rock terrain. Twenty-four water samples were collected from dug wells in hard rock terrain (associated with granites, gneisses and charnockites of Archeans) of Guntur district to assess their quality for drinking purpose. The waters have the TDS in the range of 768 to 4200 mg/l. As per the TDS classification, the water belongs to two types. They are, fresh water (TDS<1000 mg/l) and brackish water (TDS: 1000 to 10000 mg/l), the latter being most dominant, accounting for about 80% of the samples. The TA lies between 246 and 639 mg/l. In the waters, the TH ranges from 193 to 1548 mg/l, suggesting a very hard category. The relation of TA with that of TH indicates that about 67% of the samples have non-carbonate hardness due to predominance of Cl ions. Among alkaline earths, the concentration of Ca is in the range of 30 to 270 mg/l, while the Mg content lies between 25 and 310 mg/l. Among alkalies, the content of Na varies from 120 to 900 mg/l, whereas the K content is from 6 to 25 mg/l. The groundwater has the HCO_3 between 300 and 780 mg/l. the concentration of Cl ranges from 100 to 2000 mg/l. The SO_4 content varies from 5 to 64 mg/l. The concentration of F is in the range of 0.7 to 1.5 mg/l. The sources for ca, Mg, Na and K are plagioclase and orthoclase feldspar and, ferromagnesium minerals of the country rocks. In addition these, climate, soils, slow movement of water, topographic features and agricultural fertilizers have also contributed for the increase in cations as well as anions in the groundwater. In this, an attempt is made to study hydrochemical parameters of groundwater associated with greywackes around Kittur. The hydrochemical parameters are further scanned to classify the groundwater to delineate the different hydrochemical facies to demarcate the areas of salinity and alkali hazards. Further, an attempt has been made to establish the flow direction of groundwater and also the mechanism controlling the chemistry of groundwaters associated with greywackes. From this investigation it is observed that majority of the area is covered by shales, followed by greywackes. The area forms only one cation facies and three anion facies. Three hydrochemical facies are distinguished by Piper's classification.

I. Carbonate hardness exceeding 50%

II. Non Carbonate hardness exceeding 50%

III. No one cation-anion pair exceeding 50%

The values of standard deviation and coefficient of variation are comparatively more in facies I than in facies II showing more consistency of the chemical attributes in facies II. The mechanisms controlling the groundwater chemistry associated with greywackes are evaporation and rock dominance indicated by Gibb's diagram.

High Chloride concentration zones is found in Nargund, Navalgund and Gadag taluks of Dharwad district of Karnataka State. High sulphate, sodium and bicarbonate concentration zones are existing almost in all command areas to various degrees and dimensions. In Tamil Nadu, the groundwater pollution are found in Vaniyambadi-Ambur region in Palar river basin, and groundwater quality problem in Kuttur of Cauvery basin (Paliwal, 1991). Majumdar et al. (1996) also found the high concentration of chloride in the groundwater of Palar river basin.

High concentration of Nitrates in ground water is also indicates evidence of pollution. Water containing more than 100 PPM of nitrates has bitter taste and may cause physiological distress. Krupanidhi (1975) found 640PPM Nitrate concentration in the groundwater of shallow aquifers in Vedavati sub-basin in Chikmagalur district, Karnataka. Kulkarni and Puranik (1996) studied the geochemical characters of the groundwater of the Hosur Halla Basin, Saundati taluka of Belgaum district, Karnataka. The Housar Halla Basin was divided into 45 grids of one-minute dimension. In each grid a groundwater sample was collected from existing bore well wherever available. Total 41 groundwater samples were collected and pH and EC values were determined. The water samples were analyzed within a fortnight for major cations and anions by routine titrometric and spectrophotometric methods. The TDS was determined by gravimetric method. The Na and K were determined by flame photometric method. This study reveals that the groundwater of Hausar Halla Basin is slightly alkaline in nature. Ec values and values of total dissolved solids are within the maximum limits, proposed by WHO (1971) and ISI (1983). The groundwater samples were classified based on the Piper's (1994) classification. Three lithounits namely basalts, granitic gnesses and phyllites are identified within the basin. The water samples belong to Ca + Mg and Ca+ Mg - Na + K cation facies and HCO_3- Cl+$SO_4$and Cl+SO_4-HCO_3 anion facies. Among the other constituents, nitrate is found to be more than the permissible limit. The average NO_3 concentration is 83 ppm. Higher concentration of NO_3 indicates the pollution of groundwater. The groundwater of non-residential area was less than 50ppm and the residential area, which has no proper sewerage systems, has NO_3 in excess of 50 ppm. More than 100 ppm of NO_3

exists in that part of the town where the population is very high and dense, sewerage is extremely poor and latrine pits are in abundance.

Recently, Purandara (1999) and Agrawal (1999) studied ground water pollution due to urban waste and found a nitrate concentration in the ground water. Purandara studied the water quality of Belgaum City. The Belgaum City generates a sizable amount of solid waste. The solid waste amounts to about 80 tones per day, which is directly dumped into depots located within the Corporation limits. Since, There are no sewage treatment plants and recycling facilities. The entire sewage is directed through Bellary nala, which is linked though gutters and sewer lines. This nala passes through a highly fertile black cotton soil, which is underlain by a very good aquifer. Farmers in the region, pump out the sewage water for irrigating sugar cane, paddy, vegetable etc., Thereby passing the toxic contaminants into the food grain. It is observed that, though most of the major anions and cations are within the permissible limits, there is a trend of deterioration. Nitrate is one of the major contaminant, which is affecting the ground water. Higher concentration of Sodium and potassium are also observed in some of the localities. Likewise, Agrawal et al. (1999) studied the nitrate pollution of groundwater due to urban waste and industrial effluents usually centers around cities. This study has shown that nitrate levels in groundwater over vast agricultural areas can be corrected with intensive irrigated agriculture, corresponding use of nitrogenous fertilizers and groundwater development, consequent diffuse agriculture pollution has already endangered the safety of potable groundwater for future generations in both rural and urban areas. Chemical and bacterial treatment of groundwater for nitrate removal relies on advanced technology and is considered costly even in the developed world. In a country like India where economic resources are inadequate, action on the suggested preventive measures may be taken without delay at this stage when alarming trends have been recorded.

The application of fertilizers, pesticides and irrigation water may have influence on ground water quality. Murugaboopathi and Krishnaswamy (1992) and Padmanaban and Krishnaswamy (1993) studied the impact of agriculture on both quality and quantity of ground water. Murugaboopathi and Krishnaswamy studied the impact of agriculture on ground water in Kammavarapalaym village, near Cholavaram, 20 km from Madras. Two sets of borewells, each set having four wells, were drilled in an agricultural field for different depths. Samples were collected every months from August 91 to November 91 and analyzed for major ions present in water. Also, another two samples were collected from wells located in agricultural fields in the villages Azhinzhivakkam and Panjetti to find any variation in the concentration of nitrate with respect to previous data that were available in the Centre for Water Resources, Anna University, Madras. The analysis indicates the concentration of nitrate in the subsoil water varies from 0.0 PPM to 9.1 PPM. The analysis shows that the ground water is having higher concentration of nitrate, which increases during the period of application of fertilizers. The water samples collected from the villages Azhinshivakkam and Panjetti are also having low nitrate concentration differing much from the nitrate concentration reported. While, Padmanaban and Krishnaswamy studied the impact of agriculture on both quality and quantity of ground water underlying a cultivated field in Araniya-Kortalayar basin (AK basin) situated about 20 km north of Madras in Tamil Nadu. Water samples were collected from two sets of borewells located in an agricultural land, penetrating to different depths and were analyzed for the concentration of each major ions present in the samples during November 1989-August 1992. The variation in concentration of each ion and total dissolved solids (TDS) with respect to time and depth were compared with the fertilizer application. The variation in ground water type was assessed with the help of expanded Durov diagram. To assess the impact of agriculture on ground water recharge, a conceptual recharge model based on soil moisture balance was developed. The recharge from the barren land was also estimated using the model and the net recharge from the study area was computed. The computed net monthly recharge values were compared with the observed water table fluctuation. It was concluded that the application of fertilizers, pesticides and irrigation water has the influence on ground water quality.

Potassium content in natural water is usually low as compared to its abundance in earth's crust. Natural water usually contains less than 12 mg/l; K. But chemical analysis of groundwater samples collected under various investigation programs from different parts of Karnataka State reveals abnormally high concentration of potassium in groundwater. An average content of potassium in exploratory borewells and tube wells is about 2.60 mg/l, K. where as it is 56.10 mg/l, K, in dugwells water. Potassium is an essential element for human, plant and animal and is evolved in biosphere especially in food, vegetation and soil. It is more abundant in sedimentary rocks and commonly present in feldspar, mica, illite and other clay minerals. Woods ashes have been used by humans as a potash source for many centuries and is lost by crop harvesting and removal as well as by leaching and runoff action on organic residue (Hem, 1989). Potassium is extensively used in fertilizer, in glass and in limited way in the chemical industry-hydroxide, iodide, cyanide, sulphate and chromate. Potassium toxicity may be reached in adult with dosage of 7-10 gm/day. It acts as cathartic in excessive concentration. Potassium is essential to animal nutrient. But a concentration of 1000-2000 mg/l in stock feeding water is regarded as extreme limit permissible (Moore, 1950). It causes foaming, as does sodium in boiler feed water, otherwise, is not significant in industrial water supplies. Potassium stimulates plantation growth and is more toxic to fish than Ca, Mg or Na (Brawn, et al. 1970).

Suryanarayana and Pratap Reddy (1994) analyzed the Iodine and Bromide concentrations in Groundwater of Aruku and Ananthagiri Area of Visakhapatnam district, Andhra Pradesh. The Bromide concentration varies from 0.035 to 0.142 PPM in the higher altitude and an average content is 0.053 PPM and the content of Iodide ranges between 0.003 and 0.010 PPM and average concentration is 0.007 PPM. In the Madhuravada plain areas the content of Bromide ranges from 0.109 to 1.543 PPM and an average concentration is 0.489 PPM, while Iodide concentration varies between 0.007 and 0.198 PPM and an average content is 0.048 PPM. The Maduravada plain areas have higher concentration (average) of Bromide and Iodide relative to hilly terrain of Ananthagiri, Aruku and down to Muliaguda. A model for predicting the ground water potential based on weights and ratings is proposed using 4 geophysical and 3 geomorphic predictor variables. Using this model "Ground Water Potential Index " is calculated and mapped over the entire basin. It is found that the value of this index should be in the ranges of 35-40 in order to achieve the desirable success rate of 75 % in well sitting. Further, in 1995 Suryanarayana analyzed the twenty five groundwater samples for Iodine content from the higher altitude of Aruku and Ananthagiri areas down to Muliagudu and Borra caves in the Eastern Ghat, Visakhapatnam district, Andhra Pradesh and found Iodine concentration in the range of 0.003 to 0.046 PPM with the average of 0.007 PPM. The range concentration of Iodine varies from 0.004 to 0.046 PPM in red and alluvial soils in and around Aruku Valley and at Bhagmari Valasa and 0.003 to 0.007 PPM in Khondalites rock, 0.005 PPM in charnockites and 0.006 PPM in limestone near Borra caves.

Majumdar et al. (1996) analyzed the groundwater quality data. The data of groundwater quality observed at 24 observation wells in the region are collected for the period 1972-1990 along with other meteorological, hydrological, geological, hydrogeological, industrial, agricultural and surface water quality parameters and processed. It was observed that the ground water quality deteriorated to such an extent that the socioeconomic condition of the locality got badly affected to a larger extent Total dissolved solids are found more in locations like Ambar and Minnur of upper Palar river basin in Tamil Nadu. Na and Cl concentration are more in all locations with an increasing temporal trend. Bicarbonate concentration is more in Vaniyambadi, Kailasagiri and Gudiyattam. In Ambur and Minnur it is more in some years but reduced subsequently with good amount of rainfall. In general, contamination level of groundwater system has been on the increasing trend and most effected areas are Ambur and Minnur. The study reveals that the contaminants are more when ground water recharge is less. Therefore, it may be concluded that if proper flushing arrangement of the surface and subsurface contaminants can be made during dry periods, the contaminant level may be controlled. Further, in 1997, Majumdar et al. studied the Groundwater quality scenarios of worst affected region of Nargund-Navalgund area of Malaprabha command by simulating through a Three Dimensional Finite Difference code SWIFT III

Biocarbonate found to be the predominant anion in both granitic and basaltic terrains. Isocone map prepared for total dissolved solids has shown that the concentration of dissolved ions is more in the southern parts and southeastern parts, attributing to the lithological variations. Graphical treatment of chemical data reveals that. the area has mainly basic water and devoid of primary alkalinity. It further shows that about 60% of the area over come the salinity problem. Mechanism controlling the chemistry of groundwater indicates that chemistry of groundwater is predominantly controlled by rock dominance. Raviprakash and Rao (1994) studied the quality of groundwater of Paravada Area, Viskhapatnam District of Andhra Pradesh. In the groundwater of the Paravada area, the carbonate ions are present in very small amount (0 to 159 mg/l). These ions decrease or may be absent in the central or northern parts of the area. The bicarbonate content varies from 70-886 mg/l depending on the carbon dioxide content in water and following the same trend as that of carbonates. The pH values range between 7.3 and 9.2, where the increase of salinity content in the central and northern parts leads its reduction and the reverse happens towards the remaining parts where the salinity decreases. The hydrochemistry of the unconfined aquifer in the granitic terrain of Hyderabad city encompassing the area of Musi valley was investigated by Ranganathan and Prabhakar (1997) to examine its relationship to groundwater conditions, and yield of the wells. It is found that the Chloride, Bicarbonate and total hardness show increasing concentration with distance travelled and contact time of the groundwater with the soils. The bicarbonate content is higher in elevated areas than chloride but decreases relatively to chloride in valley regions. The chloride content in the groundwater is derived from soils and from contamination. Concentration is of two types- prevasive type of contaminated spread all over the city and high level contamination in isolated areas associated with industries. The second type of contamination can be identified from the chloride versus depth to water table plot in which it forms a separate population. Good yielding wells have higher concentration of chloride, bicarbonate and total hardness located in the valley portion of Musi River.

Lokesh and Shenoy (1997) carried out preliminary hydrogeochemical studies in Udupi area to assess the groundwater quality in view of the mega industries coming up in the area in near future. Groundwater samples from 46 public bore wells from hard rock areas of Udupi taluk were collected both in pre-monsoon and post-monsoon seasons and were chemically analyzed. It is found that, in general, most of the chemical constituents are within the maximum permissible limits of W. H. O. standards for Drinking water and Indian drinking water standards. However, nearly 19.57% of the samples during pre-monsoon and 25.58% during post-monsoon period have pH less than 6.5. The analyses also reveal lower concentration of fluoride than the desirable limits (< 0.6 mg/l). Problems like high hardness and excess iron (> 1.0 mg/l) are also observed. Though there is not much seasonal variation in TDS, increased in concentration of EC, Ca, HCO_3 and Fe has been observed during post-monsoon period. Piper's trilinear diagram shows that groundwater of this area is bicarbonate type with mixed cations. Gibb's variation diagram shows that chemistry of groundwater is controlled by lithounit of the region. The necessity of periodic monitoring of the water quality of the area has been stressed.

The Kanga river basin, which forms a sub basin of Krishna River, encompasses mainly crystalline hard rocks including granites and Deccan trap basalts. Rao et al. (1997) analyzed groundwater samples collected from 47 representative locations for the major ion concentrations to identify the controlling mechanism. The pH ranges from 7.8 to 9 indicating the basic nature of groundwater. The groundwater of the granitic terrain has the electrical conductivity ranging from 536 uS/cm to 896 uS/cm and over the basaltic conductivity ranging from 560-990 uS/cm.

Remote Sensing application in groundwater quality studies-

Remote sensing has an important role in water quality evaluation and management strategy. The synoptic view provided by remote sensing gives an environmental scientist very different data from that which can be obtained with surface data collection and sampling. What may not be achieved with absolute accuracy is more than made up for by the spatial and temporal nature of the data. Remote sensing is limited to surface measurements of turbidity, suspended sediment, chlorophyll, eutrophication and temperature. These characteristics of water quality can be used as indicators of more specific pollution problems.

Hydrological and Geophysical surveys for targeting ground water is often time consuming and expensive. With the advent of Space Technology Remote Sensing Technique came to the rescue of the ground water explorer as an effective reconnaissance too l in narrowing down the areas to be covered under geophysical measurements. Moreover, if the various Hydrogeomorphic units delineated through remote sensing study are correlated with available geohydrological data it is possible to get a rough estimation of ground water potential in unknown places within the similar hydorgeological setting. The image of a typical Khondalitic terrain covering under the drainage of Khandivalasa river sub basin of Vizianagaram district of Andhra Pradesh taken by SPOT satellite is visually interpreted by Chandra Mohan and Venkateshwara Rao (1993) and various maps such as hydrogeomorphological map, recharge and discharge areas map, slope map, drainage map and lineament map are prepared. Well yields and geophysical data available in the upper part of the basin are correlated with various hydrogeomorphic units and then potential geomorphic units are established. It is found that wells located in shallow buried pediplains (BPPS) and Wash Plains (WP) are yielding higher than the other geomorphic units such as moderately buried pediplain. It is also found that Flat Uplands and intermittent area are yielding better than the low lying, recharge and discharge areas. Drainage is largely controlled by lineaments (Fault Zones). In between two fault zones or to say two streams most of the successful wells are located. Incidentally, the areas classified as intermittent areas, shallow buried pediplains, flat upland and the area between two fault zones is one and the same. Hence a general ground water potential map is prepared delineating the common area covered under above classification for further exploration program in the lower part of the basin.

Further, in 1994 Venkateswara Rao and Durgaiah studied the ground water hydrology of Khondalitic suite of rocks through an integrated study of hydrogeophysic, hydrogeomorphology and hydrogeochemistry of Kandivalsa river sub-basin situated in this type of hard rock terrain of Viziabagaram district, Andhra Pradesh state, India. During the period 1986-1990, vertical electrical soundings are conducted in the study area at a total number of 80 sites. Based on the interpretation of sounding data, 42 bore well locations are recommended for drilling. 27 of the 42 wells drilled in the study are considered to be successful wells judged from the yield criterion of 8000 LPH per well and success rate of 75 % in well sitting, which are the stipulated norms of financial institutions of the Government to found the irrigation bore well schemes.

With the help of 12 contour maps and 11 profile sections of resistivities and thickness of sub surface layers, useful relations are identified between these geometric parameters and the ground water potential as decided by the success rate of bore wells. Cluster analysis is also carried out to identify of the study are obtained from TM bands 1,2 and 3 of Landsat satellite. The satellite imagery is also used to locate and map 32 lineaments in the basin. The ground contours of the basin are used to compute the topographic slopes. The ground water potential of every point in the basin is examined based on its location with respect to geomorphic unit, lineament and topographic slope position. Ground water samples are collected from 36 open wells and 3 bore wells in the basin and tested to determine eleven geochemical parameters. Using these parameters the water quality in the basin is examined to evaluate its suitability for drinking and irrigation purposes.

3.3 Failure of Open and Bore wells

The history of open well construction may be traced back to 3000 BC to 800 BC for irrigation purposes and it has become an important source of irrigation water towards the end of nineteenth century along with some localised use of ground water through open wells specially in places where lack of surface water resources exist. Though large scale development was started in 1934, but in mid sixties it has become prime source for irrigation due to concurrent failure of monsoon in the various parts of the country, advent of high yielding varieties of wheat and rice, and the introduction on an incentive oriented agriculture pricing policy by the Government (Prasad, 1995). Contribution of Groundwater to National water need can be appropriated through the available statistics. Half of the country's irrigation water requirement and a major part of domestic and industrial needs are being fulfilled by the subsurface water. Use of open wells instantly got the emphasis due to its cheapness and simplicity of construction, operation and maintenance (Jain, 1977).

In the modern world of science and technology good numbered sophisticated equipment and methods are in practice to harvest the ground water for various purposes. Out of all methods, the extraction of Ground Water through open dug wells is existing since as early as 3000 B. C. The excavations in Mohanjodharo have revealed it. There are more than 9 millions dug wells in our country. It is reported that about 71 per cent of Groundwater draft in India is from dug wells (Laheri, 1975).

Dug wells of large-diameter are the preliminary source of groundwater extraction not only in India but also in central and south Asian countries, where the crystalline rocks predominate. In the areas comprising hard rocks, like granites, gneisses and schists, for irrigational purposes, large dimensional wells are preferred. A rectangular well is the most recommended and very much preferred one in hard rocks because for the same area of cross section and the perimeter of the well, the exposed surface area (for the seepage of water into the well from fractures, fissures and cracks) is large as compared to circular and square wells. A circular-cum-rectangular shaped dug wells in hard rocks, were also identified. Such type of well with some additional structure is recommended for the places, where the problems may be expected and also to convert, the already failed structures, into circular-cum-rectangular well. This structure is recommended for semiconsolidated formation also.

Generally, in hard rock areas, the ground water is abstracted from dug, dug-cum-bore, shallow bore and deep bore wells. Dug wells are open wells, typically with a depth of 30 feet and with a diameter of 25 feet. Stone slabs may line the dug wells in order to prevent the well caving, in some areas where the rock and soil strata are loose. For viability of dug well the minimum yield of water should be 5,000 gallons per day according to NABARD. The water used to be lifted by traditional labour intensive lifts like 'yetha', 'kapile' or 'persian wheel' till the 1960s. Later the water was lifted by centrifugal pump sets of around three horsepower capacity. The dug wells continued to be the dominant structures of groundwater exploitation till the mid- 1960s. In the early 1970, one or more bores were drilled inside a dug well (which used to call a dug-cum bore well) in order to enhance the water yield. The inbore may have the depth ranging from 30 to 100 feet. The dug-cum-bore wells were the dominant structures till the 1980s. From the early 1980s surface bore wells with diameter of six inches and depth around 200 feet became popular due to the use of fast rig technology. For viability of borewell, the minimum yield of water should be 1,000 gallons per hour according to NABARD.

Now withstanding the hydro-electrical thresholds of groundwater, intensive cultivation of water intensive commercial crops is growing unabated on the extensive scale ever since the 1970s. Due to the growing demand for groundwater, substitution of labour intensive water lifts by capital intensive electrical irrigation pump sets (IPS), and due to increasing well intensities and large-scale failure of dug wells, dug-cum-bore wells and even of bore wells has occurred. Historically even though groundwater is an internal or local resource tapped from farmer's land, it has now been transformed to an external and non-local resource, since electrical or diesel energy which are external, have to used to lift the water. With such a heavy pressure on the resource and the government policy of providing electricity to lift groundwater at zero price, there has a large scale exploitation of groundwater leading to high rate of well failure and loss of investment in the well irrigation. The aftermath such loosed provides a nightmarish scenario to planners and researchers, since farmers suffer from severe economic shocks and stresses.

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 zone. 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. But, now a day failure of open wells in terms of quality and quantity are more evident. Some of the reasons are rapid increase in the abstraction rate as compared to the recharge due to increase in the numbers of borewells in region and quality deterioration due to man made developments.

In general failure of open well can be attributed to three distinct categories: Quantitative, Qualitative or both. Quality failure occurs when even though ample groundwater storage is available it can not be utilized for various purposes due to excessive chemical, biological 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 results, 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 can't 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.

A pumping test is a controlled field experiment to find out the hydraulic characteristics of well. Aquifer parameters, namely transmissivity (T), and storativity (S), are determined by the analysis of the pumping test data. Two types of test are generally used i.e. steady state and non-steady state test. In a steady state test, a well is pumped long enough so that the drawdown becomes reasonably constant. Theim's equation (1906) is used for calculating transmissivity of a confined or unconfined aquifer as the case may be. However, Theim's equation does not yield the value of storativity. Storage equation can be determined using non-steady state flow equation or other procedure given by Lohman (1972).

In a non-steady state a well is pumped at a constant rate and drawdowns are recorded at various time intervals. The data so recorded are then used in determination of not only the transmissivity but also the storativity of the aquifer. Theis (1935), Cooper and Jacob (1946) and Chow (1952) are widely used to determine the Transmissivity and Storativity from unsteady state pumping test. Since, large diameter wells being most appropriate structure for groundwater exploitation in hard rock areas are difficult to analyse by these methods due to large contribution of storage and boundary conditions imposed by seepage face etc.

In hard rock areas, the large diameter wells are generally shallow and penetrate the weathered or intensively fractured layers. In these areas the hydraulic conductivity of the unconfined aquifer generally decreases with depth and the wells are mostly fully penetrating. Most of the inflow into these wells is lateral through the wells. Slichter (1906) considered the case of large diameter well having vertical impervious well steining and in which the flow is only from the bottom. Due to lack of theoretical validity, the specific capacity of the well calculated by this method can't used as the specific capacity determined by the method of Theis etc. Samuel in 1974 and Muskat in 1937 extended the use of Slichter's equation for estimation of transmissivity by causing it with the Theis solution (1906) for steady state flow. This equation can be applied only for dug wells tapping confined layer.

Kumaraswami (1973) observed that the conventional methods of determining the transmissivity and storativity can't be applied in hard rock areas because of their anisotropy and occurrence of flow in the well through planes and conduits. He felt that open wells in hard rock have appreciable storage capacity, low inflow and no formation of cone of depression during pumping. Therefore, he recommended following parameters to be determined during pumping test on open wells in hard rock areas. (1) Hard Rock Well Permeability, (2) Maximum inflow capacity of well and (3) Time taken for 99% recuperation.

Papadopulos and Cooper (1967) were the first to present a type-curve solution technique for the analysis of test data from large diameter wells with storage in confined aquifer. Boulton and Streltsova (1975) produced type-curve for the early drawdown phase for particularly penetrating large-diameter wells in unconfined aquifers having both compressibility and water table storage capacity. The work of Zdankus (1984), Rushton and Holt (1981) and Rushton and Singh (1984) are of particular significance in this regard. Further in 1985, Sharma carried out the hydrological investigation in hard rock area especially for large diameter dug wells and concluded that the use of Theis non-equilibrium formulae and the type curve method of Papadopulos and Cooper tends to under estimate the aquifer transmissibility. In absence of any other methods, the time drawdown data should be analyzed for the calculation of the transmissibility and the results may be multiplied by a factor of two, to get nearly representative aquifer properties. Also, when the pumping test are conducted on large diameter open wells, it is preferable to provide observation wells/pizeometers of shallow depth upto 1.5m below water level in the pumped well. The time drawdown and recovery data of observation wells are likely to provide more reasonable aquifer properties. It may also mention that for such analysis, the last phase of recovery of time drawdown may be used for working out the residual drawdown.

There are quite a few literatures available on performance of wells in hard rock regions. Krupanidhi et al. (1973) studied the specific capacities in Mysore State. In 1985, Raju et al. studied the specific capacities in Himayantnagar, Ranga Reddy district, Andhra Pradesh. Raju (1979) checked the performance of dug wells in Mahaboobnagar district of Andhra Pradesh. Viswanathaian et al. (1979) has found the specific capacity of wells in some hard rock of Karnataka State. Rao et al. (1991) compared the specific capacities of large diameter wells in different terrain of crystalline rocks in Southern part of India using Slichter's formula (1956). All these works concludes at a similar conclusion that specific capacity increases with increase in cross sectional area of wells and permeability decreases with increase in depth beyond 5.5m from the ground surface.

Singh and Mishra (1989) made an attempt to analyse of unsteady flow to a partially penetrating dug well taking into account the well storage. Three dimensional groundwater flow model developed by Mc Donald and Hrbaugh as an extension to the cell theory proposed by Bear has been used for the analysis. This has been carried out for different well penetrations. Set up type curves has been presented using which aquifer parameters can be determined. The performance of the way, i.e., contribution of well storage to pumping, has been evaluated for the different penetrations. The component of the well loss for different penetrations has been estimated. The results are useful for the design of diameter and depth of a well for a required pumping rate and schedule.

The study conducted in Vaigai basin of Tamil Nadu by Janakarajan (1993) reported that there is a tremendous increase in the original well depth. Out of 345 samples wells, whose original depth was less than 30 feet farmers have moved on to a higher depth range at the time of survey. 23 per cent of sample wells whose original depth was 30 feet have moved 5 feet down and about 10 per cent of the sample wells whose original depth was 50 feet were deepened upto 75 feet. Rao (1993) conducted a detailed study in two small watersheds in Malur taluk of Kolar district and Davanagere taluk of Chittradurga district to understand the serious implications of water level decline in hard rock areas of Karnataka State. Farmers tackled the problem of declining water level by constructing bore wells, which actually hastened the decline of water levels because these structures, by virtue of their depth, are capable of withdrawing more water than the conventional dugwells. As a consequence, many dugwells became dry and investment in them and in pumpsets became unproductive. Thus, large numbers of farmers who had reliable dugwell irrigation a few years back are now deprived of irrigation because they didn't have resources to attempts boring after the dugwell became dry or because the bore well drilling they attempted didn't prove successful. Such farmers have now switched over to dry land farming and the poor among them are supplementing their meager and uncertain farm income through agriculture labor. The over exploitation of groundwater resource in many taluks of Banglore, Kolar and Tumkur districts has forced abnormal drop in water levels. This has resulted in failure of dugwells and tubewells, scarcity of drinking water, an increase in electricity consumption, dropping efficiency of pumps, increase in the unit cost of wells, and negative impacts on small and marginal farmers.

In 1988, Shah has shown that, the private exploitation of groundwater involved powerful and extensive externality effects. The externality affected both the poor and rich people, both spatially and temporally. These factors are discussed to show how the bore well farmers get better access to groundwater when compared with the traditional dugwell farmers. Un-restricted, private exploitation of these vulnerable resources, enabled both borewells and dugwell owners to earn surplus, because of the failure of market in reflecting the acute cost of extraction.

Kolavalli and Atheek (1993) observed that the declining groundwater tables in hard rock areas of Karnataka combined with increasing probability of not striking water led to increase in capital and consequently the annual fixed cost of irrigation. The cost of successful well was RS. 50,000. Considering the probabilities of not striking water and considering the cost of failed (initial) borewell, the estimated cost of successful well was about RS. 62,500. Such colossal investment requirements restrict the small and marginal farmers from venturing well irrigation. Further in 1994, Nagaraj observed that around 71 percent of the farmers constructed earthen overground tanks to store the pumped water, to circumvent both irregular supply of the power and lower discharge from the well. On an average, farmers were found to invest Rs. 23000 on additional wells to combat the well failure. Arun (1994) observed that farmers responded to well failure by drilling additional well(s), reducing area under high water intensive crops, shifting to the low water intensive crops like mulberry or by investing on water saving technologies like drip or sprinkler irrigation systems. The marginal willingness to pay for and additional well was Rs.48,370.

In 1995, Shivakumaraswamy found that the gross area irrigated in interfered high well failure area (IHA) was 8.85 acres per farm where as it was 11.32 acres per farm in interfered low well failure area (ILA). The farmers in IAH incurred irrigation cost RS. 14,000 per well and it were RS. 10,717 per well for the farmers in ILA, the proportion of gross area under perennial crops were 52 percent, while in IHA the proportion is 33 percent. The increase in the annual cost of irrigation is due to the repair and maintenance cost of pump set. Umapathi (1996) carried out hydrogeological traverses in the parts of Chengalpet, Thiruvannamalai Sambuvarayar and North Arcot Ambedkar Districts of Tamil Nadu. Based on this Hydrogeological traverses, seven types of causes, which are endangering the rectangular shaped dug wells in hard rocks, were identified as given below,

1. Interstitial pore pressure at the lining of the wells, which are located well within the area of influence of infiltration of the tanks and lakes.
2. Flooding and submergence of wells in command areas during monsoon
3. Swelling pressure due to swelling during rain and contraction during summer, of clay formation may lead to collapse of the wells.
4. The-pump house constructed on a part of well itself will cause unequal load on the well and different sink of foundation. Thus weaking of the well structure.
5. Improper Unlined Excavation/Pits made by the side of wells
6. Vegetation- The roots of plants which run more radially for longer distance with large diameter, like of Tamarind, Mango, Banyan and pipele trees give continuous thrust to the walls of lining and thus create weakness and in due course, collapse of structure.

Nagaraj and Chandrakanth (1997) studied the Intra and Inter Generation equity effects of irrigation well failure. Equity in access to groundwater is of concern as groundwater offers considerable potential to enhance land productivity. In addition to existing inequity in landholdings, the inequity in access to groundwater further widens the skewness in assets and income distribution. The food security and equity was well provided by dug well irrigation.

The failure of dug wells, shift to high water-high value crops and policy instruments like soft loans to sinks wells and zero marginal cost for electric power to lift groundwater, distributed the equity in well irrigation, and paved the way for the use of expensive technologies for rapid harness of groundwater. As a results the dugwell-cum-borewell and borewell contributed inter and intra-generational inequity even though they increased the overall growth in agriculture. Shyamasundar (1997) in his study on the interplay of markets, externalities, institutions and equity in groundwater development- in Athani taluk has shown that farmers coped with well failure by adjusting their crop pattern in favour of less water intensive crops. The cost of deepening the original dug well ranged from RS. 11,438 to 14,352. A logit model was used to find out the probability that the farmers will make an additional investment in well irrigation. The probability that farmers would make additional investment in well irrigation was 0.47.

A study conducted by Satisha (1997) in Madhugiri in Central dry zone of Karnataka on the coping mechanisms adopted by farmers of Channagiri. A few farmers bought groundwater to grow paddy, ragi and aeronaut at a price of Rs. 8 per hour for paddy, while on other hand farmers paid one third of the paddy output as crop share. The farmer's irrigation wells they suffered due to cumulative interference. Subramanian et al. (1997) had studied the geohydrological features of the hard rock areas of Vidhrabha region of Maharashtra. The region shows a varied geology with rock types of Archaean to Recent age. However, the most prevalent rock formation of the region is Deccan trap basalts. The rock of Archean age occurs in Nagpur, Bhandara, Chandrapur and Gadchiroli districts. A small patch of Vindhyan formation occurs in Chandrapur districts. It is also found that the productive zones are mostly restricted to 100m bgl in Archaean formations although the deepest aquifer occurred at a depth of 219.50m bgl. The Vindhyan do not include good aquifers. As the hard rocks are devoid of the primary porosity, the success or failure of the boreholes depends on the presence of secondary porosity. The fractured zones, which result due to structural disturbances, are seen as lineaments in the maps. A significant feature in Deccan trap Formations is the occurrence of red-bole beds at varying depths, which resulted in the collapse of the bore holes in some places.

Prasad (1997) and Lokanathan (1997) list out the following coping strategies in the wake of well failure:

1. Reduction in cropped area

2. Water sharing by farmers

3. Fodder cultivation

4. Shift to less water intensive crops i.e. from paddy to silk cotton

5. Shift to crop having short gestation period namely beans ladies finger, coriander etc.

6. Transfer of water through cement pipe

7. Irrigation just to keep the soil wet

8. Shift to tree crops such as coconut, guava, mango etc.

9. Deepening of wells

10. Risk aversion through crop diversification

11. Save half, leave half-irrigate standing crop to the extent possible and allow the remaining crop to die

12. Drip irrigation and

13. Secondary occupation overtakes primary occupation (e.g. Dairy)

Recently, to understand the various geological and hydrological reasons behind the well failures, Majumdar et al. (1997) carried out the study on failure of open well in Hukkeri taluk in the Ghataprabha command area, which shows an enormous increase in the number of bore wells and a large number of failures of open wells. It is found that failure dose occur mostly in the northern part of the region around Hukkeri town, whereas southern part still looks in a better shape in terms of ground water recharge. Less rainfall, more evaporation, intermittent stream flow due to extensive lift irrigation from wells and minimum soil cover may be some of the reasons for the failure of these wells. Open wells of the region having large cross sectional area have failed even with shallow depths. Well rock permeability, maximum inflow rate and time taken for 99% recuperation are considered as more useful parameters as compared to specific capacity, transmissivity and storativity and these are ranging from 0.08 to 0.346 m/hr, 10543to 13.42 cum/hr and 61.5 to 295.4 hr. respectively. The specific capacities estimated through Slichter's method ranges between 0.0124 to 0.078 cum./min/m.

Quantitative failure of any well is the reciprocal of the disbalance between yield and exploitation of ground water. Hydrologically yield is very much depending upon the structural geology of the location as real and temporal variations of geophysical parameters are frequent both in terms of quantity and direction. It can be concluded that groundwater exploitation be regularized as per the estimate of safe yield calculated on the basis of sensitive parameters. Various analysis including pumping and recovery test were carried out in a test plot in a location where most of the failed wells have been noticed. Kumaraswamy's method of calculating well rock permeability has been preferred as against Transmissivity and storativity. Permeability values ranges from 0.08 m/hr. to 0.346 m/hr.

3.4 Ground water Balance

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 hydrological 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.

With water balance data it is possible to compare individual source of water in the system over different periods of time and to establish the degree of their effect on variations in the water regime. Further the initial analysis used to individual water balance components and the coordination of these components in the hydraulic balance equation make it possible to identify deficiencies in the distribution of observational stations and discover systematic errors of measurements. Finally, water balance study enables evaluation of one unknown component of water balance from other known components.

Ground water is mostly distributed in the earth's crust and it is a replenishable resource of the nature. Ground water exists wherever water penetrates beneath the surface, the rocks and the rate of infiltration is sufficient that the rocks are saturated to an appreciable thickness. So the distribution of ground water depends upon the geology of the area, i.e. aquifer materials, its structures, composition, porosity and permeability. Aquifers are groundwater storage reservoirs. A confined aquifer is overlain and underlain by confining layers and water in the confined aquifer occurs under pressure which is more than the atmospheric pressure. An unconfined aquifer is not overlain by and confining layer but it has a confining layer at its bottom and it is partially saturated with water and the upper surface of saturation is termed as water table which is under atmospheric pressure.

In hard rock region, there is a growing demand for the groundwater 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 impact of man's activities on surface and groundwater.

The law of conservation of matter applied to the hydrologic cycle defines the water balance. It states that within a specified period of time the excess/deficit of inflow into a storage medium like aquifer over the outflow from the aquifer must either go into storage within its boundaries or be consumed internally. With reference to groundwater regime the inflows include precipitation infiltrating to the water table; natural recharge from the streams, channels, lakes and ponds; groundwater inflows through the boundaries and artificial recharge from irrigation reservoirs, spreading ponds and injection wells. The element of outflow include evaporation from capillary fringe and areas of shallow water table; transpiration by phreatophytes; natural discharge from seepage and spring flow to stream's lakes and ponds; groundwater outflow through the boundaries; and artificial discharge by pumping or wells or drains. Groundwater balance requires that in any interval of time the total inflow does not equal the total outflow and there is no unaccounted for consumption any difference should cause equivalent change in the groundwater storage.

The basic concept of water balance is:

Inflow to the system - Outflow from the system = Change in storage of the system, over a period of time. The general steps involved in the computation of water balance include:

-Identification of significant components,

-Evaluating and quantifying individual components, and

-Presentation in the form of water balance equation as

Inflow - Outflow = Change in storage

Considering the various inflow and outflow components, the terms of the water balance equation can be written as:

$$R_i + R_c + R_r + R_t + I_s + S_i = T_p + E_t + O_s + S_e + \Delta S$$

Where,

R_i = recharge from rainfall

R_c = recharge from canal seepage

R_r = recharge from field irrigation

= R_{rs} + R_{rg}

R_{rs} = recharge from surface water irrigation

R_{rg} = recharge from groundwater irrigation

R_t = recharge from reservoirs and tanks

I_s = Subsurface inflow

S_i = Influent seepage from rivers

T_p = draft from ground water

E_t = evapo-transpiration losses

= E_{tf} + E_{tw}

E_{tf} = evapo-transpiration losses from forested area

E_{tw} = evapo-transpiration losses from water logged area

O_g = sub-surface outflow from the study area

S_e = effluent seepage to rivers

ΔS = change in ground water storage, positive for increase and negative for depletion.

In 1973, Department of Mines and Geology, Govt. of Karnataka carried out the study on Groundwater availability in Ramadurga and Gokok Taluk of Belgaum district to explore the possibilities of developing groundwater for irrigation. Geologically the Taluk is made up of basement gneiss, quartzite, limestone and shale (Kaladgis) and layers of horizontal basaltic lava (Deccan traps). Discharge from the existing irrigation wells in the taluk is estimated to be 8.15 mm^3. The estimated annual recharge to the groundwater reservoir is placed at 20.36 mm3 of water. There is a balance for further development. From the available potential it is possible to provide an additional 800 wells in the taluk during the first stage development. Further, in the same formation in the Gokag taluk of the same district of Karnataka, it is found that there has been large-scale development of groundwater resources. Good well yields 27,300 to 45,460 liters per day and the discharge from the existing irrigation wells is estimated at 36.06 mm^3. There is 7.22 mm^3 of water available for further development. From the available potential it is possible to bring an additional 1,000 hectares of land under well irrigation.

Subramanian in 1980 evaluated the ground water recharge in Noyil river basin, a typical hard rock area in Tamil Nadu during the water Balance Projects executed by the Central Ground Water Board. He employed the water balance method for the recharge estimation. In these areas the ground water recharge occurs from the rainfall as well as from the canal water, which are imported into the basin from outside. The results obtained through this study clearly indicated that within the same basin, the recharge could vary widely from less than 6% to more than 30% of the rainfall depending on the basin characteristics and soil characteristics.

In 1981, Sutcliffe et al. carried out the groundwater balance study for the Betwa basin, a tributary of Jamna, drains from the Deccan Plateau and found the ground water recharge is about 8.6% of the net mean annual rainfall. Athavale et al. 91978) estimated the 8.3% and 6.1% of the annual rainfall to be a recharge during the groundwater balance study in Granite and Gondwana sand stone region respectively.

Muthu Kumaran and Krishnasamy (1984) studied the ground water balance of Madras aquifer. Its forms part of the combined hydrological basins of Araniyar and Kortalaiyar. It has a length of 42 km on the East-West direction and 30 km in the North-South direction at the widest part. The areal extent of the Madras aquifer is 810 sq.km. Seacoast forms the eastern boundary. The Northern and Southern boundaries are mainly impervious formations. The Western boundary is fixed arbitrarily. The Madras aquifer supplies water for irrigation and for a number of major industries situated in and around the city of Madras. It also supplements the city water supply during the water scarce periods. The well fields situated in this aquifer are Minjur well field, Tamaraipakkam well field and Panjetty well field. The required data such as rainfall water level, pumping quantity for the water balance study was obtained from the Public Works Department and MWSSB. Meteorological data were collected from the Meenabakkam observatory and from Tamaraipakkam and Agarambedu meteorological stations, which are situated in the study area.

The inflows and outflow that occur in the Madras aquifer are divided into six flows. The rainfall recharge, irrigation recharge and river bed recharge from the inflows. The outflows are the irrigation abstraction, industrial and city water supply abstraction. Among the above flows the rainfall recharge and irrigation abstraction form the major input and output from the aquifer respectively. The monthly flows are calculated for the years 1976 to 1983. The study indicates that the yearly change in storage is a negative value in each year of the study. The computed yearly change in storage with the change in water level of the aquifer.

In 1993, Ramanathan and Karmegam have studied a water balance study of the Lower Vaigai sub-basin. Rainfall (52 years), surface flow (15 years), evapo-transpiration (12 years), evaporation from water bodies (12 years) and domestic and industrial water needs have all been analyzed in detail leading to a water balance analysis for the Lower Vaigai sub-basin. This study concludes that; (i) The North- East monsoon accounts for a greater part of the annual rainfall confining to a small period between October and December. However, the annual average rainfall remains the same over the years. (ii) The post-monsoon water table is by large at the pre-monsoon level indicating that the ground water pumping is as much as the recharge taking place during the monsoon season and no appreciable pumping during the rest of the period. (iii) There is a general decline in the water table during the eighties indicating that the ground water potential might be going down. (iv)The storage capacity available in the sub-basin is low. (v) The surface inflow into the sub-basin is decreasing at an alarming rate in the recent past. (vi) Evapo-transpiration from the fallow lands (which is nearly 33 % of the area) is as high as 41 % to 71 % of the evapo-transpiration from the cultivated lands.

Chandra Mohan and Chandra Kumar (1994) carried out a study for the estimation of groundwater balance of Ghatprabha representative basin and found that the groundwater situation of the area is steady. For the assessment of net groundwater balance, Water table Fluctuation Approach based on recommendation of the Groundwater Estimation Committee, Ministry of Irrigation, govt. of India was used. Using the available monthly groundwater level data at sufficient number of wells for the period 1989-93, rainfall data of sufficient number of stations and other required data, the recharge coefficient was calculated, which is found to vary between 10.60% to 13.50%.

Marihal and Wodeyar (1995) have been carried out detailed hydrogeological investigations over 2900 km^2 area of the Varada lower basin falling in Dharwar district of Karnataka State. Varada River Lower basin has fairly good groundwater potential and fertile land. The groundwater in biotite schist region could be exploited by dug-cum-bore wells of rectangular shape. Taking into consideration, the present groundwater balance of 123.39 Mm^3 and utilization and density of wells on an average 4-5 wells/km^2 can be sunk in the potential zones of the area, to utilize judiciously the available resources.

Further, in 1996, Shetty and Varadarajan carried out the evaluation or the assessment of the need and availability of water, and the extent of waterlogging in the Gangawati Command area of Tungabhadra project, Karnataka by rainfall analysis, groundwater trend analysis, water requirement, groundwater requirement, groundwater balance, and water quality analysis. The analysis of geohydrological data of the study area shows that, there is urgency for balanced use of surface and groundwater resources available in the study area. However in the past, water resources in the study area have been used with almost complete disregard of subsurface storage and the interrelationship that exists between surface and groundwater resources. The judicial use of subsurface and surface water resources could be the possibility to bring down the water table, which is alarming in the some parts of the study area. Some measures have been recommended for the roper and productive utilization of surface and sub-surface water resources conjunctively.

Recently, Cerntral Ground Water Board (1998) published the detailed guidelines for implementing the ground water estimation methodology and stated the recent Ground Water Committee Norms for calculating various losses occurs during the flow for estimating the ground water balance which are as follows.

i) For seepage loss from the canal, the canal seepage factor is stated below,

Sl. No.	Canal type (Unlined/lined)	Soil type (normal/sandy	Seepage factor in hectare meters per day per million meters of wetted area
1	Unlined	Normal Soil	15 to 20
2	Unlined	Sandy Soil	25 to 30
3	Lined	Normal Soil	3 to 4
4	Lined	Sandy Soil	5 to 6

The above norms strictly apply only for alluvial terrain in which the water table is also relatively deep. The seepage factor in the case of canals in hard rock terrain is assumed to be the same that given above for lined canals in normal soil. The values for the seepage factor as given above may be also suitably reduced in the case of canals in shallow water table and waterlogged areas. In Karnataka and Goa states where greater than 90% of area is underlain by hard rock aquifer unlined canal seepage for normal and sandy soil types, seepage factor are fairly assumed to be 10-12 ha-m per day and 15-20 ha-m per day respectively.

ii) The norms for Return Flow factor for Irrigation Water applied by Surface Water Irrigation is given below,

Sl. No.	Type of Crop (Paddy/Non paddy)	Range of depth to watertable below ground level (<10m /10m to 25m / > 25m)	Return flow factor as a fraction
1	Paddy/Sugarcane	< 10 meters	0.50
2	Paddy.Sugarcane	10 to 25 meters	0.40
3	Paddy/Uugarcane	> 25 meters	0.25
4	Non-paddy	<10 meters	0.30
5	Non-paddy	10 to 25 meters	0.20
6	Non-paddy	> 25 meters	0.10

And the norms for Return flow factors for irrigation water applied by ground water irrigation are as follows

Sl. No.	Type of Crop (Paddy/Non paddy)	Range of depth to watertable below ground level (<10m /10m to 25m / > 25m)	Return flow factor as a fraction
1	Paddy/Sugarcane	< 10 meters	0.45
2	Paddy.Sugarcane	10 to 25 meters	0.35
3	Paddy/Uugarcane	> 25 meters	0.20
4	Non-paddy	<10 meters	0.25
5	Non-paddy	10 to 25 meters	0.15
6	Non-paddy	> 25 meters	0.05

The return flow factor as given above are applicable for rotational supply of irrigation water from the outlet. They are to be increased by another 0.05 if the supply of irrigation water from the outlet is contineous.

iii) The norms for the rainfall infiltartion factor for Hard Rock Terrain are stated below

Sl. No.	Rock type	Rainfall infiltration factor as a fraction		
		Recommended value	Maximum value	Minimum value
1	Vesicular and jointed Basalt	0.13	0.14	0.12
2	Semi-consolidated Sandstone	0.12	0.14	0.10
3	Weathered Granite, Gneiss and Schist with Low Clay Content	0.11	0.12	0.10
4	Weathered Granite, Gneiss and Schist with Significant Clay Content	0.08	0.09	0.05
5	Weathered Basalts	0.07	0.08	0.06
6	Laterite	0.07	0.08	0.06
7	Consolidated Sandstone, Quartzite, Non-cavernous Limestone	0.06	0.07	0.05
8	Granulite Facies like Charnockite etc	0.05	0.06	0.04
9	Phyllites, Shale	0.04	0.05	0.03
10	Massive Poorly Fractured Rock	0.01	0.03	0.01

The Rainfall Infiltration Factor' obtained on the basis of the norms given above has to be incresed by 0.02 for those sub-units in which watershed development with associated soil and water conservation measures are implemented.

iv) The norms for Specific Yield for Hard rrock Terrain are given below

Sl. No.	Rock type	Rainfall infiltration factor as a fraction		
		Recommended value	Maximum Value	Minimum value
1	Karstified Limestone	0.08	0.15	0.05
2	Sandstones	0.03	0.05	0.01
3	Weathered Grinite, gneiss and Schist with Low clay Content	0.03	0.04	0.02
4	Laterite	0.025	0.03	0.02
5	Limestone	0.02	0.03	0.01
6	Weathered or Vesicular Jointed Basalts	0.02	0.03	0.01
7	Weathered Grinite, gneiss and Schist with Significant Clay Content	0.015	0.02	0.01
8	Quartzite	0.015	0.02	0.01
9	Phyllites, Shales	0.015	0.02	0.01
10	Massive Poorly Fractured Rock	0.003	0.005	0.002

The recommended value of the 'Specific Yield' alone as given above is to be adopted, unless results from pump tests indicate that a value diiferent from the recommended value can be used. It can also adopted on the basis of 'Dry season Ground Water balance Method'. This method can be however used, only for the non-command area in hard rock terrain.

3.5 Regional flood formula

The main objectives of hydrological studies of flood is to develop appropriate procedures in order to arrive a desired design variable for the particular structure to be 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 available, 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 un-gauged locations, through appropriate regional multiple regression relationships of statistical parameters of the flood series and cathchment characteristics. The choice of catchment, morphometric characteristics depends on the (1) Judgement of the likely predictive success of variables, and (2) Numerical calculations of regression equations and the interpretation of their coefficients. However, these characteristics are of 10 dodged by correlation, resulting in interdependence amongst independent parameters. 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.

In regional frequency analysis, attempts are made to define a region that is hydrologically homogeneous in terms of the characteristics being studied. Then hydrologic data from several locations within the region are combined for analysis. There are many ways that regional studies can be made. Some methods of importance are USGC Index Flood Method (Dalrymple, 1960), parameter regionalisation method (USWRC, 1977), methods based on regression equations (Benson, 1962) and the regression curve method recommended in U.K. flood studies report (NERC, 1975).

During the first two decades of the twentieth century, the data acquired with the expansion of stream gauging activities were used to advantage by the early practitioners of statistical methods (Jarvis, 1936). This made it possible to relate the peak discharge with the corresponding return period of T-years. Given the flood value corresponding to T-year return period, the prediction of flood flows for un-gauged river basins within the same region may be approached in several different ways. The separate equations may be derived relating the flood value corresponding to T-years return period to the catchment characteristics for each return period. One of most widely used methods of regionalising flood estimates is that devised by the U. S. Geological Survey (USGS) and reported by Dalrymple (1960). The USGS method involves the preparation of two graphs:

(i) A curve based on Gumbel EV-I distribution showing the variation with return period of the ratio between the T-year flood and the mean annual flood obtained from graphical fitting of Gumbel EV-I distribution.

(ii) A plot relating the mean annual peak flood of all the sites to the size of the drainage area of the corresponding sites.

The USGS method has been applied in many parts in which, the catchment area is adopted as the sole independent variable, relating to the mean annual flood as:

$$Q = C\,A^{m}$$

Where,

Q is the mean annual flood by the graphical fitting of Gumbel EV-I distribution to the given annual peak flood series,

A is the catchment area, and

C and m are constant

The form of the curve based on Gumbel EV-I distribution, which is often referred to as the regional growth curve, may be expressed graphically following USGS practice (Cole, 1966) or by means of equation relating the coefficient of variation of observed floods (Nash and Shaw, 1966) or the quotient of the T-year flood and the mean annual flood (Gunter, 1974) to the catchment characteristics. Thiruvengadachari et al. (1975) carried out regional frequency analysis using USGS procedure and annual flood series data for 16 small and medium catchments ranging in size from 133 to 8550 km^2 in magnitude having exceedance probability of 0.43 as index flood $Q_{0.43}$ (m^3/sec) which was related to catchment area A (km^2) and mean annual rainfall R (cm) as follows:

$$Q_{0.43} = 0.0055\,A^{0.79}\,R^{1.11}$$

The frequency curves were derived only for two ranges of index flood (i) $Q_{0.43}$ greater than 93.8m^3/sec and (ii) $Q_{0.43}$ less than 357m^3/sec. In 1980, RDSO and Central water commission prepared a report indicating a method for any un-gauged basin in the subzone of Lower Godavari (sub-zone 3-f) to arrive at a 50 year return period flood based on Unit Hydrograph Principle. The rainfall and runoff data has been supplied by the Research Designs and Standards Organisation of the Ministry of Railways, the rainfall depth-duration frequency studies, areal-point rainfall relationship and the time distribution of these storms are made available by the Hydrometer, Directorate of India Meteorological Department. Processing and analysis of data for deriving unit hydrograph, establing relations to develop synthetic hydrographs, developing general methodology for estimating 50 year flood for small and medium un-gauged basin of the sub-zones and preparation of this report are done by the Hydrology (Small Catchment) Directorate of Central Water Commission. Processing and analysis of data for catchments less than 75km^2 was done by RDSO.

Further in 1985, RDSO and CWC carried out a flood estimation study for Upper Godavari Subzone-3 (e) to estimate the design flood for fixing the waterway of bridges and culverts. The sets of flood formulae based on regression analysis were estimated to compute the 25years flood, 50 years flood and 100 years flood. The sets of N-year flood formulae were used to find out the general features of Upper Godavari. The nature and period of data collected, analysis of storm rainfall and flood events to derive the unit graphs, relationships between physiographic and unitgraph parameters of the gauged catchments to derive synthetic unitgraph for un-gauged catchement, design storm rainfall, design loss rates, baseflow, computation of design flood peak and hydrograph for un-gauged catchments, design storm rainfall, design loss rates, baseflow, computation of design flood peak and hydrograph for un-gauged catchments, formula for linear water way of the cross drainage structures were also analysed. It also recommends the estimation of design flood for small medium catchments varying in size from 25 to 2500 sq. km. Further, it may be used for larger catchments also. The utility of the report for frequency flood estimation in respect of small dams and minor cross drainage structures has also been brought out.

Perumal et al. (1985) has studied the Gumbel's parameter estimation method of EV-I distribution by using Monte Carlo tests. In earlier studies on the Gumbel's parameter estimation of EV-I distribution, in which sample size are corrected by using Weibull plotting position formula, demonstrated that it gives poor estimates when compared with other two methods viz., the method of moments (MM) and the method of maximum likelihood (MML). In this study the Gumbel's method is modified by replacing the Weibull plotting position formula by that of Gringorton formula, the most suitable for EV-I distribution plotting. The method is tested for bias, variability and root mean square error (RMSE) in the estimates with reference to the estimate of MM and MML. Study shows that even after incorporating Gringorton plotting position formula, the Gumbel estimation method is still biased and more variable in comparison with the MM and MML methods. It is also shown that MML is the most suitable parameter estimation method for Gumbel EV-I distribution.

An application of Probability Weighted Moment (PWM) technique of parameter estimation to regional flood frequency analysis was proposed by Landwehr et al. (1979) and Wallis in 1982. The method posses to combine regional and site specific information by simple averaging and scaling. Moments of the regional distribution are obtained by simple averaging of the respective probability weighted moments at each site. The regional quantile estimate is then obtained by scaling at sites estimate by a regional estimate of the mean. This methodology appears to work well for situation where records are extremely short and streamflow observations are highly skewed and highly kurtotic.

Perumal and Seth (1985) have suggested a regional analysis approach in which the annual peak flood data of each gauging site is normalized with reference to the mean annual flood and based on the assumption that normalized series of different gauging sites are the realization from a single population. These normalized samples of different length are combined to form a single series. Analysis is performed on this series to estimate the normalized floods of required return periods. The mean annual flood is related to the catchment area as adopted in the Index-Flood method.

Singh and Seth (1985) have suggested the use of Wakeby distribution for regional frequency analysis. In this method, the regional parameters of Wakeby distributions are estimated using the probability weighted moments technique and the catchment area is related with the James-Stein corrected mean (as quoted by Wallis, 1982). The regional parameters of Wakeby distribution and James-Stein corrected means are used to estimate floods of different return periods. The results obtained in this study indicate good performance of the procedure adopted for regional frequency analysis.

Hydrological data contain errors which, are introduced during measurement, recording and processing. The measurement errors in the data result in erroneous assessment of the design flood. The under estimation or over estimation of the design flood due to measurement error in the data lead to under design or over design of the water resource structures. If any structure is under designed, then the risk of its failure increases. On the other hand, over design of any structure may lead to an uneconomic proposal. The effects of errors in the observed data are highly pronounced on the design flood estimation. In case of design flood estimation by flood frequency analysis, the observed values of the peak discharges are used which are more prone to measurement and other types of errors than the normal flow data. Such errors may lead to wrong estimation of design flood during extrapolation; as the design floods are usually estimated for a very large recurrence interval on the basis of short record length.

It is further observed that effects of errors in design flood estimation follow a well-defined trend in case of the systematic errors. Once the type of the error is identified and the extent of errors at a particular site is established, it may be suitably incorporated in the design flood estimation by flood frequency analysis after proper studies (Haque, Rakesh Kumar and Jose, 1990).

Huq (1985) carried out regional flood frequency studies of Cauvery basin subzone 3 (i) using multiple regression technique for developing relationship between frequency flood (Q) as dependent variable and physiographic parameters like catchment area A (km^2), slope of main stream S (m/km), percent of surface storage area of tanks plus 0.5 percent, St., length of main stream L (km), shape factor of the catchment, Sh = (L_2 /A), 24 hour rainfall in cm of recurrence interval T years I_T as independent variables. The data of 23 catchments ranging in size from 66 to 10619 km^2 was used for analysis using Gumbel distribution. It was seen that relationship involving A, S and S_t, provided better and reliable estimates.
Some typical relationships are as follows:

(a) Return period T = 2 years

$Q_2 = 0.628\ (A)^{0.902}$, r = 0.884

$Q_2 = 0.38\ (A)^{0.98}\ (S)^{0.007}\ (St)^{-0.52}$, R=0.9238

(b) Return period T= 100 years

$Q_{100}=5.88(A)^{0.757}$, r=0.8624

$Q_{100} = 1.17(A)^{0.96}\ (S)^{0.32}\ (St)^{-0.42}$, R=0.8925

Where r is simple and R is multiple correlation coefficient.

In 1986 Venkataraman et al. presented a regional flood study for subzone 3(f) in lower Godavari basin using 26 years data of 14 small and medium railway bridge catchments with areas ranging from 15 to 824 km^2. At these sites, the daily peak flood stages are observed during monsoon and are converted to discharge values using rating curves. The rating curves are based on regular gauging observations of both stage and discharge. Before proceeding for analysis, the length of peak flood data for all 14 sites was brought to common length using some procedure not stated by authors in their paper. They examined choice between (i) general extreme value (GEV) and Gumbel EV1 distribution, (ii) regional pooling of data vis-à-vis averaging of ratios of floods for particular return periods to mean annual flood obtained at individual sites, and (iii) using parameters like catchment area A (km^2) , length of main stream (L) statistical slope S, 50 years 24 hour point rainfall R24 (cm) and 2 year one hour point rainfall R1 (cm) for developing regression relations with mean annual flood Q taken as $Q_{2.33}$ (m^3 / sec) , for important hydraulic structures. The authors concluded that for subzone 3(f), the mean annual flood can be expressed satisfactorily as a function of A and R_1 or only A, as follows:

$Q_{2.33} = 1.23\ A^{0.74}\ R1^{-0.98}$

$Q_{2.33} = 7.1\ A^{0.755}$

It was further concluded that 50 years return period flood could be obtained from graphical approach as per USGS method. For less important structures, where economic considerations may decide the choice, the authors suggested use of GEV growth curve.

Thirumali and Sinha (1986) carried out regional frequency analysis for 14 small and medium railway bridge catchments in Krishna Basin, having catchment areas ranging from 30 to 730 km^2 and flood series from 6 to 26 years. Mean annual flood Q (m^3 / sec) was related with catchment area A (km^2) and 2 year 24 hour point rainfall R_{24} (cm) as follows.

$Q = 3.35\ A^{0.682}$

$Q = 1.009\ A^{0.664}\ R_{24}{}^{0.64}$

The used Chow's approach modified by Nash in the analysis.

Seth and Singh (1987) have further used this approach with the Wakyby distribution using data of catchments for Lower Godavari basin subzone 3(f) and obtained encouraging results. The following relationships were obtained:

(a) Lower Godavari subzone 3(f)

$JSM = 9.02\ A^{0.71}$

Where JSM is James Stein corrected mean annual flood (m^3/sec) and A is catchment area in km^2.

In order to evaluate the predictive ability criteria, synthetic flood series have been generated using the regional EV1 and GEV distribution parameters, derived from the historical records. Generated data sets have been considered for 10 sites for a specific record length (same as the record lengths of historical data for respective gauging sites) and two independent sites, considering one at a time, of variable record length (1,5,10,2024,30 or 40). EV1 (PWI) method has been applied to the generated data of different sample sizes for an independent site considering 1)at site data, 2)at site and regional data, obtained from the generated data of the ten gauging sites, and 3) regional data alone involving the relationship between the mean annual peak flood and catchment and the regional parameters for the concerned distribution. The computations have been repeated for second independent site on the same lines. Similarly, GEV (PWM) method was also applied to the generated data and computations have been made for the two independent gauging sites taking different sample sizes. The performance of different methods have been evaluated based on the predictive ability criteria viz. bias, coefficient of variation and root mean square error computed from the generated samples of different sizes by considering 1000 replications of the computation procedure for each sample length. The results obtained from EV1 (PWM) and GEV(PWM) with generated data of two different populations have been compared for the different methods. It is seen that the method based on GEV (PWM) approach using at site and regional data in a combined form, provides estimate of flood peaks for different recurrence intervals with computationally less bias and, comparable root mean square error and coefficient of variation for the independent catchments. The study, thus establishes the applicability of GEV(PWM) approach for regional flood frequency analysis's. Considering at site and regional data in the combined form of the Godavari Basin sub-zone(3f) region.

James et al (1987) has carried out regional flood frequency analysis using data from nine stations in the Chaliyar river basin of Western Ghat region. The relationship between mean annual flood Q (m^3 / sec) and area A (km^2) was obtained as:

$Q = 3.53\ A^{0.37}$

The estimation of the extreme flood at a site is required for the design of a variety of urban planning and river engineering works. An accurate estimation of extreme flows for the associated recurrence interval is difficult to obtain if the length of the available stream flow records at the site of concern is shorter than the recurrence interval of interest. An even greater difficult occurs if there is no flow record available at the site of interest. To cater the problem arising due to an insufficient length of data record, the trade off between the spatial and the temporal characterization of extreme flows can be effected through the use of regional flood frequency analysis. Regional flood frequency analysis facilitate the estimation of an extreme flow value at a location for which limited flow data exist, basin on an extreme flow relationship derived using the information from basins with similar hydrologic responses.

This report describes the study of regional flood frequency analysis using peak flood series data of 34 gauging stations of Krishna basin using the following methods.

i) Index-Flood distribution

ii) PWM based EVI distribution

iii) PWM based GEV distribution

iv) PWM based Wakeby distribution

Out of 34 sites, 6 sites were omitted after USGS homogeneity test. From the remaining 28 sites, 26 sites were considered for analysis under 3 different sub-group i) medium catchments, ii) large catchments and iii) considering the basin as whole. In order to evaluate the fitting performance of different methods used, some of the error functions respectively their descriptive ability are computed. The results indicate that, the Index-flood approach and PWM based EVI distribution are best suited for medium catchments for the basin as whole. However, it is recommended to include the other physiographic characteristics also for developing more rational regional flood formulae using good database.

Recently, Venkatesh and Singh (1999) developed the regional flood formulae for Krishna basin covering the part of Karnataka and Maharashtra states. The study has been carried out using Index- flood and EV-I, GEV and Wakeby Distribution. The gauging sites at Shimoga and Marol having a catchment area of 2831 and 4901 km^2 are considered as test sites to verify the developed regional flood formulae under different cases namely, i) medium catchment, ii) large catchment and iii) considering the basin as a unit. The gauging records of the two test sites were used to compute the parameters of Index-flood, PWM based EV-I distribution, GEV distribution and Wakeby distribution. The relationship between catchment area, mean annual peak flood and the return period of the flood are given as follows

For Medium catchment,

1.Index- flood method: $Q_T = (37.93 + 19.73(-\ln(-\ln(1-1/T))) A^{0.39}$

2. EV-I Distribution method: $Q_T = (36.94 + 21.45(-\ln(-\ln(1-1/T))) A^{0.39}$

3. GEV Distribution method: $Q_T = (117.43(-\ln(1-1/T))^{-0.155} - 81.87) A^{0.39}$

4. Wakeby Distribution method: $Q_T = (2.219+21.65(1-(1-F)^{16.095} - 457.7(1-(1-F)^{-0.055})) A^{0.39}$

For Large catchment

1.Index- flood method: $Q_T = (4.136 + 1.809(-\ln(-\ln(1-1/T))) A^{0.64}$

2. EV-I Distribution method: $Q_T = (4.032 + 1.974(-\ln(-\ln(1-1/T))) A^{0.64}$

3. GEV Distribution method: $Q_T = (51.56(-\ln(1-1/T))^{-0.037} - 47.56) A^{0.64}$

4. Wakeby Distribution method: $Q_T = (1.318+1.695(1-(1-F)^{5.25} - 49.31(1-(1-F)^{-0.55})) A^{0.64}$

Considering basin as a unit

1.Index- flood method: $Q_T = (13.71 + 7.03(-\ln(-\ln(1-1/T))) A^{0.52}$

2. EV-I Distribution method: $Q_T = (13.58 + 7.25(-\ln(-\ln(1-1/T))) A^{0.52}$

3. GEV Distribution method: $Q_T = (65.60(-\ln(1-1/T))^{-0.1} - 52.35) A^{0.52}$

4. Wakeby Distribution method: $Q_T = (3.16 + 6.16(1-(1-F)^{9.165} - 4211.54(1-(1-F)^{-0.002})) A^{0.52}$

The flood values obtained from these methods (independently applied on the data of test sites) were compared with those values computed for test sites using the developed regional flood formulae. It is observed that the flood estimated using the relationship developed between Q_T and catchment area (A) using Index-flood method and PWM based extreme value type-I distribution for the medium catchments and the case of considering the basin as a unit yielded very good result. The ratios of absolute difference between observed and estimated using the regional parameters is very low for those methods compared to the ratios obtained by other two methods for most of the cases. It is concluded that for the basins having catchment area below 5000 km^2, the following equation can be used for the estimation of quantiles quite accurately,

$Q_T = (36.94 + 21.45(-\ln(-\ln(1-1/T))) A^{0.39}$.

For the case of considering the basin as a unit, it is seen that the regional coefficients of the EVI distribution are different than the coefficients for the medium catchments and it is shown below,

$$Q_T = (36.94 + 21.45\,(-\ln(-\ln(1-1/T)))\,A^{0.39}$$

Also, the study reveals that, the size of the catchment plays an important role in developing the regional flood formula. For the basin having catchment area of 5000 km^2 and above the relation could not be established, as there are few gauging stations in the basin which falls in this category.

3.6 Tank studies

Irrigation systems in India are being categorized for administrative purposes into major, medium and minor irrigation works. Major irrigation works are generally constructed on perennial rivers involving large dams and canals irrigating many thousands of hectares, while medium irrigation works consist of reservoirs to store run-off water, so called large "tanks". The category of the minor irrigation works includes all surface and ground water resources, which cost less than RS. 2.5 million per project with a command area of 2000 hectares or less (Yon Oppen and Rao, 1980).

A tank is a small storage reservoir constructed using the locally available materials and is mainly used to impound the runoff from the monsoon rains, which occur during a few month of the year and to regulate the water for agricultural purposes. These tank also helpful to recharge the groundwater potentials and facilitate supplemental irrigation wells. Tanks can be grouped into system tanks or non-system tanks. System tanks are those, which receive supplemental, water from nearby streams in addition to the yield from their own catchments. The supplemental flow help in stabilizing irrigation supplies and in most cases lead to an additional crop possible. Irrigation through system tank is possible even if there is no rain in the location of the tank but due to the water from the feeder stream. Non-system tanks depend mainly upon the rainfall in their own catchments. These tanks are not connected to any river system. But, the non-system tanks may receive the surplus from an upstream tank of the same kind.

As per the function the tank can be grouped into irrigation and percolation tank. An irrigation tank is a small reservoir constructed across the slope of the valley to catch and store water mainly for the purpose of the irrigation. Percolation ponds or tanks are essentially small tanks whose area can be approximated to 1 hectare and less. The water that gets stored can percolate, depending upon the soil quality. If the soil is completely sandy, the percolation reaches the groundwater reservoirs directly below the tank surface. This is not of any use. Instead, if the substrata of soil are of clayey one, the percolation need not necessarily be vertical, but the dispersion can be lateral, also. This dispersion of lateral flow is of vital interest and this is the one to be tapped. A chain of percolation ponds in very steep slopes may be very helpful in improving the groundwater table and recharges potential of the wells in the terraces. Everywhere people are conscious of the increasing rate of carbon dioxide level in the atmosphere. This necessitates a deep involvement into all aspects of global, regional and micro climatological factors and their control. In this context, percolation tank/pond is the answer at microclimate level. It is possible that a chain of percolation pond may play a vital role in the reduction of carbon dioxide level in the atmosphere.

Percolation ponds or tanks, for convenience, may be defined as a system of ponds either along the streams or besides, natural or man-made in generally low-lying areas. The percolation tanks are used to impound water, and hence used to recharge the downstream zones for the benefits of the farmers. However, the water so impounded in the ponds is not directly used in irrigation but is used only in recharging the underground water, which may be used for irrigation. If man-made, the water may at times overflow the embankment across the stream and such water may be used in filling up similar tanks at downstream (Thiruvengadasamy, 1989).

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 tanks are widely distributed in many parts of Karnataka, Tamil Nadu, 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 dugwell. 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).

In this century, more and more complex water resources systems have come into practice due to constantly increasing demand for water. For planning and subsequently operating such systems, quantitative information regarding availability of water at a particular location through out the year is needed. The yield models give this information. However, data inadequacies pose a problem in hydrologic analysis of yield. For assessment of inflows, rainfall-runoff relationship has to be established using long term records of precipitation, evaporation and discharge observations. When some of these data are not available, it is difficult to assess the inflow and it becomes necessary to go in for a simple procedure so that with the available data inflow can be estimated. The water balance approach is used to assess the inflow at the desired location.

However, the purpose of construction of tanks 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.

In 1978 NGRI prepared a report on tank study. The Guntur Municipality is at present utilizing groundwater and surface water, the former from infiltration galleries at Vengalapuram and the latter from Krishan canal drawn at Commamur village. Water supplies from these two sources are quite limited and hence they cannot meet the growing demands of this city. Badarupalli major canal of the Nagarjuna Sagar canal system is a major source and is close to Guntur. Required quantities of water can be drawn from it and supplied to the city, that too without pumping due to its higher elevation, but not round the year because of its closure during summer months. In order to have uninterrupted supply of water from this Bandarupalli major, the Department of Public Health, Guntur, proposed formation of a summer storage tank (SST) for storing water in it when the major is full besides direct supply to the city, so that the stored water can be utilized during the summer months.

The site proposed for the formation of the summer storage tank is located in a hilly terrain near Pericherala, about 10 kms form Guntur. It has an area of about 180 acres, sufficient enough to form reservoir of the required capacity. The ground here is flat and is surrounded by hills, which serve as natural bunds covering large distance. Retaining walls have to be constructed only in the saddles, the building material for which is readily available within the easy reach in the surrounding hills. Further, water once stored here can be supplied to the city without pumping by gravity. Thus it can be seen that this site offers several engineering conveniences.

Now it has to be examined whether this site allows easy formation of watertight reservoir by offering sound bedrock at workable depths devoid of undesirable geological of retaining walls. This can be done by carrying out drilling at regularly spaced points, but it is highly expensive, tedious and time consuming, whereas geophysical methods are quite cheap, relatively easy and comparatively quick, and they give reliable estimates of depth to bedrock and allow easy inference of the presence of otherwise of the undesirable geological features.

Engineers, planners and all concerned with water resources require an estimate of evaporation losses from lakes and reservoirs from the efficient reservoir operation and water balance studies, especially in arid and semi-arid region and in drought affected area while designing drought alleviation schemes. The exhaustive and detail review of literature indicated that the method of mass transfer and penman equation can be considered as good alternative to provide relatively better estimates of evaporation losses from lakes and reservoir in the absence of large amount of data required for the energy budget method. The evaporation loss obtained for Bhadra Reservoir Project by using mass transfer method generally points towards a lower value. Estimate obtained by Penman method appear to be relatively more reliable and in this period pan coefficient is also relatively more in winter period (i.e. 0.99) as compared to that of summer period (i.e. 0.88) which is same as the normally accepted trend (Goyal and Sikka, 1987).

Prabhakaran and Gopalakrishnan (1987) have studied Watershed Bounded Network Model (WBNM) with only one parameter; namely "C" is used to model the rainfall excess-surface runoff relationship. This model is based on more detailed consideration of geomorphological relation and contains two different types of storage elements. These represent ordered basins where rainfall excess is transformed into runoff and interbasins area, where there is the additional component of transmission of upstream runoff. The relations used for transformation and transmission are different. Linear and nonlinear versions of WBNM are available. In the linear version, the lag is constant for all storms events and is related to the size of the sub area whereas in nonlinear version the lag is related to both sub area and instantaneous discharge. Computer programs are available for nonlinear model with areally uniform and areally varying rainfall excess.

The irrigation tank considered for the application of WBNM is Padianallur tank located in Chengalpattu district. Nonlinear version of WBNM is applied to this tank. The rainfall excess is assumed as areally uniform. Out of 12 storms identified from five years data, 8 storms are considered for calibration of the model after drawing the model structure for each of the sub basins. The value of "C" which gives maximum correlation coefficients between observed and computed hydrographs are obtained for all the 8 storms for different routing periods. The "C" value range from 1.0 to 8.0 for any routing periods. Since the correlation coefficients for the 8 storms used for calibration using this mean "C" value do not vary significantly with the maximum correlation coefficients of the 8 storms, a mean value of 'C' is suggested to the model.

Pardhasaradhi (1989) has studied the percolation tanks in Maharashtra State. Many tanks were constructed thereby impounding minor watercourses. The average catchment area is 3.5sq. km. with average gross storage of 200 TCM- both with a high coefficient of variation. There are about 475 such tanks in the Sina and the Man basins where a representative study is made by selective monitoring of the tank levels, content, ground water levels in the wells and evaporation rate. Evaporation on an average accounts for 10.7 % of the total depletion of the tank contents. An average percolation rate of 45 mm/day was estimated for post monsoon period, which may include the visible seepage appearing in watercourse downstream. Those wells, which are influenced by percolation show increased yield of 10 to 30%, by taking into consideration water levels and time factor. Similarly, In 1989 Central ground water board in collaboration with Directorate of Irrigation and Research Development, Government of Maharashtra has undertake tanks study in Jeur sub-basin, Ahmednagar district of Maharashtra State. The basin has 12 percolation tanks with a total storage of 626 Th. cu. m. The study concluded that around 11 percent water stored in the percolation tank goes as evaporation, and 39 per cent goes as visible seepage, the residual 50 per cent goes to recharge to ground water. The visible seepage also recharge to ground water body far from percolation tanks (Kittu et al., 1990). Subramanian made an attempt to bring out the influence or control exerted by the geology on the presence of tanks/ponds and the cropping pattern in Bhandara District of Maharashtra State. Similarly, Kulkarni et al. (1990) studied the percolation tanks and their contribution in recharge of ground water in Maharashtra State. The study concluded that, if the geology is favourable, and adequate CCA is available on the downstream, percolation tanks can be successful and overall efficiency of utilization of water is high, as no conveyance losses are involved.

Murlidharan et al. (1990) was carried out resistivity surveys and recharge measurements on the bed of a percolation tank having sandy-loam soil and granitic basement. Schlumberger resistivity soundings were observed at ten locations and the data was used for preparing a contour map showing depth of bedrock. The average interpreted depth was found to vary between 0.5 to 5.0 m in the impoundment area. Detailed interpretation of the resistivity soundings indicated possible existence of fractures at few locations. Recharge measurements were carried out at eight locations by using the Tritium injection technique.

The injection sites were aligned across the tank-bund axis and were located at distances of 11,20,40,60,100,150,200 and 300 m from the tank bund. Tritium was injected in June 1985 and soil cores were collected with an auger tool in January 1986, after the tank bed had become dry again. The soil core collection could be made down to depths ranging between 1.5 to 1.7 m only, as the basement along the injection axis was shallow. Tritium and moisture content of various depth sections of the soil cores were measured and recharge values were calculated from these data. There was practically no tracer movement (no recharge) in the case of five out of eight injections. Recharge in the case of the remaining three sites were also found to be rather small ranging from 32 to 70 mm. The three sites were in areas where the resistivity soundings had indicated existence of fractures.

These studies indicate that the overall percolation rate in the particular tank during 1985 - 86, was rather low and restricted to specific favourable zones. The shallowness of the basement and the existence of shallow water table conditions both in the tank bed and in the immediate command area, even in the premonsoon period, are considered to be the plausible causes of poor infiltration. It is suggested that construction of a series of micro-percolation tanks or check-dams having less storage depth may be a more appropriate and economical alternative in hard rock terrain having thin soil cover.

Chandrasekaran and Palanisamy (1990) have studied the percolation tanks constructed in Coimbatore district of Tamil Nadu. The main thrust of this study has been to quantify the recharge in relation to soil characteristics. Twelve percolation ponds located at difference places of Coimbatore district were chosen. Hundred open wells both u/s and d/s of the percolation ponds were taken up for study. It is concluded that the percolation ponds produce tangible and intangible benefits, enhancing the land value 5 times. Aerial recharge per ponds was 5 to 10 ha and sodic soils are not suited for recharging the ground water. It is also visualized that the construction of a large number of smaller percolation ponds would be more beneficial. Further, Kulandaivelu and Jayachandran (1990) has undertaken a study in Coimbatore taluk, Tamil Nadu State to find out the extent of ground water utilization and methods of recharging so as to maintain the water balance. The study revealed that there is an over exploitation of ground water and every year the water table is going down by 25.3mm. An empirical assessment of crop water demand based on the climate for the cropping system in Coimbatore taluk of Tamil Nadu was worked out following modified Penman method.

Narsimha et al. (1990) studied the impact of percolation tanks on the groundwater regime in hard rock areas of Andhra Pradesh. It was concluded that the appropriate combination of check dams, percolation tanks will offer the most cost-effective solution for the artificial recharge measures.

Experience has shown that percolation ponds are one the best measures to impound surface water to aid in the recharge of ground water. In order to evaluate the usefulness of a percolation pond, the influence zone must be identified. We compare the efficiency of a fluorescent dye tracer method with conventional methods to delineate recharge zone. The percolation pond in Sarkar Nattarmangalam village in Salem taluk was monitored by Mohandoss et al. (1990) for water levels in 53 wells considered to be in the influence zone, quantity of water pumped for irrigation and meteorological data from August 89 to January 1990. Water samples from the wells were monitored for chloride ion monthly. Rhodomine B was used as the fluorescent dye tracer. The tracer method indicated only 32 of the 53 wells in the proposed influence zone as actually benefited (1300x450-1000m). The ground water slope method gave infinite zone of influence. The chloride ion method gave a larger zone of influence than the tracer method. However, water balance study by ground water level fluctuation and adhoc norms method gave similar results only when the zone of influence indicated by the tracer method is used.

A comparison of water balance arrived by the two methods indicated almost similar results. The zone of influence used for these calculations are based on the area delineated by Rhodomine B dye tracer method. Therefore, it can be suggested that the dye tracer method is a more reliable direct method with greater general applicability.

Subramanian, (1990) has studied percolation pond at Krishnakuppam, located in a tertiary formation, overlain by laterite as topsoil. From the detailed field test and data observed, it is concluded that the zone of influence of recharge is about 500m. It is summarised that a system of percolation ponds may improve the ground water potential. It is further suggested that periodical maintenance of the pond is necessary to maintain the recharge.

Madhavi Ganesan and Ambujam (1993) have taken a study on temple tanks to infer its storage potential, recharging capacity, effects of landuse pattern on the temple tanks, storm water drainage system feeding the tank. To estimate yield from the catchment SCS Curve number technique is used. The catchment area of 61,286-sq. m for the Tirupporur tank is delineated by the field survey using Digital Theodolite. Rainfall analysis was done for a dry, average and wet years in a series of 22 years daily rainfall data. It is found that 61,286 sq. m was to fill the tank on any average rainfall year and had a 5 feet depth of water at the beginning of next monsoon. This was verified by field observation for the North-East monsoon of 1992. Mylapore temple tank, which has been dry for the past five years had no obvious o the original catchment left because of the rapid urbanization. Hence reduced levels were taken to delineate the boundary of an area which would act as a catchment. The aerial photographs were used to interpret the landuse pattern. As a first step a small area of 1,40,000 sq. km was identified which already had storm drains and rainfall analysis of this area showed that it could yield 8 feet of water to the tank on an average rainfall years. The field observation for 1992 showed that the tank had received 6 feet of water by the end of this year. So to fill the tank to its full capacity during and by the end of the North-East monsoon season can additional area of 3,81,663 sq. km is identified. The study recommended that the storm drains should be laid in this area and diverts water to the temple tank. As the tank bed was already been made with highly plastic puddle clay, the percolation has been brought to a minimum. The unavoidable evaporation loss being 6.75 feet per year, the tank will retain enough water till the beginning of next monsoon. Thus serving as a storage pond discharging its function as a direct use. Storage tank for the temple as harvesting the precious rain water from an urban landscape.

Tanks are structures, which impound water for irrigation and other uses. To have more than one crop in a tank command conjunctive use of tank water and ground water is important. An attempt has been made to view the tank irrigation holistically tanking into account all aspects. An LP model is formulated considering all the above factors and to get maximum returns from the command. An irrigation schedule is prepared for the optimized area, which gives the maximum returns. The result shows that in 1989 the profit is maximum with less irrigation. IN 1988 the profit is atleast and the number of wetting are more (Chandrasekhar and Thayumanavan, (1994)).

Basaveswara Rao and Anji Reddy (1994) studied a general Remote Sensing method for monitoring suspended sediments concentrations for a surface water body of Husain Sagar lake I Hyderabad (A.P). Water samples are collected from the lake on the day of overpass of IRS-1B Satellite i.e. 23 rd January. Twenty-four samples are collected. These samples are analyzed to determine the suspended sediment concentration at the predetermined sample locations. The 3*3 pixel array was used for the development of the mathematical model of the stimulation of suspended sediments concentration. The regression techniques are used to develop the model by considering the four IRS Bands and measured suspended sediments concentration (SSC). The measured SC is taken as the dependent variable and the mean radiance values in all the four bands of IRS are used as independent variables in developing the regression models. All the combinations of bands are considered for the development of the best model. This model is validated using test at 95 % confidence level. The best fit model for 1994 is compared with the 1992 model developed by earlier investigators. The best fit model consists of B1 and B2 and B3 as partial coefficients. The earlier studies also show that the partial coefficients of the best fit model are also B1, B2 and B3. Hence, it is confidently concluded that the bands B1, B2 and Be of IRS can be utilized for the estimation SSC and also can be utilized for the preparation of the map showing the spatial distribution of nay physical water quality for the preparation of the map showing the spatial distribution of any physical water quality parameter in any surface water body like Hussain Sagar Lake.

3.7 Reservoir sedimentation

Soil erosion and reservoir sedimentation are the threats to the water resources development in our country. The surveys conducted in some of the reservoirs have indicated that siltation not only occurs in the dead storage but also encroaches in the live storage zone which impairs the intended benefits from the reservoir. Sedimentation in many reservoirs is encroaching on the live storage resulting in continuous reduction in its capacity. The decrease in storage capacity impairs the functioning of the reservoir for which it has been designed.

Sediment deposition is a continuos and complex problem drawing the attention of many hydraulic researchers. Sediments in a river originating from the land erosion process in the catchment area are propagated along with the river flow and are deposited in the reservoir, thereby reducing the storage capacity, increasing the back water levels, forming shoals and affecting intake of irrigation and power channels. Frequent hydrographic survey mainly involves with depth measurements at known positions and usage of the data to determine level versus spread area and level versus capacity of a reservoir. The contour map prepared by using the same data may help in identifying preventive measures.

This problem of sedimentation starts with the impounding of water in the reservoir. When the sediment laden flood water enters the reservoir the velocity of the inflowing current is reduced. Consequently nearly all the coarser particles, including sand/gravel and boulders are deposited in or near the tail end of the impoundment. The silt and clay particles remain in suspension longer and are carried forward into the water body where deposition takes place.
The following factors are responsible for reservoir sedimentation (Rao et al, 1990)

(i) Physical and hydrological characters of the catchment

(ii) Trap efficiency of reservoir, method of reservoir operation

(iii) Intensity of erosion in the catchment

(iv) Landuse pattern in catchment

(v) Quality, quantity and concentration of the sediment brought down by the river

(vi) Growth of vegetation at the head of the reservoir

One of the important aspects of planning of reservoirs by 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.

Poondi (1989) studied the sedimentation in Manimuthar Reservoir to determine the rate and pattern of silting in the reservoir by conducting survey operations such as Ground Survey, Echo Sounding etc. and thereby assess the useful life of the reservoir and to estimate the rate of silting. This reservoir is situated in Tirunelveli District of Tamil Nadu. This reservoir surrounded by a range of hills and dense forests. There are six rainfall stations within the catchment of the reservoir. The average rainfall of all stations during South-west monsoon is 108 cm and during North-east monsoon is 167 cm making a total of 275 cm. The capacity of the reservoir at FRL is 156 M C M. Range pillars have been erected along the periphery of the FRL both in Right Flank and Left Flank and Geodetic survey has also been done to fix the location of the range pillars. Levels of the waterspread across the range have been taken by hydrographic survey using echo sounder. Portions not covered by hydrographic survey have been covered by ground survey (Poondi,(1981)).

The following conclusions have been arrived at:

a:This reservoir can be classified as foot hill type

b: While the original capacity of the reservoir at the time of construction was 159.73 M cu. m(including the borrow pint quantities, the present capacity of the reservoir as per the survey is 155.41 M C M . The loss in total capacity over 22 years thus is 4.32 MCM. the annual rate of silting works out : 2705 / and average annual rate of silt load coming to 0.1212 Mcm/100 sq.km., the possible reason for the higher silting rate could be due to a heavy precipitation experienced by the catchment.

c. Trap efficiency of the reservoir is 95.8%.

d. The life of the reservoir is worked out to be 576 years trap efficiency estimation method.

For the economic design and successful operation of a reservoir it is necessary to predict the storage loss, sediment deposition and its distribution with respect to time. Though extensive work has been done in the area of sediment transport, due to the complexity of many variables involved in the process of erosion, transport and deposition of sediment, a universally acceptable method could not be evolved so far. The limitations in the calculation methods for prediction of storage loss, sediment deposition and its distribution. Though the prediction of distribution of sediment, a universally acceptable method could not be evolved so far. The limitations in the calculation methods for prediction of storage loss, sediment deposition and its distribution. Though the prediction of distribution of sediment is an inexact procedure, several approaches have been developed based on the existing data. Chandramouleeswaran and Narayanan, (1984) applied the semi-empirical method, developed by Garde et al. to Krishnagiri, Satanur and Vagai reservoir. The semi-empirical method gives an estimate of the life of the reservoir, which agrees fairly well with that of the estimate made using the present annual rate of silting. Also, when the deposition is of delta type, the deposition profiles predicted by this method resembles the actual observed profiles.

Techniques used in modern sediment engineering require knowledge of the fall velocity of the natural particles, dimensionless parameters were employed to give general solutions to the equations involved. The principal parameters used to be the Reynold's number plot revealed certain deficiencies and a parameter settling velocity to that of a sphere having the same volume as that of particle, is used instead of coefficient a drag. Particles were selected from previous investigator data. The shape factor of these particles was computed. By having the fall velocity and the shape of the particle, the dimensionless parameters previously listed could be computed and graph of settling velocity ratio vs. Reynolds's number with shape factor as acting variable could be prepared. the data obtained by Schule on natural particles and Masaika on artificial particles was also plotted on the graphs. Other information regarding the relation of fall velocity to shape factor have also been investigated by Kumar and Rao,(1986).

Sediment yield studies have undergone major changes in the last three decades. In India, the studies concerning the effect of land use changes on sediment yield are limited and are mostly on the experimental watersheds. Very few attempts have been made to study the effect of land use changes on the sediment production for large catchments. The problems of erosion and subsequent sediment yield are very wide spread and are of great concern to hydrologists and water resources engineers. The phenomena of sedimentation affect the reservoirs, lakes, rivers and other water bodies. This sedimentation would, in a big way, depend upon the soil loss or silt production in the catchment. The silt production soil loss would largely depend upon the land use pattern and land management practices. In 1986, Bhatia has made attempt to present the results of various experimental studies conducted by researchers in India for the amount of soil / loss sediment yield from different land uses. The results are presented for various land uses, e.g. forests, grass lands, agricultural land, fallow lands, ravine lands, bare rocks, horticultural lands. Form the results of various studies a summary table has been derived which specify ranges of sediment yield for each land use.

For proper management of reservoirs, it is essential to assess the current stage of siltation and predict the manner in which reservoir will get silted and will change the hydrologic conditions in the area. Most common conventional technique for sedimentation quantification is (I) direct measurement of sediment deposition by hydrographic survey (II) indirect measurement of sediment concentration by inflow-outflow method. Both these methods are laborious, time consuming and costly and have their own limitations. The successful management of large reservoirs is possible if cheap, efficient and accurate means for determining the instantaneous suspended sediments in large water bodies are available. The remote sensing approach which uses the satellite data can provide synoptic, repetitive and timely information regarding the water spread area of the reservoir for the periodic estimation of the reservoir capacity between observed water levels. This technique is easy to apply and is cost effective for assessment reservoir sedimentation. These technology has passed its nascent stage of development and now it need to be standardized for wider application

Remote sensing, owing to the inherent benefits of synoptic coverage, repetivity, cost effectiveness, ability to map inaccessible areas, is gaining use in reservoir sedimentation. Passive remote sensing systems emerges as a useful tool for understanding various facets of reservoir sedimentation. In addition, active remote sensing also seems promising to study few aspects of reservoir sedimentation especially the bed proofing/Bathymetry. Whereas Passive remote sensing system (conventional aerial photographs, IRS-1C/1D(LISS III, PAN, WiFS, LANDSAT TM sensors, for example) are concerned with the detection and imaging of reflected or emitted solar radiation from the water body. In contrast, an active remote sensing system(for example microwave, LIDAR) supplies its own source of energy and receives the reflected signal back from the water body. In terms of loss assessment, quite a few options are available that will be useful to the user of this technology. Application scenario of remote sensing in reservoir sedimentation can be seen in terms of its use to serve the information need regarding: reservoir water spread; reservoir capacity and sedimentation rate; sediment yield from catchment; suspended sediments concentration; reservoir water depth profile/bathymetry etc.

Remote sensing methods can be used to assess sedimentation in reservoirs. Remote sensing of reflected solar radiation could provide timely and repeated information concerning suspended sediment flow pattern in reservoirs. The sensors aboard various remotes sensing missions provide data from various sensors operating in different regions of electromagnetic spectrum (EMR). Remotely sensed data from satellites is based on interaction of EMR from sun with various surface features, which interact in different fashions with the incident EMR and hence give rise contrast in the remotely sensed data. Jonha et al. (1985) carried out digital image processing of remote sensing data for reservoir study. Some of the image processing techniques such as image enhancement, band rationing, principal component analysis and unsupervised classification have been applied on 'IMAVISION' system for analyzing digital data of Jayakwadi reservoir.

The suspended material discharged by river into reservoir, transport pollutants and are the natural material that fills channel and reservoir. The input of suspended material to reservoir is variable in concentration and composition from river to river, as well as changing with time in any particular river. The variation in average concentration is related to seasonal changes in precipitation and runoff within the drainage basin of rivers. The composition of the suspended material discharge by rivers into reservoirs varies from river to river, depending on the composition of the rock and soils in the rivers drainage basin, the weather climate to which these rocks and soils have been exposed and the energy of river to transport various size of material. Remote sensing of reflected solar radiation could provide timely and repeated information covering suspended sediment flow pattern in reservoirs, Choubey (1988).

Rao et al. (1990) predicted rate of sedimentation of Tungabhadra reservoir. In this study, Miraki's mathematical model was used. First the model was verified by comparing with the available data. For this, sedimentation rate for thirteen years (1973-85), the computed rate was 7.862 ha-m/100 sq. km./year average rate of sedimentation for 53 years (1986-2038) was predicted as 8.0741 ha-m/100 sq.km/year or 22.75 Mcm/year i.e. reservoir losses its capacity by 0.6065 percent of its original capacity every year.

Manavalan et al. (1991) carried out capacity evaluation of Ghatprabha reservoir using digital analysis of IRS LISS-II data. Reduction is six contour areas of the Ghatprabha reservoir between the RLS 835.24 m and 662.94 m were studied and the change in capacity of the reservoir storage between these levels was computed.

Ramasamy and Pundarikantahan (1991) have an attempt to evolve a procedure developed by Grade et al. to estimate the rate of depletion in storage, useful life of reservoir, future rate of sedimentation and distribution pattern of sediment to Manimuthar, Lower Bhavani and Aliyar reservoirs. The empirical method gives an estimate of the useful surveys and present annual rate of silting. Hence it is revealed that the empirical method is a useful technique which is less cost, less labour oriented and can be applied with ease. As it is possible to compute the objective of sedimentation study analytically with the help of few hydraulic data, it is observed that huge amount of money being spent for conducting capacity survey for reservoirs may be diverted for conducting some other in depth studies other than capacity survey of reservoirs.

Sedimentation is a very serious problem affecting any water resources project. It has been established that sediments are distributed in the live storage of reservoir also. It is, therefore, very necessary to understand the extent of reduction in the live storage of the reservoir at the stage of planning itself so as to derive maximum benefits from the project sticking to various design criteria. Jain et al., (1991) briefly discussed the reservoir sedimentation and distribution of sediments in reservoir by Empirical -Area -Reduction Method through a computer program developed for the purpose. The most commonly employed technique for sediment distribution in the reservoir is the well- known Empirical-Area Reduction method. This method is a trial and error procedure consuming considerable time in arriving at the Dead Storage level and the Revised-Area-Capacity curves expected after the feasible and full service time for which the project is proposed to be planned.

The computer program has the capacity to accurately determine the levels and the Revised-Area-Capacity needed for simulation studies considering a user supplied sediment rate. The computer program is developed in FORTRAN-77 language and are interactive programs making it easy for use. Original Elevation-Area-Capacity table, sediment rate, catchment area, type of reservoir, the trapping efficiency and the number of years after which the revised sediment area-capacity is needed, are the inputs required. The programme is operational on HP-1000 system and also on IBM compatible PCs.

Concentration of suspended sediment is an important parameter for monitoring the effectiveness of the reservoir. In order to map and assess the suspended sediment in the inland water body, Tungabhadra reservoir on Tungabhadra river in Krishna basin has been selected. The study has been carried out Choubey (1992) using Landsat MSS and IRS-1A-LISS-II images. Digital analysis has been performed to obtain the information on the location and extent of sediment distribution in the water spread area of the reservoir. ILWIS system has been used for the purpose. density slicing approach has been employed to obtain various turbidity levels. Visual interpretation techniques have been used to obtain the information on the location and extent of sediment distribution pattern in the water spread area of the reservoir. It has been possible to monitor the seasonal fluctuation of water to assess the volume of water in the reservoir as well as monitor the seasonal changes in the suspended sediment distribution pattern in the reservoir. Attempt has also been made prepare area capacity curve.

Quantitative assessment of sediment deposit at various elevation levels of the reservoir were made taking water spread area from the satellite images and elevation levels from the KERS 1985 sedimentation survey report. The results indicated that the high concentration of sediment is observed at the western confluence of the Tungabhadra river and low concentration at the dam site. On the basis of the degree of sediment concentration, the reservoir could be divided into three major zones viz., very high at the river confluence, moderately at the fringes and low at the dam site. The area capacity curve derived for the area has been found to be in close agreement with that obtained from hydrographic survey. The computed average sedimentation rate of ha m / 100 sq. km / year for this study compares well with that of observed rate of siltation of 6.48 ha. m / 100 sq. km / year.

Further in 1993, Jain et al. has been carried evaluate the sedimentation rate using IRS-1A LISS images and digital analysis have been performed to obtain the information on the location and extent of sediment distribution in water spread area of reservoir. ILWIS system has been used for the purpose. Density slicing approach has been employed to obtain various turbidity levels.

Srinivas (1999) estimated the Nath Sagar Reservoir sedimentation by using the Remote Sensing and Grid Area Based approach. The average value of the sediment yield is found to be 10.14 tonnes/ha which is comparable with the value reported by Ionita Ichim for the Carpathians region in Romania having the comparable characteristics with the study area. The methodology developed based on grid area analysis for soil erosion and sediment yield estimation constitute a major improvement to the conventional method of souring the data to the point observations.

Use of quick and accurate solutions to the problems in water management have to be frequently resorted to in the fast changing, scenario of the urban and rural population. Reservoir operation has certainly been getting enormous importance due to the thrust put on the management in scarcity years. Use of remote sensing satellite data for arriving at the revised reservoir capacity evaluation and sedimentation study has therefore, been made in M.E.R.I. by Kambale et al. (1999). In this study, an effort is made to overcome the limitations of using remote sensing method in case of Manjra reservoir in Maharashtra. Use of remote sensing satellite can be very effectively used to study the sedimentation in the reservoir, even within the dead storage during the scarcity period. This in turn can be used to ascertain the rate and the distribution of sedimentation in the reservoir and to revise the silt load factor and for planning necessary treatment for arresting the erosion in the catchment area.

Babu Rao et al. (1999), have conducted the hydrographic surveys in some of the Major and Medium irrigation reservoirs of Andhra Pradesh and observed the variation of sediment deposition with respect to Khosla's theory. It was found that very large variation of values of rate of sediment was observed over and above the designed values in Nizam Sagar Project and other medium reservoirs, which is given in appendix III. It was also found that, though the rate of siltation is high in the initial years it trends slow down over the subsequent period. It further concluded that the realistic and logical results can be obtained by using sophisticated equipment having precise horizontal and controls like Digital Distance Measuring Unit (DDMU) and recommended to conduct the repeat hydrographic survey at every 5 years to know the behavior of sediment and to assess the capacity of reservoir.

Bapat et al. (1999) carried hydrographic survey of Gangapur Reservoir using Differential Global positioning system (DGPS) for position fixing, Echo Sounder for depth measurement and a Personal Computer with commercially available Hydrographic survey software for survey planning, navigation, data collection and analysis. The DGPS based hydrographic survey system provides an easy and elegant way to estimate the storage capacity of the reservoir. Water spread area and capacity as obtained from this survey are also presented. The DGPS based hydrographic survey system provides an easy and elegant way to estimate the storage capacity of the reservoir. At Gangapur, the entire reservoir of about 22 sq. Km could be surveyed with in a week's time. It concluded that the method is accurate, fast and most convenient wherein the line of sight and communication difficulties make the conventional method very cumbersome. The DGPS based survey is expensive to start with, but in the long run the cost factor becomes immaterial considering the fact that hydrographic survey is required to be carried out quite often. Similar effort was done by Kulkarni et al. (1999). Approximately 22 sq. km. water spread area is combed parallel to the dam axis with an offset of 100 m between the survey tracks. The depth data collected are used to estimate the current storage capacity of the reservoir. In parallel, the storage capacity was estimated using satellite remote sensing data collected during the past years. In this study an attempt has been made to compare the storage volume and water spread area of the reservoir, estimated using both the techniques. Water spread area and storage volumes for different reservoir levels obtained for Gangapur reservoir using DGPS survey and satellite remote sensing data have been compared. The results show a very good match between the estimates obtained using these two techniques. In DGPS survey, the storage capacity estimated from the data collected during a short period, hence the estimate can directly represent the current capacity. On the other hand remote sensing data are obtained from the data archived over a period of eight months.

3.8 Drought analysis and development of drought indices

Droughts and floods are two major catastrophes, which often affect the economy of developing countries. Floods are sudden and short, while droughts are subtle, in tedious and much devastating. Drought is a recurring climatic condition, which affects large areas on earth. The most powerful effect of drought is to reduce agricultural production over a wide area. Other adverse impacts are reduction in hydropower generation, shortage of drinking water, deterioration in water quality, loss of aquatic lives and reduction in recreational facilities. The effects of this calamity can be mitigated to a greater extent by proper drought management. As the historical records available are short, the long term behavior of droughts is not known. Also, the extreme values of drought in any given sequence of time play an important role in planning drought management strategies.

Drought may be defined as a period of abnormally dry weather that is sufficiently prolonged to cause serious hydrologic imbalance in the affected area (Huschke, 1959). Whipple (1966) defined a drought year as one in which the aggregate runoff is less than the long-term average runoff. A large number of draught definitions and indices are available in the literature (Hounam et al., 1975; Subrahmanyam, 1967; Palmer, 1965, Sikka, 1984; Wilhite and Glantz, 1985; Apparao, 1986; Ramakrishna, 1986; and Das, 1986). It is evident from the literature that the notice of the drought is relative. The Uncertainty about drought is reflected in these varied definition of drought as there are no standard and unified definition of drought. In spite of a lack of a unified definition of drought among the community of hydrologists, meteorologists and agriculturists, all tend to agree, that it is basically a situation of water deficit for a given use caused due to occurrence of below normal natural water availability. The industrial uses, agricultural and fodder production and stream water quality because of the occurrence of drought, leads to low depletion of soil moisture and ground water.

Subrahmaniam (1967) identified six types of drought- meteorological, climatological, atmospheric, agricultural, hydrologic and water management. Some researchers have also defined economic drought. Further, in 1976, National Commission on Agriculture broadly defined three types of drought- meteorological, agricultural and hydrological. The meteorologist is concerned with drought in the context of a period of below normal precipitation. To an agriculturist, drought means a prolonged shortage of soil moisture in the crop root zone. To a hydrologist, it means below average content in streams, reservoirs, lakes, tanks, ground water aquifers and soil moisture. Hydrological droughts are concerned with the effects of rainfall deficiencies in hydrological components such as surface water, ground water and soil moisture. 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 capabilities". Linsley et al. (1975) defined hydrologic drought as a "period during which stream flows are inadequate to supply established uses under a given water management system".

Regardless of many specific discipline or user oriented definitions and concepts of drought advanced with the purpose to enable the objective identification, characterization and classification of droughts, all tends to agree that drought is synonymous with water deficit or water scarcity cover a significant length of time and space. Yevjevich (1967) has rightly suggested that the mathematical analysis of the time and space distributions of water demand results in feasible way of establishing an objective framework in order to define and analyze drought for any particular use or interest in water resources. In the present context the mathematical formulation of the definition of drought is synonymous to a corresponding drought index of particular use or interest.

Inspite of the various types of definition or index being used, drought are analyzed and characterized by the selected set of variable(s) on the basis of magnitude (average water deficiency), duration (period of water deficit), severity (cumulative water deficiency), frequency (probability of drought occurrence) and beginning and ending of drought. The variables generally used to define drought are rainfall, temperature, evaporation, evapo-transpiration, soil moisture, streamflow, reservoir/tank levels and storage, ground water levels, crop parameters like critical growth stages and crop yields, fodder production, land use etc. The water demand defining variables like drinking and domestic water demand, live stock water demand, industrial water demand, crop water demand and other necessary water demand variables are user, location and interest specific and these may be relatively more problem oriented. Invariably, most of the drought indices consider the water demand variables in indirect way, if so.

Drought indices may be conceptual or operational based on whether they identify some boundaries or threshold of drought concept or identify various drought characteristics.

Meteorological drought indices

In early days, droughts were defined solely on the basis of the duration of the dry period and the degree of the dryness by considering some threshold values. Subsequently the meteorological drought definitions were improved by interpreting the precipitation characteristics at a place with respect to its comparison with the corresponding long-term average of that place. Ramdas et al. (1950) defined drought as a week with actual rainfall equal to half of the normal rainfall or less. Statistical analysis of the long-term record is carried out to derive long term mean, standard deviation and coefficient of variation (Cv) of the rainfall. If annual or seasonal Cv of rainfall is 30% or more, the area is termed drought prone. The probability of occurrence of dry spells of the short and long duration have been studied by Rao et al. (1971), Ramana Rao et al. (1976), Victor and Sastry (1979), Correia and Bohra (1980).

Von Rooy (1965), cited from Kalyansundaram and Ramasastri (1969) developed an anomaly index I from annual rainfall series and prepared maps showing the probability patterns of rainfall anomalies. Herbst et al. (1966) developed a technique for evaluating drought by using monthly rainfall data. The technique determines the duration and intensity of droughts as well as the months of their onset and termination. Agarwal et al. (1991) have been carried out drought study for the year 1988-89 in six selected districts of Maharashtra namely, Ahmednagar, Aurangabad, Pune, Sangli, Satara and Sholapur. The rainfall and ground water data have been used for finding deficit of rainfall and trend of water table, as a result of drought incidents. The seasonal rainfall departure analysis and monthly rainfall departure analysis were carried out. The frequency analysis in all the districts is above 89 % expect in respect of Pune indicating that the districts selected for analysis are not drought prone, based on this analysis as per IMD criteria. Herbst's analysis shows that Ahmednagar, Pune, Sholapur, Sangali and Aurangabad experienced drought during years 1984-91. The maximum intensity of drought was recorded in the case of Satara district and numbers of drought spells varied from 4 to 12. The longest period of drought spell over the entire period was found in case of Ahmadnagar district during late 70's and early 80's. An attempt has also been made to see the effects of scarce rainfall on ground water regime by carrying out statistical analysis of groundwater level data. In all the districts selected for the analysis, the seasonal rainfall for 1987-89 showed deficiency in the range of 9% to 60% except in case of Sholapur. The rate of decline in water table was found increasing in Pune, Satara and Sangli. However, Aurangabad, Pune, Sangli and Satara Districts experienced an increase in water table. During 1987, the storages in the four selected reservoirs, namely Jayakwadi, Khadakwasla, Koyana and Bhima were deficient as compared to preceding 2-3 years and year 1989.

Panda and Ramaseshan (1978) have analyzed the drought frequency of six stations of the Krishna and Godavari river basins for different duration by using Gumberl's type III extremal distribution. The parameters of the distribution are estimated by the method of moment. A three parameters type III extremal distribution fits well when the observations are all nonzero or positive. The fit is not satisfactory when the observations consist of zero or higher values. A positive, zero or negative value indicates that perennial flows are larger than, equal to or less than the diversion. Value essentially incites the order of difference between two factors. Based on data from 1875 to 1980, Chowdhury and Abhayankar (1984) have an attempt to compile and collect drought climatology of India. Only "meteorological drought", i.e., rainfall deficiency exceeding 25% of the normal has been considered. Frequency of occurrence of drought in different meteorological sub-divisions has been obtained which has been used to determine its recurrence period. Drought has been classified into moderate and severe categories and the probability of occurrence of these types in different sub-divisions computed and discussed. Depending upon the area of the country affected, drought has been further classified into different categories viz., localized, semivast, vast extensive and calamitous, observed frequency of each type determined. Decadal representation of the drought incidence has been obtained and used to predict its occurrence in any 10 years period.

As such no rational criteria to define an year as a good or bad monsoon year exists, therefore the following two categories were separately adopted to consider a year as a drought year, viz., (i) When the percentage area affected exceeds 20 % and (ii) When the area exceeds 25%. Sequences of a drought year or a good monsoon year have been obtained. This has subsequently been examined to obtain probabilities of a drought year following (a) 3 consecutive good year, (b) 4 good year, and (c) 5 good years. Similarly chances of two consecutive years of drought after each of 3,4 and 5 consecutive years have been determined. These sequences have also been utilized to find persistence in occurrence of good or bad (drought) monsoon years and subjected to Chi-square test to determine its statistical signifies.

In another study, droughts during the period 1936 to 1986 were analyzed for the Sankarankoil taluk in Thirunelveli Kattabomman District by Rajappon and Narayanan (1988). The drought years are found out by using the rainfall data during North-East monsoon period, annual rainfall period and monthly rainfall. Also using the rainfall data collected for the entire Thirunelveli Kattabomman district and V.O.Chidambranar district (Thirunelveli district was bifurcated as these districts), the drought years are identified by applying 5 year moving average for the five raingauge stations close to the study area.

The aridity index (Ia) of Thornthwaite (i.e. percentage ratio of annual water deficit to annual water need) based on Thornthwaite and Mather (1955) book keeping climatic water balance procedure first used by Subrahmanyam and Subramaniam (1964) is one amongst the most widely used indices describing the drought characteristics. The severity, given by the magnitude of the water deficiency at a place is determined by the difference between the corresponding potential and actual evapo-transpiration values during the study periods.

Aridity Index Ia = (Water Deficit/ Water need) * 100 = (PE - AE)/PE *100

Where, PE and AE are potential and actual evapo-transpiration of the areas for the given period.

The moisture index, Im (humidity index, Ih - aridity index, Ia) gives a rough estimate of the moisture status of a region and is some times used to study frequency of droughts (Seth et al., 1979).

Where,

Im =((Annual moisture surplus - annual water deficit) / annual water need)*100

The Palmer Drought Severity index (PDSI) developed by Palmer (1965) is the primary tool to describe prevailing drought conditions. Palmer defined a drought period as "an interval of time, generally of the order of months or years in duration during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply". The detailed computational procedure developed by Palmer can be found in George et al. (1972), WMO (1975) and Sikka (1984). Utilizing the Thornthwaite system for calculating potential evapo-transpiration, Palmer developed a series of equations for determining "Climatically appropriate for Existing conditions" (CAFEC) formulae, for: evapo-transpiration (ET), Soil moisture recharge (R), Runoff (RO) and Moisture loss (L). Adhering to the concept of supply and demand, he gave following equation,

$$P^{\wedge} + L^{\wedge} = ET^{\wedge} + R^{\wedge} + RO^{\wedge}$$

The CAFEC precipitation ($P^{\wedge}$) is computed for each month from the formula and then compared with actual precipitation which provides Palmer's monthly departure index d ($d = P - P^{\wedge}$). The value d, multiplied by appropriate monthly weighting factors, yields the moisture anomaly index. The moisture anomaly index classifies the station into twelve categories for the month under consideration.

George et al. (1972) have studied Drought spells in Andhra Pradesh, Tamil Nadu and Mysore during the last 60-65 years and computed the monthly Palmer index Values. For computing this index, a detailed hydrologic accounting of the area is carried out for a large number of years using data of rainfall, potential evapo-transpiration and water holding capacity of the soil. Several parameters are obtained from this accounting and these are used to compute the CAFEC (Climatically Appropriate For Existing Conditions) precipitation of each month of the period. Anomaly of actual rainfall with respect to this CAFEC precipitation is obtained for each month and this precipitation used to compute Palmer Index of the month. Several drought spells occurred in these areas during the period studies. The longest drought spell experienced in each area was : (I) Interior Mysore North -70 month (August 1922 to May 1928), (ii)Coastal Andhra Pradesh -57 months(July1904 to March 1909, (iii) Tamil Nadu- 41 months (November1949 to March 1953),(iv)Rayalaseema -36 months (march 1941 to February 1944), (v)Telangana - 35 months (May 1911 to March 1914 and July 1918 to May 1921) and (vi) Interior Mysore South - 27 months (December 1948 to February 1951). Further in 1973, George et al. carried out drought analysis for 150 meteorological stations for the period 1970-71 to study the incidence of drought using PDSI employing Thornthwaite's method of computing potential evapo-transpiration. The PDSI values compared nearly well to crop yields and well known recorded drought spells in Tamil Nadu. Percentage occurrence of droughts of class moderate and above in Kharif season have been given in table 3.

Table 3. **Percentage occurrence of drought of class moderate and above in the Kharif season.**

Sl. No.	Sub-division	June	July	Aug	Sept	Oct	Nov
1	**Telangana**	**22**	**17**	**19**	**22**	**30**	**30**
2	**Rayalaseema**	**24**	**28**	**30**	**27**	**27**	**27**
3	**Tamil Nadu**	**20**	**22**	**23**	**23**	**21**	**17**
4	**Interior Mysore South**	**20**	**15**	**19**	**15**	**23**	**20**
5	**Interior Mysore North**	**25**	**23**	**29**	**26**	**30**	**29**
6	**Madhya Maharashtra**	**20**	**27**	**25**	**23**	**31**	**30**
7	**Vidarbha**	**20**	**20**	**24**	**21**	**25**	**24**

Bhalme and Mooley (1979) reported that PDSI failed to explain the well -known 1981 drought in the country. It was also observed that the weighting factor for July in respect of Chanda district was even negative and the defective moisture factor was changes the sign of the moisture departure. They introduced modified weighing factor and severity equation using data of 21 district of the country. In subsequent studies, Rao and Subramanian (1986) further suggested modifications in PDSI for analyzing meteorological drought in Maharashtra.

Drought has been a recurrent phenomenon in the areas of Andhra Pradesh State. In fact, no district is entirely free of droughts. Drought is a major problem demanding a more systematic approach in tackling them. Improved drought management calls for effective drought prediction and assessment procedures. National Remote Sensing Agency in collaboration with Government of Andhra Pradesh and India Meteorological Department has undertaken a Project on Drought Monitoring and identify the parameters for the areas that have been repeatedly declared as drought affected and to evaluate drought occurrence. Though the State Government identified as much as 18 parameters on the causes and impact of drought only percentage rainfall deviations from the normal rainfall are expressed quantitatively. The drought impact is in general explained with quantitative figures with reference to area not shown and extent of crop damage. However even those figures are not consistent between space and time, (Jeyaseelan and Thiruvengadachari, 1986).

Remote sensing technique can play a vital role in monitoring the drought condition. Satellite observations have advantages over the traditional system of conventional ground data collection as satellite offer repetitive and synoptic coverage of same large area facilitating real time monitoring of vegetation changes with more reliability, adequacy and objectivity. Chakraborty and Roy (1979) used Landsat imagery to study the influence of drought on ecosystems in Karnataka State. Satellite data were also used to identify drought conditions through mapping and monitoring of surface water bodies (Chakraborty, 1982; Thiruvengadachari, 1982). Nageswara Rao and Rao (1984) employed NOAA-AVHRR band 3 TIR (3.55-3.93μm) for delineating drought affected areas were studied and severity of the drought was assessed using Landsat MSS imagery. Severity of drought was quantified based on reduction in green cover using Landsat MSS digital data (Nageshwara Rao and Sugimura, 1987).

In 1989, Padalinthan and Narayanan modeled stochastically the annual precipitation series of Dharmapuri raingauge station, Dharmapuri district, Tamil Nadu State by fitting an autoregressive model of first order. The model is used to generate synthetic series of longer duration and the drought characteristics are derived. The monsoon precipitation series viz., the South-West and the North-East are also modeled stochastically for generation of synthetic series for evaluating long term behavior of monsoon failures. The modeling of monthly series and fitting simple seasonal multiplicative ARIMA models enable to derive a forecasting function. The real time forecasting is also done for the historical data. A drought generating mechanism is abstracted by simple analytical formulation of the probabilistic behavior stationary Markov process. Since droughts are natural phenomena, which cannot be predicted with certainty, they are treated as random variables. The extreme values of the random variables are estimated using Poisson process and other probabilistic theories. The formulated drought generating mechanism is verified for the generated annual precipitation series and it is a good fit. Hence this drought generating mechanism is verified for the generated annual precipitation series and it's a good fit. Hence this drought generating mechanism can be used to analyze the risk associated for any size, given the truncation level and first serial correlation coefficient. The NOAA-AVHRR CCTs biweekly data of the year 1988 and 1989 were used for this purpose.

Rajakumar and Anji Reddy (1992) carried out drought study in the Nalgonda district of Karnataka State. Rainfall parameters have been taken as prime factor for analyzing the drought. Drought occurrence, drought severity and duration have been computed. Drought index is developed to categories the nature of climate. Gumbel's extremal distribution type III is fitted for the data of minimum rainfalls. The effect of drought on ground water table has also been studies. It was concluded that all the taluks considered in Nalgonda district fall under semi-arid zone with high degree of variation in rainfall. Further in another study, Pugazhendhi and Karmegam (1992) have an attempt to identify a suitable method to assess the drought in the meteoroligic context in Dharmapuri taluk of Dharmapur district of Karnataka State. The selection of a suitable method among India Meteorological Department method, Aridity Index method, Herbst's method and Palmer's Drought Severity Index method for the study area for drought assessment purposes is through a correlation analysis between rainfed crop area or crop yield and assessment performance of the methods. Based on the inherent characteristics and best correlation with the reality, Palmer's Drought Severity Index method is identified as a suitable method to assess drought for the study area.

Likewise, Krishnaveni and Karmega (1993) have been analyzed of drought in the meteorological context for all taluks of Dharmapur District. Also an attempt is made to make use of Geographic Information System for Drought assessment. For this study, different maps viz., district map, land use map and data viz., rainfall, temperature for the entire Dharmapuri district are collected from various sources. For assessing the severity, duration and intensity of drought the IMD method, Herbst's method, Palmer's Drought Severity Index method were applied. Using the GIS, the drought severity maps are generated which aid in space and time comparison of drought severity over the district.

Agricultural drought indices

Agricultural drought broadly means shortage of soil moisture for effective growth and yield of a crop. It is an outcome of either scanty precipitation or its erratic distribution both in space and time. The present raingauge density is however inadequate to provide areally representative information on rainfall and hence rainfall also cannot be a reliable indicator of drought. The large number of tanks can be considered as supplementary rain gauges to provide more reliable and areally representative information on availability of surface water.

Agricultural drought indices have been developed and used by many workers and most of them either link rainfall deficiency to agricultural impacts or soil moisture deficit or moisture stress to crop yields. A more meaningful definition of agricultural drought is the situation when soil moisture in the crop root zone and rainfall are inadequate to support healthy crop growth any part of the growing season leading to water stress, crop wilt and damage of the crops. Availability of useful moisture to crop could be a better index of agricultural drought. Meteorological droughts do not necessarily coincide with the agricultural drought.

Deficiency of rainfall has been the principal criteria in defining agricultural drought. Different limits of rainfall deficiency have been proposed by various workers and organizations to study their impact on agricultural drought (Malik, 1963, Malik and Govindswamy, 1962-63, NCA, 1976). It has been defined as occasion when weekly rainfall in four consecutive weeks is half of the normal or less (normal weekly rainfall being 5 mm or more) in the period from middle of May to middle of October or six such consecutive weeks during the rest of the year (NCA, 1976). Khambete and Biwswas (1964) inferred from their drought study over the dry farming tract of Maharashtra that agricultural drought occurs when there is rainfall deficiency of less than 18mm per week during the month June to October.

In order to replace crude rainfall indices, Presscott (1958) advanced climatic crop growth indices (CCGI) considering the fact that water need of growing plants is dependant on climatic conditions vis-à-vis complex association between soil and vegetation. This index utilize plant soil rainfall interaction concept in any indirect way and uses different ratio of pan evaporation to classify intensity of droughts. The CCGI is given as

$$CCGI = P/(E_w)^{0.75}$$

Where, P = rainfall, and Ew = measured or calculated evaporation rate

Das et al (1971) modified this equation using potential evapo-transpiration (PE) estimates instead of EW and gave the following equation:

$$CCGI = P/(0.769\ PE)$$

Further, in 1980 Das classified the country into various drought intensity classes using this concept for advocating necessary soil conservation measures. They estimated that nearly 80% of the country is subject to droughts. While only 6% to disastrous droughts, 36% to severe, 14% to large and 24 % to moderate droughts.

Hargrreaves (1974) estimated monthly rainfall at 75 % probability level and used ratio of this to the average monthly PE for classification of agro-climate of Brazil and designated this ratio as "Moisture Availability Index" (MAI). Biswas and Nayar (1984) applied MAI (defined as ratio of probabilistic rainfall of week to PE) for agricultural drought studies.

The method of aridity index has been used extensively for meteorological and agricultural drought. Chowdhary et al. (1977), Appa Rao (1983) and few others used weekly aridity anomalies using Thornthwaite & Mather (1955) water balance model to study the incidence, spread, intensity and cessation of agricultural droughts on the basis of following drought intensity classification criteria.

Drought Intensity	Aridity anomaly
Mild	25
Moderate	26-50
Severe	More than 50

Sikka and Mishtra (1986) suggested use of the soil water balance equation to determine soil moisture available for plant growth in the root zone, assuming that the affect of water table is not there. Further, Thiruvengadachari and Prasad (1987) have studied the Agricultural Drought Monitoring Methodology envisaged in the National Drought Monitoring Project involves the use of anomalies in rainfall, soil moisture availability and vegetation/crop condition. It highlights the use of the aridity index developed by the Drought Research Unit of India Meteorological Department for monitoring moisture stress experienced by the growing plant due to shortage of soil moisture. The study concluded the seasonal aridity parameters as a drought indicator.

The ratio of actual to potential evapo-transpiration (AE/PE) also known as the index of moisture adequacy (IMA) indicates the rate at which moisture is available to the crop compared to its water demand. Subrahmanyam et al. (1963), Subramaniam and Sastry (1979), Sastri et al. (1984), Patel et al. (1986) and others have employed this criteria using Thornthwaite and Mather (1955) water balance approach to study agricultural droughts in Hard Rock region. Subrahmanyam et al. (1963) concluded that most of the agricultural crops in India do not seem to have favourable conditions for development below 40 % value of

IMA (i.e. AE/PE - 0.4) which, corresponds to aridity index of 60%. A value in the range of 60-100 % IMA is required for efficient growth and development rice. However, when index falls below 80% the yield gets reduced considerably. Similarly for millets and lower riang of 40-60 % was suggested. Subramaniam and Sastry (1979) obtained the minimal value of IMA (i.e. above which, yield is always higher than the average yield and below which it would be lower than the average) for pearl millet, sorghum and finger millets for Andhra Pradesh in the range of 52 to 58%.

In 1987, Thiruvengadachari and Jeyaseelan prepared the report on satellite monitoring of agricultural drought in Anatapur district in Andhra Pradesh. This report highlights the use of Normalised Difference Vegetation Index (NDVI) using Landsat Multispectral Scanner data as a drought indicator in Tadpatri taluk of Anantapur District in Andhra Pradesh State. This is demonstrated through the comparison of satellite data based vegetation response between October 1985 and October 1986, supported by ground data. The encouraging results of this study, as well as other studies over different taluks in the district, indicate the need for integrating the NDVI response into the drought monitoring methodology. Similar attempt has been made by Bala Rama Krishna and Sastry, (1987) to assess the impact of drought conditions in Prakasham district, Andhra Pradesh State during the years 1984, 85 and 86 using Landsat satellite data supported by conventional ground data. Drought conditions were observed during early part of kharif season of 1984 and 1985 leading to withering of most of early sown crops. However, with subsequent rainfall some of them revived and late sown crops progressed. the drought in 1986 led to general decrease in yield.

Crop dynamics and crop separability studies relating to drought assessment have been done by digital analysis using both SVI (NDVI) values and simple band ratio studies based on 3 to 4 satellite overpass dates in all 3 years. Both SVI values and band ratio values are quite effective in monitoring crop dynamics through multitude observation. SVI values and simple band ratio studies could separate vegetation and Non-vegetation. The discrimination of agricultural crops from natural vegetation could not seem to be possible except in early part of season. Discrimination within the crops was also found to be difficult as the signature values are overlapping. Crop status was correlated with rainfall and available irrigation facilities and decreases in SVI values were observed whenever crop stress conditions were noticed. The multidate analysis seems to be more reliable in drought monitoring system then single data observations.

Crop signature studies will help in the operational ability of remotely sensed drought identification methodology as the deviations from the normal crop signature values can indicate crop stressed conditions. Eventhough the frequency of Landsat satellite data is 8 days with satellites in orbit, due to cloud coverage during kharif season availability of cloud free data seems to be limited. Studies have shown that coarse resolution (1.1 kg * 1.1 km) of NOAA AVHRR data need not be a constraint in monitoring vegetation conditions. The analog nature of polar orbiting NOAA AVHRR sensor and Land sat MSS wave bands enable the extension of Landsat based results, so that more frequent Metsat data can be utilised for monitor. An attempt has been made Kishan and Sastry (1987) to assess the impact of drought on agriculture and surface water availability through single data comparison of Landsat data, supported by ground data.

Srinivas and Sakthivadivel (1987) studied the occurrence of droughts with the main concentration on "The hydrological aspects of drought in Chittor and Prakasam Districts of Andhra Pradesh State". In this study while the application of the Landsat data for monitoring the seasonal variations of surface water is considered the potential limitations of remote sensing techniques in monitoring the other hydrological characteristics such as ground water, depletion, soil moisture depletion, flows in streams, are identified and reviewed. The detection capabilities of different Landsat sensors/products, of different sizes of tanks and reservoir storages are evaluated. The water spread information obtained from the Landsat data has been related to the weekly rainfall data, to evaluate the seasonal variations of the surface water during the monsoon periods of 1984 to 1985 at taluk level in the study area. The response of different sizes of tanks to rainfall distribution in the season as well as variations between the seasons is evaluated. Thus, while the technical capabilities of Landsat sensors has been demonstrated, operational utilization of such data for regular, periodic monitoring will be severely affected by the cloud occur conditions during the monsoon season. It is concluded that the operational drought monitoring system cannot be based on the use of Landsat data, except on an opportunistic basis. However such data could be used to provide more detailed information as and when cloud free data is available. The same effort were done by Reddy and Anuthaman (1988) to assess the hydrological parameters of drought in Minjur-Ponneri area in Chengalpattu district of Tamil Nadu State. The influence of rainfall on different parameters such as ground water levels, stream flows, gross cropped area and gross irrigated area was analysed and the relationships between these parameters were correlated with rainfall using time series. Thus the usefulness of Landsat data in drought assessment was estimated by comparing water spread area and vegetative area obtained from Landsat data with rainfall data obtained from ground sources.

National Remote Sensing Agency examines the utility of satellite derived inventory of surface water storages in various irrigation tanks at different times storages in various irrigation tanks at different times during the kharif season, in predicting a agricultural drought. This investigation centers around eight taluks of Prakasam district of Andhra Pradesh. The water spread information from the Landsat data at different times during the kharif seasons of 1984 to 1987 has been related to respective rainfall amounts to examine the inflow characteristics of tanks. Spatial variability of rainfall is studied both with reference to rainfall observations of different rain gauges and tank water spread at any time. Finally, the average surface water availability at taluk level has been correlated with respective agricultural drought conditions, both grounds reported and satellite derived. The study concluded that surface water storage status in irrigation tanks in a taluk could be a useful indicator of agricultural drought occurrence and severity, Basha and Sastry (1988).

Murthy and Sastry (1989), Kumar and Sastry (1989) and Nath and Sastry (1989) have studied the agricultural drought in Andhra Pradesh State. This study concentrates on the use of Normalised Difference Vegetation Index (NDVI) response based on National Oceanic and Atmosphere Administration (NOAA) data to compare agricultural drought conditions in different districts (Rayalaseema, Prakasam, Nellore, Nalgonda, Vishakapatnam, Vizianagaram, Srikakulam, East Godavari, West Godavari, Krishna, Guntur and Khammam districts) of Andhra Pradesh State during the Kharif season of the year 1986, 1987 and 1988. The NDVI parameters, i.e. Mean NDVI, gross NDVI, Average NDVI, area under Vegetation and percentage of clouds is evaluated for use as drought indictors. These quantified NDVI responses are compared with the available drought indicators such as reduction in sown area, damage to crops, rainfall and aridity anomalies, supported by ancillary information on cropping pattern, crop calendar, irrigation support, land utilization and seasonal rainfall patterns etc; supplied by different Department of Government of Andhra Pradesh as well as India Meteorological Department. The study indicates that a comparison of districtwise seasonal VI profiles can provide meaningful drought information and help to identify drought periods during the kharif season. Though this study evaluated NOAA satellite based drought monitoring with districts as the reference unit, conjunctive use of higher resolution Landsat, IRS and SPOT satellite data can help for the monitoring of taluk/mandal level.

Further, in 1990, Reddy and Kumar has studied the agricultural drought conditions in Nellore district of the Andhra Pradesh State by using Normalized Difference Vegetation Index (NDVI) response based on Indian Remote Sensing Satellite (IRS-1A) data during 1988 and 1989 kharf season. The NEVI parameters i.e., Mean Normalized Difference Vegetation Index (MNDVI) Gross Normalized Difference Vegetation Index (GNDVI), area under vegetation and percentage of cloud are evaluated for use as drought indicators. Reduction in vegetated area and decrease in both GNDVI and MNDVI responses over a unit area considering each Mandal as one unit area. The imageries of False Colour Composite (FCC) for the years 1988 and 1989 were used as parameters to compare drought conditions.

Muthuraj and Gopalkrishanan (1992) have carried out a detailed assessment of drought conditions during the rabbi season of 1988 in Bijapur district of Karnataka State by using high-resolution satellite (Landsat-TM) data. During 1988, the continuous dry spell from October to December, where the rabbi crops in the district are at the peak growth stage caused drought situation, For comparing the drought conditions with the normal crop year, data in the same period during 1989 was selected. The drought assessment was carried out in terms of difference in cropped acreage and crop conditions for cropped area estimation Landsat-TM False Colour Composites and Normalised Difference Vegetation Index (NDVI) were used, and crop conditions are assessed based on NDVI, crop and seasonal particulars obtained from the district authorities. The mid-infrared, Thermal infrared channel information of Landsat-TM were extracted at district, taluk and at different NDVI ranges were compared with NDVI, greenness, and ground data on drought situation for their usefulness towards drought assessment.

Sampath Kumar and Anuthaman (1994) have been analysed the assessment and monitoring the Agricultural drought for Mahabubnagar district, Andhra Pradesh comprising of 64 mandals. An attempt is made to facilitate interpretation of satellite based Vegetation Index (VI) with other ground parameter through GIS. For this study, different maps viz. Landuse map, Soil map, Mandal map, Hydrogeological map and data viz., rainfall, ground water levels, major crop sown details, source wise irrigation details were collected, digitized and entered in the database.

From the created database agricultural land use area only was extracted and VI was generated, This generated Vegetative Index and the available fortnightly rainfall data of 1990 and 1993 was plotted against time (fortnightly interval) for eight representative mandals constituting different crops, soil and rainfall distribution,. Based on the normal crop performance of 1990 the relative drought assessment for 1993 is made, the drought severity level was obtained. The results indicate that two mandals fall under mild drought, while remaining six mandals fall under moderate drought level. Planning of Crop and Water Management Practices Using Weekly Rainfall Data Analyses. Estimation of weekly rainfall at various probability ranges may be used to determine rainfall deficit and surplus probabilities for planning crop and water management practices. The required number of years of data my be collected for a selected region and estimate the probability of rainfall from 50 to 90 % levels using suitable statistical distribution. The rainfall deficit or surplus for different week may be computed by comparing expected rainfall and normal potential values for specific crop and respective periods.

Hydrological Drought Indices

Hydrological drought indices are concerned with the effects of rainfall deficiencies on hydrological components such as surface water, ground water and soil moisture. In the direction of hydrological drought the indices in the form of numerical numbers indicative of drought ;occurrences are not many. Rather more complex statistical and stochastic hydrologic models are found in the literature. Various researchers 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 as "Period during which stream flows are inadequate to supply established used under a given watei management system".

Six types of drought have been distinguished based upon variations in the duration, season of year, or severity by Beran and Rodier (1985) mainly relating to agricultural and irrigational needs.

1. A three week to three month runoff deficit during the period of germination and plant growth. This could be catastrophic for farming that is dependent upon irrigation drawn directly from the river without the support of reservoirs.
2. A minimum discharge significantly lower or more prolonged than the normal minimum but not necessarily advanced much in its position or relative to the growing season. Because the germination period is not affected this type of drought is of less consequence agriculture.
3. A significant deficit in the total annual runoff. This affects hydropower production and irrigation from large reservoirs.
4. A below normal annual high water level of the river. This may introduce the need for pumping for irrigation. This type of drought is related to Type-3 deficit in annual runoff.
5. Drought extending over several consecutive years. Discharge remains below a low threshold or the rivers dry up entirely and remain dry for a very long time.
6. A significant natural depletion of aquifers. This is difficult to quantify because observation of the true level of the aquifer is disturbed by the over utilization of ground water during the drought.

A commonly used simplest index is to compare the depth of precipitation and runoff depth or volume for a given duration i.e. week, fortnight, month or a year, with the long term mean or standard period normal value for the given duration. The numerical value of this index will give the drought severity. This could be classified on the basis of probability also. One such scheme as found in Europe is as below (Cited from Beran & Rodier, 1985).

	Exceedance frequency between
Very wet	0 and 15%
Wet	15 and 35 %
Normal	35 and 65 %
Dry	65 and 85 %
Very Dry	85 and 100 %

Normally 80 and 100 % exceedance frequency is considered in order to develop a regional drought summary based upon a number of flow records.

The Central Water Commission (1982) while studying drought in 99 districts of the country considered hydrological drought as a situation when annual runoff. If there are 25 such years in the area, the area is termed as drought prone. This runoff reduction ultimately results in lowering of water levels in reservoirs, tanks and streams causing situation of water deficit for the user in the area. Thornthwaite and Mather (1985) book keeping water balance model has been also used to estimate water surplus / deficit or river basin as a tool to define hydrological drought (Srivastava et. al., 1977, Subrahmanyam and Upadhyay, 1983).

Julius (1993) has attempted to identify a method to assess the drought in the hydrologic context by applying Yevjevich method, Dracup method, Herbst method, Water Balance Approach to the Krishnagiri taluk of Dharmapuri district. Since this area is mainly rainfed and also proclaimed as a drought prone area by the Government of India. The selection of a suitable method for the study area for hydrologic drought assessment purposes is through comparison of mass curve analysis with the performance of the method. Based on this comparison, Herbst method is identified as a suitable method to assess hydrologic drought for the study area.

3.9 Drainage Problems

Heavy soils and associated soils(Black soils) occur in peninsular India, particularly in the Deccan Plateau. These soils are distributed in the state of Maharashtra, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu. These soils occupies about 63.9mha areas in the Hard Rock Region of India. The extent of black soil regions in each state of hard rock region is given in the Table 4.

Table 4. **Distribution of black soil in Hard Rock Region**

Sl. No.	State	Area (mha)	Percent of total black soil area of country	Percent of total geological area of country
1.	Maharashtra	29.9	35.5	7.9
2.	Andhra Pradesh	7.2	10.0	2.2
3.	Karnataka	6.9	9.4	2.1
4.	Tamil Nadu	3.2	4.2	1.0
5.	Madhya Pradesh	16.7	23.0	5.1

Inspite of high potential productivity of these soils and favourable climatic conditions the soil remains under utilised due to a number of problems. Most of the problems arise due to their generally low water intake rate and due to poor internal drainage.

The drainage of heavy land is required in regions facing the following problems

a) High water Table

b) Low infiltrability and poor internal drainage

c) Perched water table

d) Salt affected areas

Drainage of heavy land is largely governed by the fact that the hydraulic conductivity of the subsoil is generally too low to allow percolation of excess rainwater to lower depth. Under these situations, the problem of water logging and accumulation of salts generally arises. Drainage problem particularly in irrigated heavy soils is caused by over irrigation or by surface runoff resulting from excess rainfall. The solutions depend mainly on 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.

The traditional drainage system on heavy clay soil is by surface drainage. Recently it has been proved that subsurface drainage can be used in situations where an underlying layer with a high hydraulic conductivity occurs(Van Hoorn, 1973).

The understanding of the land phase of the hydrologic cycle plays an important role in design of field drainage system. Physical features(Topography, Geology, Soil Characteristics) meteorological (Temperature, Rainfall, its incidence and variation in time and space and evaporation) and hydrological conditions of an area determine the varying needs and nature of drainage operations. The silent topographic characteristics which influence watershed process are area, shape, relief and drainage density. Relief as a drainage basin characteristics exercises an influence over runoff and sediment production in a basin. The drainage density is most important factor characterizing the conditions of flood flows formation . The method used for land drainage may be classified in two broad categories- Surface Drainage and Subsurface Drainage depending on the way water is removed.

The Coimbatore district in Southern India consists of igneous rocks. As ground water is used for irrigation it is often subject to intense evapo-transpiration and cations are removed from solution when this process concentrates the water. The ability of the soil to pick up cations is due to the formation of new clay minerals and the precipitation of calcite. This is an indication that leaching has occurred to a greater extent in the past. Owing to the intensified irrigation and the absence of ground water runoff there is a risk that the ground water in low-lying parts of the area will become increasingly saline in the future, (Jacks 1973).

Soils of Jayakwadi command area were investigated for their physico-chemical properties. All the soils are clay in texture showing highest clay content in very deep black soils. The structural indices such as water stable aggregates (>0.25 mm) and mean weight diameters (MWD) varied in a very narrow range. Very deep, deep and medium black soils are slow to moderate and shallow black soils moderately slow to moderate in drainability. All the soil types showed normal range of pH, EC and calcareous nature and found to have medium in nitrogen, phosphorus and high in potassium (Bharambe and Ghonsikar, 1985).

Considering the various physical properties viz.; saturated moisture content, field capacity, hydraulic conductivity, infiltration rate, drainable porosity etc. as per the standard method (Mishra and Ahmed, 1990) and chemical properties viz.; EC, pH, ESP (Exchangeable sodium percentage), organic carbon, CEC (cation exchange capacity) etc., as per U.S.S.L. methods (Richards, 1954) of soils and irrigability rating criteria of soil (Palaskar & Varade, 1985 and WALMI, 1985). it is revealed that nearly twenty five per cent of the soil samples comes under class "C" of soil irrigability class. It means that 25 per cent of the soil have severe soil limitations for sustained use under irrigation while seventy five per cent of the soil samples comes under soil five per cent of the soil samples comes under class "B" of soil irrigability classification. It means that seventy five per cent soil from these commands have moderate soil limitations for sustained use under irrigation.

The saturated moisture content and field capacity varies significantly in the various mechanical operations. The saturated moisture content was found to be increased maximum upto 48.613, 44.463,44.895 and 39.095% from 37.925, 38.160, 35.863 and 33.350 at 0-25, 25-50, 50-75 and 75-100 cm depths respectively. Also, increase in field capacity was maximum upto 34.038, 34.088, 32.863 & 31.065% from 29.863, 29.630, 29.770 & 27.280% at 0-25, 25-50,50-75 & 75-100 cm depth, respectively. Saturated moisture content at 0-25, 25-50,50-75 & 75-100cm depth in treatment T_1, T_2 & T_3 i.e. shallow ploughing, deep ploughing and subsoiling, respectively were found to be significant over the treatment T_4 (unsaturated fallow land) and were at par with each other. The same case was found in field capacity at 0-25 depth, except the treatment T_3, i.e. inferior to T_1 and T_2. The field capacity and saturated moisture content at 25-50 cm depth are highly significant in treatment T_2 followed by the treatment T_3. The treatments T_1 and T_3 are inferior and at par with each other. It is also seen that the treatment (mechanical operation) varies significantly in respect of bulk density, drainable porosity in all depth and infiltration rate and hydraulic conductivity as well. The treatment T_2, T_3 and T_1 are highly significant over the treatment T_4 and were found to be equipotential with each other. An increase in infiltration rate was found upto 2.728 mm/hr from 1.343 mm/hr, while the hydraulic conductivity increased upto 34.50 mm/day from 22.00 mm/day in case of treatment T_2. The depth-wise drainable porosity was found to be increased upto 16.425%, 14.823%, 17.165% and 11.685% from 9.938%, 9.383%, 9.030% and 8.410% in 0-25, 25-50, 50-75 and 75-100 cm depths, respectively. While, the bulk density was decreased upto 1.125, 1.293, 1.425 and 1.460 gm/cc from 1.230, 1.361, 1.475 and 1.518 gm/cc in 0-25, 25-50, 50-75 & 75-100cm depths respectively. The treatments T_4 in 0-25 cm depth is found insignificant in case of both bulk density and drainable porosity. These parameters were found significant in treatment T_2 and T_3 over the treatment T_4 and T_1 in case of 25-50 cm depth and 50-75 cm depths. The treatment T_3 was found to be highly significant over all other treatment in bulk density from 75-100 cm depth. The increase in infiltration rate, hydraulic conductivity and drainable porosity may be due to the decrease in bulk density.

The bulk density of soil was decreased after decomposition of material while other properties i.e. field capacity, drainable porosity, infiltration rate, hydraulic conductivity and saturation moisture content have increasing effect of decomposing material as compared to the control treatment. Hence the drainage properties can be improved by the decomposition of various crop residues and agricultural wastes in the saline soil. There is increase of maximum 11.92% in the yield of gram after the decomposition of organic material.

Firake and Pampattiwar (1993), had conducted the field experiment on sub-surface parallel drain system in monsoon, 1987 to determine the soil hydrological constants in clay loam soil. Drainable porosity (f), Hydraulic conductivity (K) and Transmissivity (T) were determined for five drainage events. It was observed that the f values were increased with the drain-out time. The average f for 15 and 30 m drain spacing (L) were 0.0407 and 0.0438, respectively. The average K for 15 and 30 m L were 0.856 and 1.134 m/day, respectively, which were observed smaller than that obtained by single auger hole method. The maximum and minimum T values for 15 m L were 1.0218 and 0.1531 m^2/day, respectively and for 30 m L were 1.9372 and 0.3434 m^2/day respectively.

The whole Purna command area was surveyed by More et al (1994) to study the salt affected soils. About 65% of the soils were affected due to salinity. The percentage of saline, saline - sodic, sodic and normal soils in the command area were 22.92, 14.58, 33.33 and 29.17 respectively. The p H of the soils was ranged from 8 to 10.74. The average of p H of sodic soils of Purna command was 9.12. The EC s of the salt affected solid were ranged from 0.84 to 39.2 mmhos/cm. Chlorides and sulphates were dominant in saturation extract of saline soils. The bicarbonate content of sodic soil was relatively high while carbonate content of all the soils was comparatively low. Exchangeable calcium was a dominant cation in all the categories of the soils. Exchangeable Na was relatively high in sodic (11.27 me / 100 g) and saline sodic soils (9.2 me / 100 g). CEC of the soils ranged from 33.60 to 48.00 me / 100 g. The average ESP of saline-sodic and sodic soils was 23.97 and 27.28 respectively. Organic carbon content in the salt affected soils of Purna command ranged from 0.48 to 0.90 %. Gypsum requirement of sodic soils of Purna command was in the range of 2.5 to 12.6 t / ha with an average value of 5.6 t / ha.

A study was conducted by Muthuchamy and Chandrasekaran (1996) at the Soil salinity Research Center, Trichy during 1986-1988 in two seasons to find out the efficiency of sub-surface drainage on reclamation of wet land sodic soil using rice ADT 36 two levels of lateral spacing (10 m, 15 m) and two levels of depth of drains (60 cm, 90 cm) were incorporated in the experiment in a factorial randomized block design. The water used for irrigation and the soil types were sodic in nature. The clay pipes of 50cm length with 15cm diameter were used as drainage pipes. The plots with drain lines having lateral spacing 10 m buried at a depth 90 cm registered significantly the highest grain yield.

The mechanical analysis of soils of Katepurna and Morna command areas were performed by Hiwase et al. (1998) and the sand, silt and clay content of soils are determined. The soils of Katepurna and Morna commands show soils of fine texture, slowly permeable, small sizepores, less drainage porosity and having less infiltration rate which offers poor drainage properties and lead to waterlogged conditions for maximum time and keeping harmful salts in the root zone area ultimately hampers the growth of most of the crops in heavy rain period or in irrigated conditions. Analytical procedure given in USDA handbook No. 60 were followed for carrying out determination of EC, pH, $CaCO_3$, Avialble K_2O, Available P_2O_5. The electrical conductivity of the soil in Katepurna command varies in the range 0.82 mmhos/cm to 1.20 mmhos/cm while in Morna command it lies in the range of 0.82 mmhos/cm to 1.06 mmhos/cm. The pH of the soil is in between 7.64 to 8.69 for Katepurna command and 7.44 to 8.34 for Morna command. The organic carbon content of the soil is in the range of 0.30% to 0.94% for Morna command while for Katepurna command it is from 0.16% to 0.76%. Calcium carbonate contents of the soil varies from 13.00% to 18.75% and 12.00% to 16.25% for Katepurna and Morna command respectively. Available P_2O_5 content of the soil range from 3.36 kg/ha to 49.84 kg/ha and 4.10 kg/ha to 65.70 kg/ha in Katepurna and Morna command respectively while available K_2O content of the soil ranges from 227.73 kg/ha to 746.68 kg/ha and 177.95 kg/ha to 746.66 kg/ha in Katepurna and Morna commands respectively.

3.10 Forest Hydrology

Watershed is a natural physiographic or hydrologic unit where land, water and vegetation interact in a perceptible manner. Watershed has a number of distinct types of land use, its extent and management are important characteristics in determining the functioning of a watershed. Watershed may have pure or mixed land use e.g. agriculture , forests, grassland , wasteland or combination of these. The hydrological functioning of a vegetated watersheds turn is influenced by the types of the vegetation its extent and management. Forest have however occupy smaller or greater fraction of watersheds. The vegetative management especially on upland watersheds is one important method to increase water yield.

The forests are largely confined to upper catchments of various water resources projects land catchments of flood prone areas. Forest occupy 22.7 % land area of the country as against 33 % envisaged by the National Forest Policy (1952). The forests are classified into 16 major forest types spread over 74 m ha of country's land area mostly restricted to mountainous, undulating and rugged terrain. The distribution of area under different land uses in the catchments of 31 River valley Projects (RVP's) spread over an area 78.6 m ha indicates that on an average agricultural lands account for 62%, forest for 20% and other lands (grass land, waste land etc.) for 18% of the total area (Das et al.,1981).There are number of subcatchments predominantly covered with forests. The poorly managed and degraded forests with tremendous biotic interference in the upper catchments are counter productive for proper hydrological functioning.

The existence of forest is generally recognized and understood as an important factor in the economy of the water resources of the watershed, closely associated with this function is that of protecting the soil from erosion. These functions of forest growth both in terms of water supply and soil conservation are of great importance to the national economy. The rapid pace of development of industry and increasing productivity of agriculture lead to ever larger amounts of water being required for industrial processes and irrigation crops. The irregular and intermittent nature of precipitation, which occasionally gives rise to floods can cause great damage to valuable land and result in the runoff and the loss of much potentially useful water. This water may to some extent be saved and stored by the construction of dams and creation of reservoirs so that accumulated runoff or thawing snow can be used to generate electric power, irrigation development and industry. On the other hand the forests also has the effect of storing water although not in a way as dams. However, much more need to be done to know about the quantities of water involved and when and under what conditions this water is drawn upon by forest itself.

Forests influences on various hydrological parameters viz., rainfall, interception, infiltration, soil moisture, evapo-transpiration, groundwater, water yield, soil loss and floods etc. Originally, a 'forest' must have included all uncultivated and uninhabited land. Today, a forest is any land managed for the diverse purposes of forestry, whether or not covered with trees, shrubs, climbers or such other vegetation. Technically, forest has come to be defined as an area set aside for maintained under vegetation for any indirect benefits, namely climatic, protective or environmental and or for production of wood and non-wood products. In the legal sense, a forest can be defined as an area of land notified to be a forest under a forest law (Agrawal, 1989).

Hydrology is concerned with processes governing the depletion and replenishment of the water resources of land areas of earth. Forest influences are defined as all effects resulting from the presence of forest upon the climate, soil water, runoff, streamflow, floods, erosion and soil productivity. Kittredge (1948) cited from Lee (1980) suggested that the important phases of forest influences concerned with water such as precipitation , soil water, stream flow, floods etc., may be grouped under 'Forest hydrology'. Forest Hydrology can thus be defined as the science of water related phenomena that are influenced by forest cover. Forest watershed management is also used extensively to denote operational activities based on knowledge of forest hydrology.

Thus forest and their environment from a complex relationship with that of forest vegetation. It has direct or indirect influence on various hydrological parameters such as rainfall, interception, evapo-transpiration, ground water, soil loss, water yield etc.

The studies concerning forest hydrology have not been done on large scale in India especially in Hard rock Region. The limited number of studies which have been done by the central soil and water conservation research and training institute, national Remote Sensing Agency, and some other organization and agencies such as universities of agriculture have been mostly on small watershed.

The type of studies being done at various places of Hard rock Region include i) to evaluate the effect of various land uses and vegetative covers on various elements of hydrological cycle e.g. interception, infiltration,, soil moisture, runoff and soil loss, ii) to study hydrological behavior of natural and man made forests, iii) to study hydrological behavior of forest watersheds under permanent vegetation and grass cover, iv) to study influence of various forest management practices and biotic interference on hydrologic cycle, v) to establish rainfall - runoff and sediment yield relationships and develop runoff prediction models for small watershed , vi) to assess the impact of soil conservation measures on runoff and soil loss. vii) to identify suitable tree species and management practices from conservation point of view, and viii) to study hydrological behavior of ravenous watersheds.

In view of this, the efforts have been made in this report to review the various research findings and presented the state of knowledge on the subject in hard rock region of India so as to study the extent of forest influences on hydrology of watershed and to identify the research gaps tanned to spell out future research needs to narrow down the existing gap.

Kittredge (1948, cited from Lee, 1980) suggested that the important phases of forest influences concerned with water, such as rainfall/precipitation, soil-water, stremflow, floods etc. may be grouped under "Forest Hydrology". Forest Hydrology can thus be defined as the science of Water related phenomena that re influenced by forest cover.

In India, the systematic and scientific studies have not been done in a planned way to study the effect of afforestation or deforestation on rainfall. The experience in India on the basis of few observations tends to suggest that forest do not have appreciable effect on rainfall over a wide area whereas they may have limited effect on local rainfall due to high rate of evapo-transpiration taking place from vegetation cover. The results of an inquiry initiated by Government of India in 1906 (Lal and Subbarao, 1981) also concluded that the influence of forest on rainfall was probably small.

However, Dr. Voelekar published interesting data pertaining to the areas of Nilgiri hills which was later updated suggesting that the number of rainy days increased with increase of forest, excluding the months of June, July and August as the rains during these months are not of local origin (Ranganatha, 1949 cited from Lal and subbarao, 1981).

The results of infiltration studies conducted at Belllary and Ootacamund under different vegetative covers as given in the following table 5.

Table 5. **Infiltration rate under different Vegetative covers**

Vegetative Cover / land use	Infiltration Rate (cm/hr)	Remarks
Bellary		
Wood land	17.00	For one hour run
Grass land	2.60	-do-
Agricultural land	1.00	-do-
Ootacamund Study No. 1		
Shola forest	16.84	For three hours run
Bluegum plantation	20.69	-do-
Grazed grassland	5.13	-do-
Ootacamund Study No.2		
Shola forest	12.50	For three hours run
Broom(Cytisus scoparius)	11.25	-do-
Grazed grassland	6.25	-do-

Tejwani et al., (1975) indicates maximum infiltration rates for woodland in Bellary (17 cm/hr) and Shola forest i.e. miscellaneous vegetation in Ootacamund (12.5 - 16.8 cm /hr). The analysis of data from small forest and agricultural watersheds of Doon valley done by Dhruvanarayana and Sastry (1983) indicates that the rate of infiltration is twice in forest watershed (shorea obust) as compared to agricultural watershed.

Rajagopalan et al. (1985) reported annual consumptive use crop coefficient for forested catchments in Khandala to be 0.542, which is on the lower side of crop coefficient of deciduous orchard. Since the study has been conducted for a short time on micro catchment, it would be desirable that such studies may be carried out in different vegetation types to arrive at appropriate crop coefficient values under different forest mixtures.

Ground Water

The effect of forest cover on ground water storage can be inferred from evapo-transpiration, soil moisture and discharge relationships. It depends partly on the depth and proliferation of the rooting system and on growing season length. It is generally believed and has also been experienced in some countries that in areas where the ground water table is near the surface, forest cutting will cause tit to rise conversely reforestation can eliminate water logged or semiswamp conditions. But in India, no efforts have been made t study the influence of forest on ground water. Recently , the ERS has taken up a project to evaluate the role of land use and different forest covers on ground water table through regular ground water monitoring at Siliguri under cryptomeria and under Bluegum, Shola and grass land at Ootacamund centers. The increase in water table due to afforestation and other soil conservation measures in a watershed of 314 ha have been evidenced in G.R. Halli Chittardugra (Annon, 1983) and else where. In most of the watershed hydrology research studies, the ground water component is normally not being mentioned which is considered to be an important component for studying the complete hydrology of a watershed. There has been a recent trend to plant fast growing tree species but as on today there has been no systematic study on the impart of the fast growing trees like Eucalyptus etc. on ground water recharge. the impact of vegetation in lowering water table and thus reclaiming waterlogged areas is also to be studied.

Studies at Ootacamund on peak discharges from different land uses indicate that the plantation of Eucalyptus and Wattle reduced the peak discharge y nearly 62 % as compared to agricultural land (Lal and Subbarao, 1981). Studies on the amount of runoff and soil loss under different vegetative covers e.g. Shola (i.e. natural forest), bluegaum, watttle, room and grasses carried out on 0.02 ha plots on 16 % slope indicate highest water loss (runoff) amounting to 1.27 % of total precipitation from wattle and shola covers where as in bluegum runoff is recorded to be 1.08 % of total precipitation. It reveals that there was not much difference in runoff between different vegetative covers, The soil loss was also negligible (Annon, 1982)

The runoff and soil loss data obtained from 0.09 ha plots with different treatments unnatural Shola forest at Ootacamund (i.e. Sholas in treatment A, B and C were clearfield in

1965 and planted with bluegum, back wattle and mixture of these two in 1968). The results do not show any appreciable change in runoff and soil loss pattern even after the application of treatments.

The hydrological studies conducted on two identical watershed (32 ha each at Glenmorgan (Ootacamund) to study the behaviour of watershed with natural as well as introduced plantation of bluegum indicate that the observed discharge from natural vegetation (grassland, Sholas and Swamps) and grassland with bluegum were 31.4 and 29.9 percent of total precipitation respectively (from 1972 - 76) and the soil loss was zero, Anon (1982). It may be worth noting here that the similar plantation produced nearly 1 % rainfall as runoff in runoff plots where as in watershed studies the same has produced nearly 30 % of rainfall as runoff. This is indicative of the limitations of small plot studies. The preliminary analysis of the runoff data of Glenmorgon watersheds indicates that at the end of 10 years rotation the watershed planted with bluegum (Eucalyptus globulus) produced 16% less annual water yield as compared to natural watershed (Research Highlights CSWCRTI, 1983).

Srinivas et al. (1996) made an attempt to study the validity of United States soil conservation Service (USSCS) curve number technique often called SCS model for forested catchments. A typical Western Ghat catchment, Sitanadi basin in the West Coast of India is selected. The land use classification of the basin is done using visual interpretation techniques of IRS-1A LISS II data. The model is developed for the influencing area to Kokkrane gauging station in the basin and is tested for its applicability.

Conclusions and Recommendations:

The variation in the geomorphological features as well as geohydrological differences makes a variety of hydrological problems in this heterogeneous physiological unit of peninsula. To take care of these problems of the regions, the scientist and researchers have to developed an understanding of the scientific problems of this region and conduct hydrological studies of interest to this region using new and modern techniques.

On the basis of review of available literature the present state-of--art on the subject is summarized below,

1. Eventhough, hydrologic network servers an important and fundamental role n the scientific management of water resources, there is no much emphasis is given for the rain gauge as well as stream gauge network design. The existing key stations for the major river stations are found to be comparatively very less as per the design requirements. Though there are number of raingauge stations and stream gauge stations were set up by Water Resource Development Organisation, Banglore as well as National Institute of Hydrology, in the Representative Basin of the Regional Centre of National Institute of Hydrology, no work for the adequacy testing for the network had been found so far. Hence, it is necessary to take such studies for the representative basin as well as other basin of the hard rock region.

2. The groundwater pollution due to fluoride and nitrate concentration were found to be in the wide spreaded scale in this hard rock region, which posses a serious health hazards in various parts. Therefore, it is necessary to take up such studies on priority basis.

3. Mostly, groundwater in hard rock areas is abstracted from dug, dug-cum-bore, shallow bore and deep bore wells. The over abstraction in existing wells, failure in identifying the exact water bearing zone, failure of open and bore wells in many parts of the hard rock region are common phenomenon. The tremendous increase in original well depth (s) as well as reduction in cropped area, shift to crop having short gestation period, adoption of drip irrigation are some major cause towards the failure of wells.

4. In this region, there is growing demand for the groundwater 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 to the water resources and impact of man's activities on the surface and groundwater. In general, the groundwater potential of hard rocks is poor, though relatively high yields may be obtained in restricted locations under favourable circumstances of topography and rainfall. The North-East monsoon accounts for a greater part of the annual rainfall confining to a small period between October and December. However, the annual average rainfall remains the same over the years. Secondly, the post-monsoon water table is large than the premonsoon level indicating that the ground ware pumping is as much as the recharge taking place during the monsoon season and no appreciable pumping during the rest of he period. There is a general decline in the water table during the eighties indicating in the sub-basin is low.

5. Most of the regional flood studies are based n the USGS approach and with RDSO data. There is a need for taking up systematic regional flood studies using large data base collected by different organisations and agencies. This would enables pulling together of vast informations for use hydrologic analysis and design.

6. Soil erosion and reservoir sedimentation are the threats to water resources development in country. Use of remote sensing satellite can be very effectively use to study the sedimentation in the reservoirs.

7. Inspite of having comparatively large areas under the black soil region in hard rock areas, there is no much research works so far conducted to focus on drainage problems due to which, this soil remain under utilized, eventhough having high potential productivity and favourable climatic conditions.

8. Forest influences are defined as all effects resulting from the presence of forest upon the climate, soil-water, runoff, streamflow, floods, erosion and soil productivity. But, it is difficult to generalize the effect of forest on rainfall and floods as hardly few scientific studies have been done in this direction in this region. For having the synergic benefits from the research activities, there is a need for close cooperation with different agencies working in this field.

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Kagan (1966) introduced a correlation function, $\rho(d)$ as a function of the distance between raingauge stations. The form of the function depends on the spatial variability of the rainfall and can be expressed as

$$\rho(d) = \rho(o)\ e^{-d/d_o}$$

where, $\rho(d)$ is the correlation function of the distance between raingauge stations

$\rho(o)$ is the correlation corresponding to zero distance d_0

Theoretically, $\rho(o)$ must be equal to 1 as it is the correlation corresponding to zero distance. however, the microclimatic variations and the random errors in measurement of rainfall make $\rho(o)$ as being less than unity and the variance of these random errors is given by

$$\rho_1^2 = (1 - \rho(o))\ \sigma_n^2$$

Where ρ_n is the variance of precipitation time series at a fixed point. The two parameters $\rho(o)$ and d_0 provide the necessary for assessing the accuracy of a given raingauge network.

Kagan has given the relative root mean square error in the average rainfall over an area S as

$$Z_1 = C_v \sqrt{\frac{1 - \sigma(o) + 0.23\dfrac{\sqrt{S}}{d_o\sqrt{n}}}{n}}$$

The above equation will give the permissible value of error Z_1 for a given number of raingauge n provided $\rho(o)$ and d_o are known. Alternatively, the number of raingauges required for a desired percentage of error can be estimated. Thus, Z_1 can be used as criteria for deciding the desired network.

Physical-statistical method includes the following steps when annual series of flow is available at two gauging sites on the river alongwith the area of the basin upto concerned site and the distance between the two sites.

Step1: Compute the means $(\overline{Q}_1)$ and $(\overline{Q_2})$ and standard deviations of annual flow series and correlation coefficient r between annual flows at two gauging sites.

Step 2: Compute S_o, the radius of correlation of which correlation function is zero by substituting the value of correlation coefficient r in the following expression.

$$S_0 = S/(1-r)$$

Where, S is the distance between two sites on the river.

Step 3: Compute relative gradient Grado $(\overline{Q}) = \frac{Q'e}{\overline{m}} = \frac{Grad(\overline{Q})}{\overline{m}}$

where, $\overline{Q}$ is long term average runoff of N years

Q_e is obtained by dividing the differences of mean annual flows at two sites by the distance between two sites.

Thus, $Q'_e = (\overline{Q}_1 - \overline{Q_2})/ S$, $\overline{m}$ is average of flow at the two gauging sites,i.e. $(\overline{Q}_1 + \overline{Q_2})/2$.

Steps 4: Compute the condition of sufficiency of streamflow gradient Sgr as:

$$\text{Sgr} \geq \frac{2.82\sigma_o}{Grade(\overline{Q})}$$

where, σ_O is the relative error. This can be estimated by the following expression

$$\sigma_O{}^2 = \frac{1}{N}\sum_{j=1}^{N}(\left(\frac{Q_{1j}+Q_{2j}}{2}\right) - \left(\frac{\overline{Q}_1+\overline{Q}_2}{2}\right))^2$$

$$= \frac{\sigma_1^2}{2}(1+r) \approx \frac{\sigma_2^2}{2}(1+r)$$

Assuming $\sigma_1 \approx \sigma_2$

Steps 5: Compute S_c; taking as S_c at zero coefficient i.e. distance between two sites as.

$$S_c \leq \frac{\sigma^2}{aC^2_v}$$

Where C_v is the coefficient of variation of annual flows at concerned sites and

$$a = \left(\frac{1}{S_0}\right)$$

Steps 6: Copmpute the Fgr, the limiting area of the gradient function as

$$Fgr \geq 8 \left(\frac{\sigma_0}{gradoQ}\right)^2$$

Step 7: Compute F_c, the limiting area of the correlation function as:

$$Fgr \leq \frac{\sigma_o{}^4}{a^2 C^4{}_v}$$

This is based on assumption of the following relationships:

$$L \approx 2F^{0.5}$$

$$S \approx F^{0.5}$$

Where, L is the length of the river and F is the drainage area.

Step 8: Compute the number of gauging stations N as

N = F/ Minimum of Fgr or Fc = F/ F min

Where, F is area of basin

Rate of Siltation observed from successive repeat suin some of the reservoirs of Andhra Pradesh

Sl. No.	Name of Reservoir	Original Capacity in M.Cum. and Year	Capacity in M. Cum. As per the hydrographic surveys and year			Rate of Sedimentation Hm/100 Sq. km. Per year and number of year			Area of catchment Survey (Ha)
			First Survey	Second Survey	Third Survey	First Survey	Second Survey	Third Survey	
1	Nizam Sagar	841.81 (1930)	451.67 (1961)	362.40 (1975)	305.82 (1992)	6.67 (31)	5.74 (8)	2.783 (17)	18,523
2	Signur	847 (1987				5.49 (10)			16,096
3	Upper Manair	84.97 (1950)	61.09 (1987)			5.531 (10)			2,174
4	Musi	142.31 (1954)	135.00 (1978)	134.15 (1982)	133.31 (1985)	1.580 (5)	1.417 (4)	1.320 (3)	2,056
5	Pampa	15.96 (1977)	15.32 (1982)	15.00 (1986)	14.84 (1990)	5.680 (5)	5.00 (4)	4.43 (4)	355

TECHNICAL COORDINATOR	**DR. B. SONI**
HEAD	**Mr. C. P. KUMAR**
STUDY GROUP	**Mr. DILIP G. DURBUDE**