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CONJUNCTIVE USE STUDY OF GANGAVATHI COMMAND AREA OF THUNGABADRA PROJECT KARNATAKA

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PREFACE

Optimum development of water resources can be achieved by the conjunctive use of surface and groundwaters. The coordinated operation of surface and groundwater supplies is required to regulate the local and imported water supplies.

Evolving an optimal and practically feasible strategy for conjunctive utilisation of groundwater and surface water resources in the command areas, underlined by hard rock formations is the main objective of the present study. The hard rock formation forms, small and discontinuous shallow aquifers of limited thickness and low well yields. Normally, groundwater has been developed in private sector and it has been found to be haphazard and ill-planned. Over exploitation of groundwater has resulted in mining of groundwater. On other hand, in some major irrigation project commands, problem of water logging have been experienced. Water logging problem could be averted, provided conjunctive use of envisaged in the canal command area during project planning stage itself. It is therefore necessary to develop a methodology for conjunctive use of these resources in these fomations.

In the present study, the analysis of geohydrological data has been presented and effort has been made to find the cause and extent of waterlogging in the command area of Thungabadra of Gangavathi taluk. This report has been prepared by A.V. Shetty, Scientist `C' with the assistance of N.Varadarajan, Research Assistant.

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ABSTRACT

The main objective of the study is to evolve an optimal and practically feasible strategy for conjunctive utilization of groundwater and surface water resources in the command area. Normally, grounwater has been developed in private sector and it has been found to be haphazard and ill-planned. On the other hand, in some major irrigation project commands, problem of waterlogging have been experienced. Waterlogging problem could be averted, provided conjunctive use is envisaged in the canal command area during project planning stage itself. It is therefore necessary to develop a methodology for conjunctive use of these resources.

Rational planning and management of study area is not possible without comprehensive assesment of the need and the availability of water resources. In the present study, the evaluation or the assesment of the need and availability of water, and the extent of waterlogging in the study area is carried out by the rainfall analyses, groundwater trend analyses, water requirement, groundwater balance, and water quality analyses.

The area selected for the conjunctive use study is the command under Gangavathi taluk of Thungabhadra project, Karnataka.

The analyses of geohydrological data of the study area shows that, there is an 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 inter-relationship 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 proper and productive utilisation of surface and sub-surface water resources conjunctively.

1.0 INTRODUCTION

Optimal utilisation of the existing water resources is an issue of ever increasing importance because of limited water resources available. It is appropriate and necessary to develop a methodology for optimising the conjunctive use the available surface water and groundwater resources. The need for such an optimal development and use of groundwater and surface water resources is brought into sharper focus in the National Water Policy document(1987) which stipulates that integrated and coordinated development of surface water and groundwater and their conjunctive use should be envisaged right from the project planning stage and should form an integral part of the project.

Operation of both surface and groundwater reservoirs with a scientifically planned approach provides a larger water storage and hence greater water conservation. Greater utilisation of groundwater in the command area of surface water project leads to smaller surface distribution system. Since pumping well would act as a vertical drainage and would aid in controlling the water table, a smaller drainage system is required where conjunctive use is in practice. In conjunctive use planning, canal lining can be reduced as seepage from canals provides augmentation of groundwater recharge. Conjunctive use leads to lesser evapotranspiration loss because of greater underground storage with lower groundwater table position.

Utilisation of aquifer storage in conjunction with surface reservoir has been thought of since 1940. The specific problem of inter-relationship between surface and groundwater for arid zones has been studied and reported by Khosla. The importance of conjunctive use of surface and groundwater can be judged from the fact that in Central valley of California, an aquifer of storage capacity six times larger than that of feasible surface reservoir is available.

A number of developments took place in U.P., Punjab, Maharashtra, Tamilnadu and other States in the forties with respect to utilisation of groundwater. However, conjunctive use of surface and groundwater was adopted to meet specific requirements without considering optimum utilisation. From 1960 onwards, increased attention of Central and State Governments was focused on increased use of surface and groundwater resources conjunctively.

The waterlogged extent of 971,000ha, in 1964 which got reduced to 169,000ha. by 1974 after sinking of a large number of tube wells in Punjab.

In Haryana State, tube wells are of two types. One type is augmentation tube wells which are installed along canals and these water pump into canals for utilisation in the canal command areas. Other type is direct irrigation tube wells which provide local irrigation facilities out side the canal command areas. In Bihar, it is only in the command of the Sone Project that groundwater has been used with canal supplies. Conjunctive use of surface and groundwater has been introduced in certain areas in Chambal Command in Kota and Bundi districts. In Gujarath , tube wells are being installed in canal commands of Mahi, Dantiwada etc.. Similar projects envisaging conjunctive use have also been taken up in the command areas of the Ghataprabha Left Bank Canal in Karnataka and the Godavary Canal Systems in Andhra Pradesh. In Madhya Pradesh, the government has taken up a project with the help of World Bank for conjunctive use studies in Chambal Command.

In general, groundwater has been developed in private sector and it has been found to be haphazard and ill-planned. Over exploitation of groundwater has resulted in mining of groundwater. On the other hand, in some major irrigation project commands, problems of waterlogging have been experienced. Waterlogging problems could be averted conjunctive use is envisaged in the canal command area during project planning stage itself.

Evolving an optimal and practically feasible strategy for conjunctive utilisation of groundwater and surface water resources in the command areas underlined by hard rock formations is the main objective of the present study. Unlike in soft rock formations both in India and abroad where conjunctive use is already in vogue and the practice is well established, the hard rock formation form small and discontinuous shallow aquifers of limited thickness and low well yields. The carry over storage of these aquifers is limited and groundwater development in these formations is essentially a farmer's enterprise. It is therefore necessary to develop a methodology for optimising conjunctive use of these resources in these formations. The determination of optimal allocations of surface water and groundwater resources that will accomplish the objective efficiently as measured by maximising net benefits is to be developed by the help of the available models after taking into consideration of various alternative options.

The concept of conjunctive use of surface water and groundwater is based on surface reservoirs impounding stream flow, Which is then transferred at an optimum rate to groundwater storage. Surface storage in reservoirs behind dams supplies most annual water requirement, while the groundwater storage can be retained for cyclic storage to cover years of subnormal precipitation. During periods of above normal precipitation, surface water is utilised to the maximum extent possible and also for artificial recharge into the ground to augment groundwater storage and raise water table. Conversely, during drought periods, limited surface water resources are supplemented by pumping groundwater, thereby lowering groundwater levels. The feasibility of conjunctive use approach depends on operating groundwater basin over a range of water levels, that is, there must be space to store recharge water, and in addition, there must be water in storage for pumping when needed.

Management by conjunctive use requires physical facilities for water distribution, for artificial recharge and for pumping. The procedure does require careful planning to optimise use of available surface water and groundwater resources. Such operations require competent personnel, detailed knowledge of hydrogeology of the basin, records of pumping and recharge rates, and continually updated information on groundwater levels and quality.

A conjunctive use management study requires data on surface water resources, groundwater resources, geological conditions, water distribution systems, water use, and waste water disposal. A basin model has to simulate the responses of a basin to variations in variables such as natural and artificial recharge and pumping so that the best operating procedures for basin management can be practiced.

Rational planning and management of a study area is not possible without comprehensive assessment of the need and the availability of water. In the present study, the evaluation or the assessment of the need and the availability of water, and the extent of waterlogging in the study area is carried out by the following analyses and estimations.

1. Rainfall Analyses
2. Groundwater Trend analyses
3. Water Requirement
4. Groundwater Balance
5. Water Quality analyses

The area selected for the conjunctive use study is the command under D-29 distributary of Sriram Sagar Project situated in Karim Nagar district, Andhra Pradesh state.

2.0 REVIEW OF THE LITERATURE

The complexities of the problem of conjunctive operation of ground and surface water reservoirs and advantages were formally recognised nearly four decades ago. Since then, several analytical approaches for conjunctive utilisation have been developed. Literature dealing with the concepts of conjunctive use of groundwater reservoirs and surface water facilities is extensive. However, most of the literature dealing with conjunctive use has been of a qualitative nature and has dealt primarily the local aspects.

Authors who have dealt with the problem of conjunctive use of ground and surface water systems such as Clenderen(1954), Thomas(1957) and Macksoud(1961) have discussed the economic advantages of such combination and have pointed out its effectiveness in the conservation of sizable volumes of water. When these authors have dealt with the problems of economic optimisation, the method of analysis is based upon investigation of a limited number of alternatives and selection of the best one according to the benefit-cost ratio during the economic life of the project. The work of these authors, however has been concerned mainly with the engineering problems on the design and operation of the conjunctive use system.

Todd (1959) indicated positive economic factors in conjunctive use, including greater water conservation, smaller surface storage and distribution system, better flood control, ready integration with existing development, less danger from dam failure, and better timing of availability of water for distribution.

Renshaw (1963) presents the argument that decisions regarding the use of groundwater resources should be based on the value of the groundwater resource. The basis of the argument is that the water left in the storage has economic worth. The economic returns from water left in the ground can be estimated by two methods presented by the author. In the first method the returns are based on reduced pumping cost due to reduced mining of groundwater. The second method is based on the economic returns on the capitalised value of water left in the storage. Renshaw's arguments emphasize the value of not pumping groundwater.

Koenig (1963) presents the opposite view regarding the economics of groundwater development and use. Koenig's thesis states that the attitudes and practices of groundwater development in the nation as a whole are far too conservative and he recommends a much greater use of groundwater resources.

Koenig argues that extraction from groundwater reserve should be viewed in the same manner as extractions from other resource reserves such as oil or coal or natural gas. Without consideration of any further replenishment of groundwater reserves, the life of current reserve of groundwater is more than 18 times greater than the corresponding life of any other non-replenishable resource with the exception of bituminous coal. According to Koenig, if the present rate of depletion of groundwater storage is continued, the reserve life would be 7800 years. Alternative to local storage of groundwater are reducing the level of the economy in the local area or importing water to the water short areas from areas of abundance. The conservative attitude toward groundwater development can not be justified economically, according to Koenig.

Fowler (1964) has suggested that solving the engineering problems associated with development of a conjunctive use system requires a thorough understanding and investigation of the geology of the groundwater basin, of the hydrology of surface and groundwaters, of the existing surface and groundwater facilities including storage and transmission characteristics and of existing and expected water demands and the economics associated with meeting those demands. Fowler states that when groundwater basin can be operated in a fully integrated fashion with surface water supplies, then optimum use of water resources can be achieved. However, in order to achieve this integrated operation, new methods and institutions must be devised to coordinate and manage the operation.

Tyson and Weber (1964) use a computer simulation approach to formulate a "most economic plan" for operating groundwater basins in conjunction with surface facilities. The computational procedure involves two phases: 1) development and verification of the model and 2) use of the model in predicting basin behaviour under imposed conditions. An electromagnetic differential analyser or analog computer is used for the first phase and a digital computer is used in the second phase. In order to develop a mathematical model of the groundwater system, the groundwater complex is replaced by a simplified model divided into small polygonal zones. Assumptions used in deriving model are that the aquifer is unconfined, there is no vertical variation in aquifer properties and that the aquifer thickness is small in comparison to its lateral dimensions. Flow in the aquifer is defined by single linear equation derived by combining the continuity equation with the Darcy equation. The time dependent flow rate in the aquifer is the algebraic sum of the several extraction and replenishment flows.

Chun, Mitchell, and Mido (1964) present an approach of this nature for studying the conjunctive operation of groundwater basins with surface supplies. Their approach is applied to a regional water supply system supplying the Los Angeles basin. In this study alternative plans are formulated representing use of the groundwater basin in coordination with surface facilities in order to meet imposed demands in the system. Each alternative plan which was studied presented in terms of groundwater basin operation. Each alternative plan of operation involved four decision variables: a) the areal pattern of groundwater extraction, b) the methods of prevention of sea-water intrusion, c) a schedule of spreading artificial recharge water in given locations, and d) the pumping schedule for fixed locations. The design is based on the use of existing facilities and on a limited number of possible recharging areas. From the vast number of alternatives, the relatively few having practical importance were selected in a preliminary examination. For each practical alternative, analyses were carried out separately for the surface and subsurface systems. The subsurface system was simulated on an analog computer in order to develop a mathematical model of the subsurface system. Operational studies of the subsurface system were then carried out on a digital computer. In the analyses of the surface system, future water demands in the region were taken into account. The most economical surface and subsurface facilities were selected on the basis of the operation studies. The final optimum alternative combination of subsurface and surface facilities were selected according to the criterion of minimising the total annual costs. Economic comparisons of alternative plans of operation are made on the basis of converting these annual cost into total present worth.

Saunders (1967) states that in order to assess the value of planned conjunctive use in relation to a particular area or basin, it is necessary to look at the economic, hydrologic and legal system as a whole. A planning procedure is then presented to enable a planning agency to determine, at minimum cost, the feasibility of planned conjunctive use. The procedure consists of determining system characteristics and discussing in terms of system analysis and linear programming.

Domenico, Anderson, and Case (1968) present a mathematical expression relating to economic worth of groundwater mining to the remaining worth of a basin after it has been partially depleted. This expression permits the establishment of an optimal, one-time storage reserve that may justifiably be exploited. In this argument, sustained yields are taken as use rates determined by and limited to natural replenishment and mining yield may be mined rapidly or slowly, but the volume extracted is limited. Maximisation of present worth is taken as the conventional management objective. Optimality is determined by conventional calculus methods.

The techniques for dynamic programming and linear programming were commonly used among the studies of this category. Castle and Lindberg (1961) formulated a linear programming model to allocate water from two sources to agricultural areas. Buras (1963) adopted dynamic programming technique to optimise the conjunctive operation of water released from two storage sources for irrigation into agricultural areas. The optimisation process involved the solution of three problems (1) determination of design criteria for the surface storage and recharge storage (2) determination of extent of the system service area and (3) determination of the operating policy specifying the reservoir releases and aquifer pumpage. The operating policy was developed for a number of seasons using the logic of dynamic programming. Burt (1964) used dynamic programming to derive decision rules for the optimal allocation of water resources. The decision rules were based on the volume of water pumped in each season which was a function of the storage available at the beginning of the season. The optimum policy was determined based on the maximum present worth of net benefits. Dracup (1965) used a parametric linear programming model to optimise the groundwater and surface water system. The optimal policy minimizes the costs of water importation, storage, boostage and artificial recharge. Five sources of water were used to satisfy the requirements. The analyses extended over a 30 year period and three different decision rules were analysed. Aron (1969) used dynamic programming to optimise the conservation and use of a groundwater and surface water system involving several streams, reservoirs, recharge facilities, distribution pipe lines and aquifers. The complex system was sub-divided into smaller sub-systems and wherever the inter-dependence between these subsystems was relatively small, they are optimised independently. Milligan (1970) developed several linear programming approach models for economic optimisation of the use of surface and groundwater. The models were formulated for one hypothetical basin and two real basins. Cocharn and Butcher (1970) used a dynamic programming model to determine the optimal allocation of existing water with possible augmentation from imported water to Las Vegas Valley. Nev Longenbaugh (1970) developed linear programming model allowing for a constant interaction between an aquifer and connected system. This interaction was assumed to be unaffected by the pumping of the aquifer, although it poses practical limitation on its use. The model was applied to the Arkansas River·Valley in Colorado.

Yu and Haimes (1974) have developed a multi-level optimisation technique for conjunctive use of water for complex systems, emphasising hierarchical decision making in a general sense. The basin was divided into several subregions and each subregion was optimised separately. They conclude that the aquifer is the key element in optimal operation of conjunctive use systems. Chaudhary et al (1974) used a decomposition and multi-level optimisation technique for optimal conjunctive use of water in the Indus basin in Pakisthan. The sub-model was to minimize the cost of supplying water to meet given irrigation water requirement. Maddock (1974) developed operating procedure and rules for conjunctive use when both demand and supply of water are stochastic. Jonch-Clausen (1979) used iterative quadratic programming to optimise the allocation of water resources considering economic and hydrologic characteristics of a river basin. The basic element in the planning model was a single period, single allocation objective model. Other works of significance are Haimes (1973), Moody (1976) and Boster and Martin (1977).

Development of the mathematical models to generate irrigation management programme has received the attention of many researchers. Flinn and Musgrave (1967) presented a dynamic programming model having one state variable, namely, the quantity of irrigation water available for application over the remainder of the season. Hall and Butcher (1968) proposed a dynamic programming model with two state variables, the quantity of water available for application over the remainder of the season and the soil moisture condition at the beginning of the season. In this approach, the growing season of a crop was divided into a number of stages determined by its physiology. The information on the response of the crop to different deficits at each stage, in terms of the final yield recorded, was based on field experiments. The optimal schedule was then determined as that which specified the amount of irrigation water to be applied at each stage, when a given total quantity of water is available at the beginning of the season. Dudley et al (1971) considered the problem from a stochastic point of view but made many unrealistic assumptions or simplifying the structure (e.g., crop growth at any stage is independent of the previous growth pattern). All these procedure suffer from the dimensionality problem of the dynamic programming approach.

In that, they become unmanageable when a large number of state variables are involved.

The USDA-ARS model developed by Jensen et al (1970) describes a computer program for scheduling irrigation by estimating soil moisture depletion based on climate, crop and soil data. Stewart and Hagan (1975) and Stewart et al (1974) developed an optimal irrigation program based on evapotranspiration and a linear water production function. The model generates irrigation management programmes that take into account evapotranspirational deficits at critical stages of crop growth. Some studies describe the computation of evapotranspiration and soil water depletion (e.g.Wright and Jensen, 1978) while others deal with simulation of crop growth under moisture stress (e.g. Childs et al 1977) which may be incorporated in the irrigation scheduling programmes (Jensen and Wright, 1976).

A comparatively novel approach is that of Fogel et al (1974, 1976) they drew an analogy between the farmer's problem of determining an optimal irrigation policy and the businessman's problem of determining an optimal ordering policy. In both cases, the state of the system is examined periodically to determine the optimal quantity and frequency of replenishment in relation to demand. The procedure employs the use of existing solutions of inventory control problems as found in operational research literature. Both deterministic and stochastic approaches were considered.

Development of Cropping Pattern: Models described above generate irrigation management programmes for each crop. Information from these can be used to determine cropping patterns which will maximize economic returns for a given water supply and land
area.

The Ralph M Parson's Co (1970) report on efficient water use and farm management in India uses the Hall and Butcher (1968) model for irrigation programming and suggests a linear programming model to be used for selecting optimum crop patterns at the district planning level. The cropping pattern is generally decided on the basis of available water, other inputs and some basic data on climate, soil etc. Anderson and Mass (1971) developed a digital computer simulation model which can be used in determining how best to allocate irrigation water among crops and among farms when supply is limited. The effects of various water supply restrictions and rules for water delivery on cropping patterns, crop productions and farm incomes could be examined with the use of this model.

3.0 DESCRIPTION OF THE STUDY AREA

3.1 Location

The Thungabhadra Project is one of the important major irrigation projects in Karnataka is formed across River Thungabhadra at old Mallapur village about 5 km from Hospet of Bellary district. The project has an extent of 3,49184ha cultivable command area covering the districts of Bellary and Raichur.

The length of left bank main canal is 226km, in Raichur district. The canal passes through two subsidiary reservoirs, sanapur and Shivapur, before it enters the open country through a tunnel.

The left bank canal command area in Gangavathi taluk covers 703 km^2. The main left bank canal runs about 42km in Gangavathi taluk with net work of 34 distributaries. The geographical area of the study and is confined by global co-ordinates 15° 15’ 00" and 15° 40’ 56" North latitudes and 76° 18’ 36" and 76° 48’ 30" east longitude. It is bounded by river Thungabhadra on South-eastern side as shown in the figure 3.1.1.

3.2 Physiography and Drainage

The study area forms a part of Raichur doab region of the northern maidan country in Karnataka exhibiting a smooth rolling topography, gently sloping from NW and SE from an elevation of 440m to about 369m. The southern and western part of the area exhibit a pronounced rolling topography. Geomorphologically, the area represents terrain which has reached the base level of erosion, hence the thickness of soil is very thin and rocks are exposed prominently in the elevated regions thereby limiting the scope of groundwater recharge and storage. The highest elevation is 604m above mean sea level, the other prominent ridges have an elevation of 594m and 586m above MSL. As a part of semi-arid region, the natural vegetation is very sparse except for a few species of acacia, prospissicigera(shemi) and neem trees. The rocky hills are mostly bare.

The Thungabhadra river flows a length of 54km in the NE direction, forming the southern and eastern boundary of Gangavathi taluk. The river has number of rivulets and streams serving as tributaries, the more important among them being them are Marali stream(17km) and Hirehalla(23Km)as presented in the figure 3.2.1. There are few isolated patches of low lying areas which

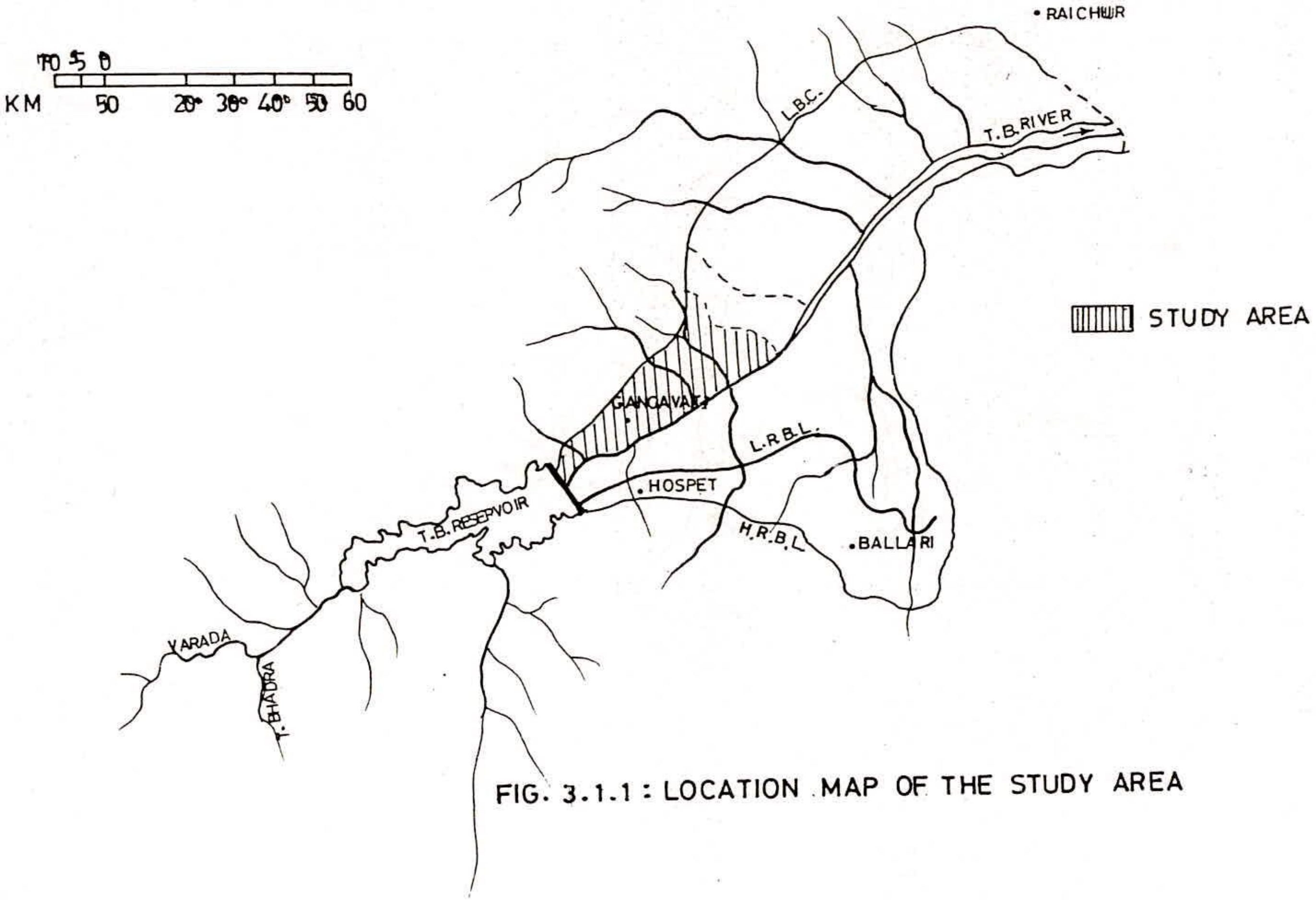

FIG. 3.1.1 : LOCATION MAP OF THE STUDY AREA

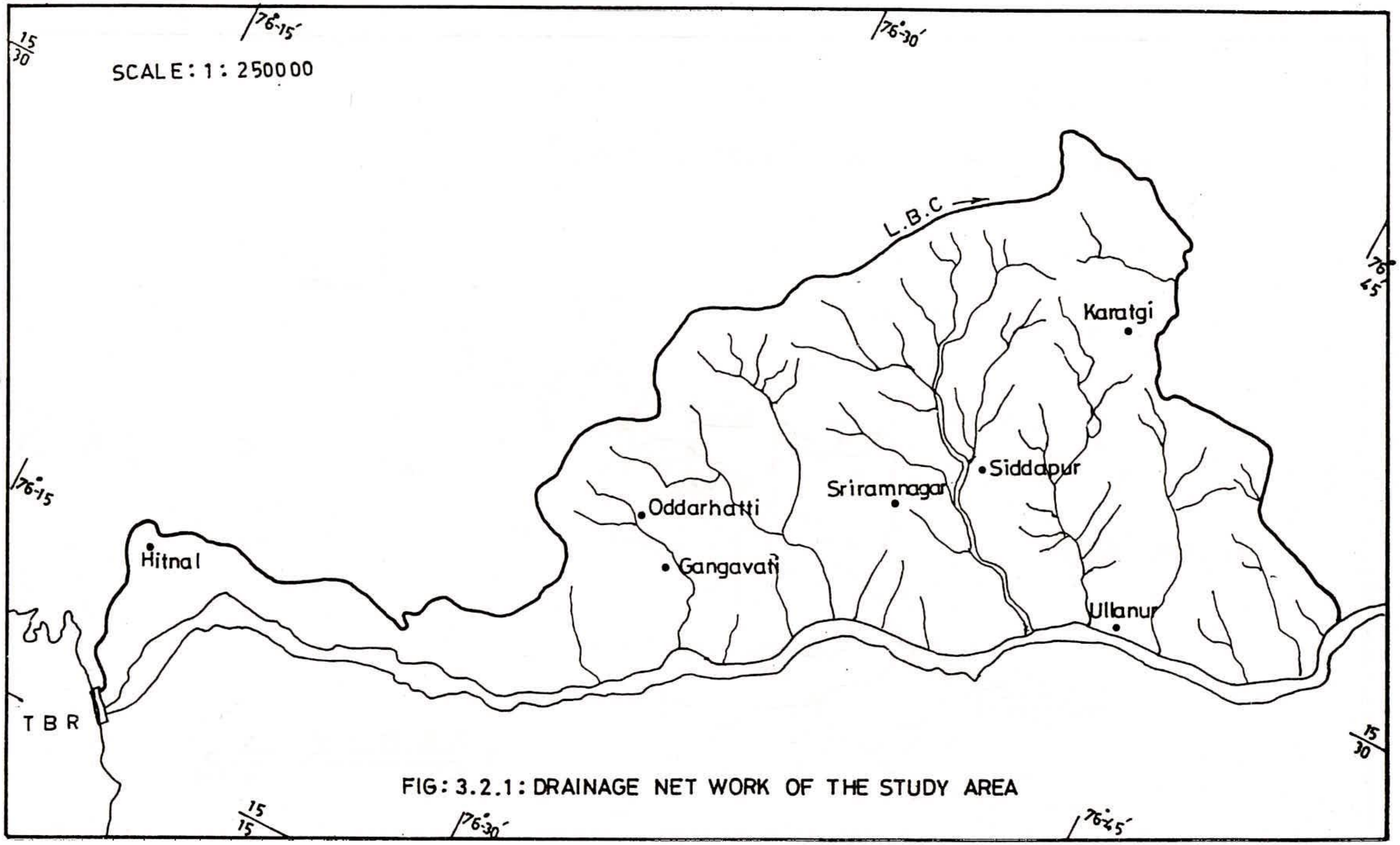

FIG: 3.2.1: DRAINAGE NET WORK OF THE STUDY AREA get water logged due to poor drainage conditions and intensive canal irrigation.

3.3 Soils and cropping pattern

The predominant soil type of the area is red to mixed and black soil almost evenly distributed in extent. The occurrence of vast stretches of red soil in the region is an exception in the Thungabhadra command area. The red soil generally occur at higher elevations and around hill slopes as shown in the figure 3.3.1. The red loamy sand soils are usually well drained, containing very small amount of water soluble salts. The black soil are deep dark grey to black in colour and are composed of silty clay to clay which becomes sticky when wet. Black soil are thin in the uplands and are moderately deep in valleys. They contain fair amount of soluble salts. The deep black soil is generally underlined by a yellowish clayey material mixed with lime kanker at a depth of about one metre.

Out of 703.0 km^2 of geographical extent of the Gangavathi taluk in the Thungabhadra command area, at present, about 49 per cent of the area has been brought under canal irrigation covering 69 villages. Localisation envisages the ear marking of lands seasonwise, for growing different kinds of irrigation crops depending upon the availability of irrigation water, topographic situation, drainage condition and inherent properties of soil. The land has been localised for wet crops(Paddy, sugercane) and dry-cum-wet crops like sunflower, jawar, cotton and groundnut sugercane or two crops of paddy are earmarked for areas of perennial irrigation. Paddy blocks are generally localised in reddish soil in plain and valley reaches. Sugercane blocks are localised mostly medium black soil.Garden blocks are confined to areas having deep loamy soils. The progress of irrigation under light irrigated crops are comparatively fast in red soils when compared with the black soil of the area.

3.4 Distributary Network

Out of 703.0 km^2 of geographical extent of the Gangavathi taluk in the Thungabhadra command area, at present, about 49 per cent of the area has been brought under canal irrigation covering 69 villages. The length of left main canal is 226km, in Raichur district as shown in the figure 3.4.1. The canal passes through two subsidiary reservoirs, Sanapur and Shivapur, before it enters the open country through a tunnel. In the reach upto 24km, the canal has been designed to carry discharge of $190m^3$/sec for generation of power.

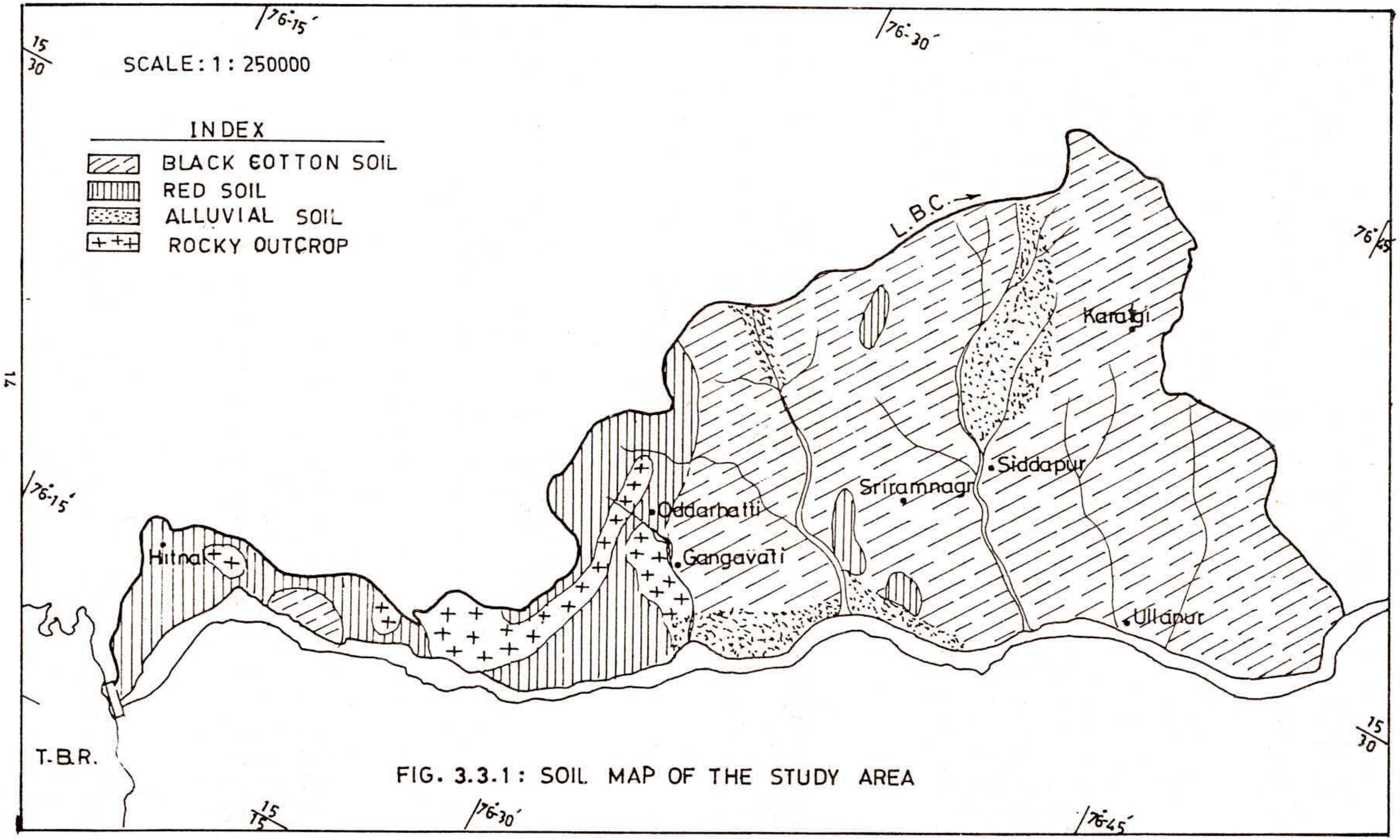

FIG. 3.3.1 : SOIL MAP OF THE STUDY AREA

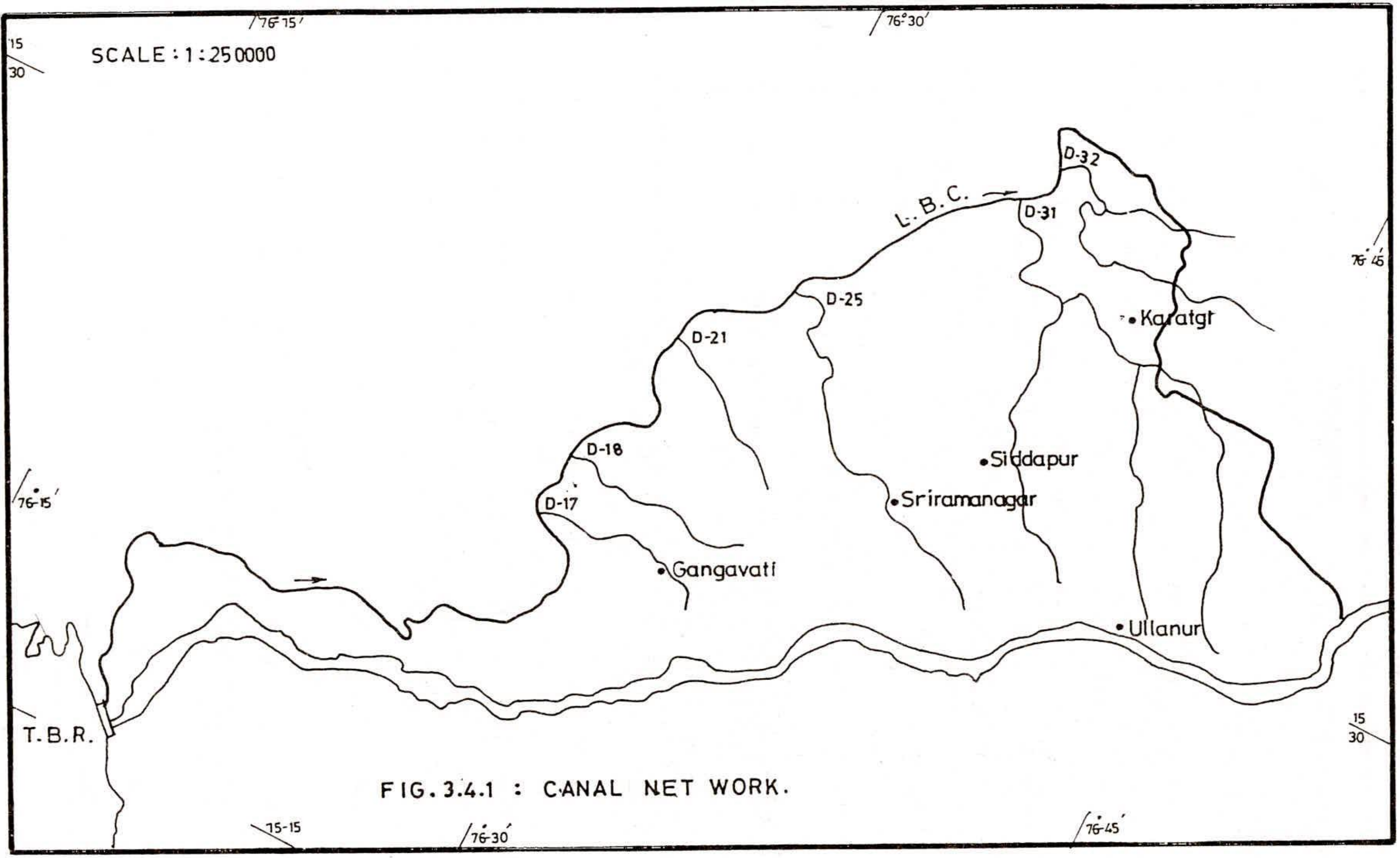

FIG. 3.4.1 : CANAL NET WORK.

Thereafter it carries $88m^3$/sec for irrigation. The complete length of the canal is lined by RCC slabs. Water was let in to the canal during 1953 upto 24km. The canal upto 226km were completed in the year 1968. The present study area covers upto 42nd km with 34 distributaries.

3.5 Hydrogeology

The study area forms a part of the early precambian terrain of peninsular shield. The area is composed of schistose formations of Dharwar supergroup, occurring amidst peninsular gneisses as shown in the figure 3.5.1. The grey peninsulargnesses range in composition from tonoliteto tronndhjemite. The schistose formations include amphibolites, hornblends schists and quartzite. These formations are intruded by pink and grey porphrites granites. The granite form conspicuous hill ranges covering a major part of the area under the study.

The weathered portion of the granitic and gneissic rocks, upto a depth of 20 to 25 metre, and jointed and fractured levels. The average yield of water in the dug wells range from 10,000 to 20,000 gallons per day. Yield ranging from 500 t 1000 gph are encountered in many of the bore wells drilled in the granitic terrain. Better yields are obtained from dug-cum-bore wells in these regions. Normally after 50m depth, the fissures and fractures encountered. These rock types rendering the bed rock unfavourable for any groundwater movement and storage.

In the study area, groundwater occurs under unconfined condition in the weathered sections of the rocks at shallow depth and in semi confined condition along the joints and fractures at deeper levels. The depth of dug well in the area ranges from 3m to 15m below ground level and depth to water table ranges from 0.1m to 8m below ground surface in different areas.

3.5.1 Well yields

The wells of different sizes and depths are constructed to suit the land holdings and cropping pattern. The well yield ranges from $120m^3$ /day to $30m^3$/day as shown in the table below.

Yield and depth range statistics of PHE bore wells

Yield range (in LPH)	Number of Bore Wells and Range of depth (in metres)				Total No. Bore Wells
	Below 20m	20 to 40	40 to 60	60 to 80	
0 - 200	1	9	1	-	11
200- 500	2	11	6	2	21
500-1000	-	11	3	-	14
1000-2000	-	15	4	5	24
2000-5000	1	13	3	2	19
5000-8000	3	5	4	1	13
8000-12000	1	4	5	1	11
12000-24000	-	1	1	-	2
Total	8	69	27	11	115

(Source: Department of Mines and Geology)

3.5.2 Well density and draft

There are 107 irrigation open wells and 33 irrigation bore wells in the study area. It is worked out to be 0.20 per km2. Assuming that these wells were pumped for eight hours a day for 150 days in a year. The annual draft per well is about 8208.3 M^3.

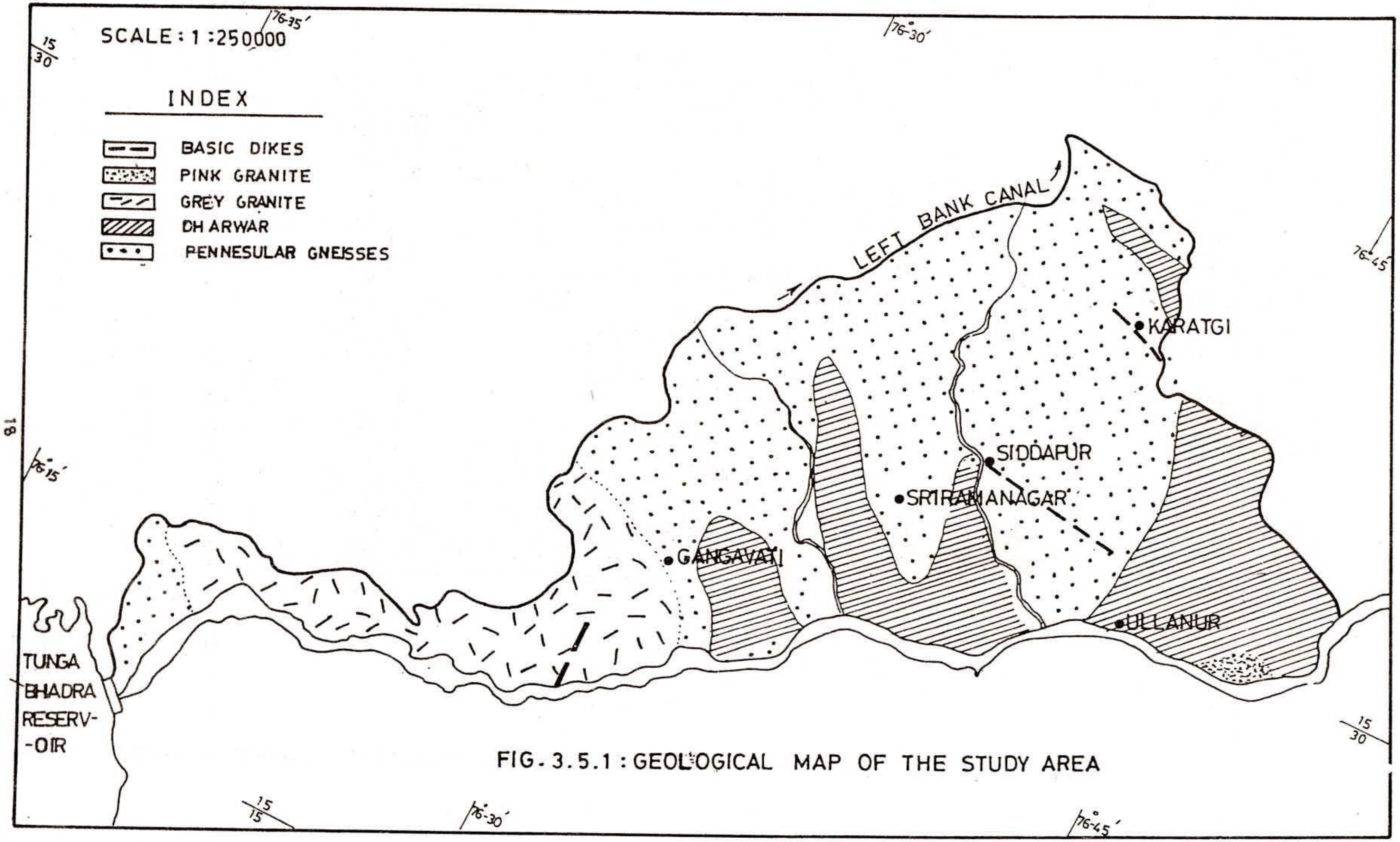

FIG. 3.5.1 : GEOLOGICAL MAP OF THE STUDY AREA

4.0 METHODOLOGY

4.1.0 RAINFALL ANALYSIS

The raingauge station selected for the rainfall analyses is Oddarahatti which falls under the study area. The rainfall analysis has been carried out with the data of Oddarahatti rain gauge from 1955 to 1990.

The analysis of rainfall trend over the study area is carried out by annual rainfall departure analysis and probability analysis of annual rainfall. The annual rainfall departure analysis is a good indicator of the deviation of the rainfall from the normal rainfall over a period of time. The probability analysis of annual rainfall is useful to predict the relative frequency of occurrence in different group of intervals of annual rainfall.

4.1.1 Distribution of rainfall

Rainfall over the years ranges from 1075mm to 288mm with standard deviation 166.86. The symmetry of the rainfall pattern is +0.573 with variability +0.287. The normal annual rainfall is estimated to be 582.0mm. However the study area receives 12 per cent of rainfall from January to May, 83 per cent from June to October and 5 per cent from November to December.

4.1.2 Annual rainfall departure analysis

For analysis purpose the yearly rainfall data of every year has been used. In order to work out the normal rainfall for a study area, the rainfall values of the raingauge station are taken without giving any weightage as only one station is considered. Percentage departures on annual basis are worked out based on rainfall and normal annual values. The difference of annual rainfall and annual normal gives the departure which is converted into percentage as has been presented in the table 4.1.2.1. The departure from the normal expressed in percentage from 1955 to 1990 have been plotted and shown in the figure 4.1.2.1. The study area recorded annual rainfall deficit of the order of 50 % in the years 1985 and 1989.

4.1.3 Probability analysis of annual rainfall

Probability is a constant characterising a given set of objects or incidents in a particular period. The probability analysis of annual rainfall is useful to predict with reasonable accuracy the relative frequency of occurrence in different group intervals of annual rainfall. It is also possible to work out the percentage probability of occurrence of 75% of annual rainfall or more for identification of drought proneness of the study area.

Table No.4.1.2.1 Annual Rainfall Departure

sl.No	Year	Annual rainfall	Annual normal Rainfall	Percentage of departure
1.	1955	1010.61	582.00	+73.65
2.	1956	728.99		+25.25
3.	1957	713.21		+22.55
4.	1958	642.15		+10.30
5.	1959	418.55		-28.10
6.	1960	518.32		-10.95
7.	1961	468.77		-19.50
8.	1962	845.60		+45.30
9.	1963	460.97		-20.80
10.	1964	677.11		+16.35
11.	1965	599.21		+2.95
12.	1966	492.10		-15.45
13.	1967	485.20		-16.60
14.	1968	714.90		+22.80
15.	1969	625.80		+7.50
16.	1970	641.50		+10.20
17.	1971	533.60		-8.30
18.	1972	377.30		-35.20
19.	1973	568.00		-2.40
20.	1974	621.70		+6.80
21.	1975	1072.40		+84.25
22.	1976	370.20		-36.40
23.	1977	604.1		+3.80
24.	1978	758.20		+30.30
25.	1979	438.50		-24.65
26.	1980	442.50		-24.00
27.	1981	693.00		+19.10
28.	1982	517.80		-11.00
29.	1983	576.90		-0.90
30.	1984	548.06		-5.80
31.	1985	299.93		-48.45
32.	1986	527.56		-9.35
33.	1987	585.40		+0.60
34.	1988	487.30		-16.30
35.	1989	288.50		-50.40
36.	1990	593.90		+2.00

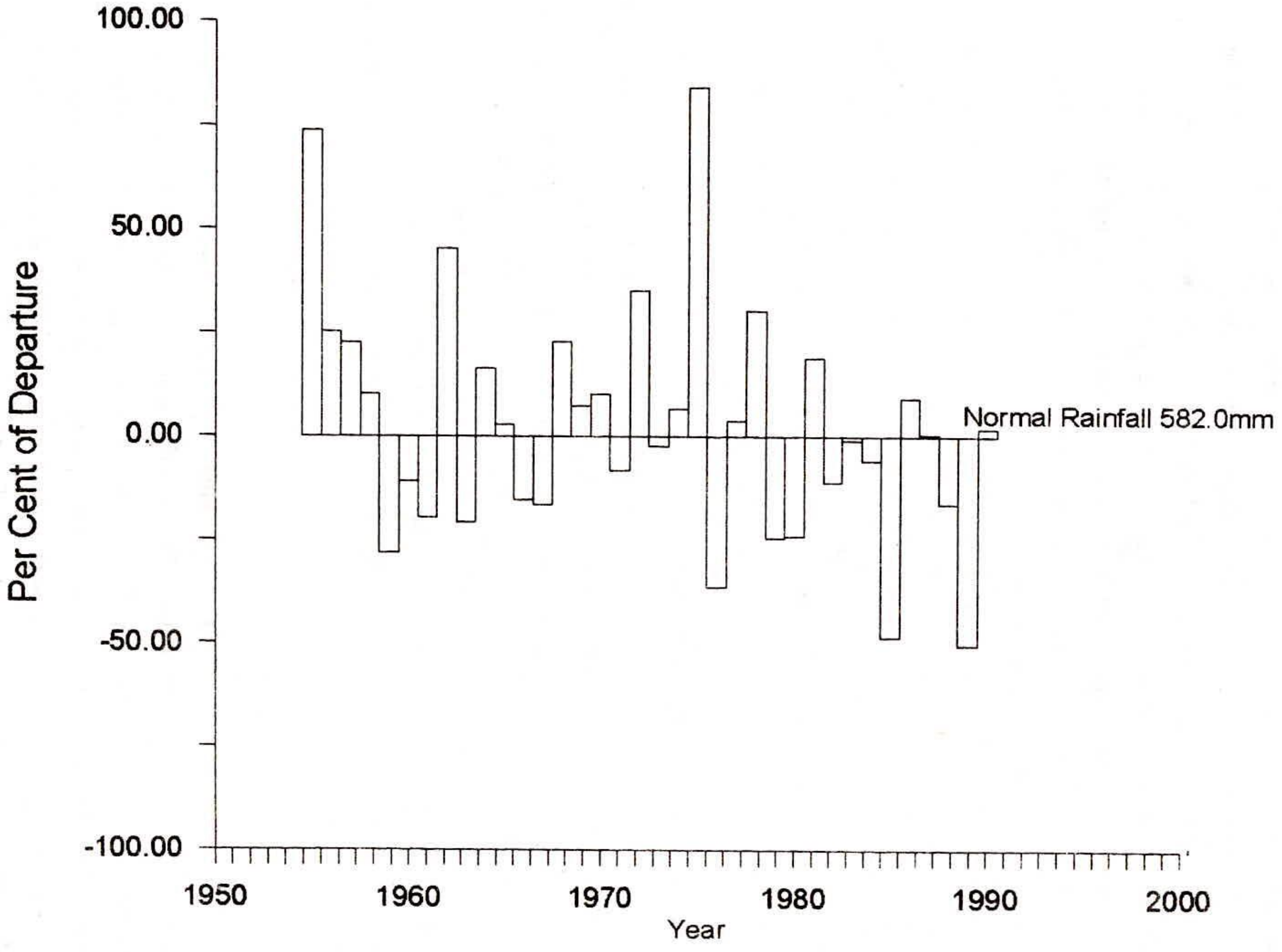

Figure 4.1.3.1 Normal Departure of Rainfall

Rainfall events in the study area have been selected for probability analysis of annual rainfall. The analysis has been carried out based on the data availability and probability expressed both in number of years of occurrence and the percentage of years for each group interval. Group interval of 50mm has been considered for the analysis.

The probability distribution curves have been drawn by plotting the values of percentage of cumulative probability in respect of various groups at their corresponding midpoint. The cumulative percentages are worked out starting from the maximum rainfall group downwards adding the successive percentage(table 4.1.3.1). Probability graph for the study area have been shown in the figure 4.1.3.1.

The range of rainfall group for the study area which has a probability occurrence of 75% or more has been read from probability distribution graph and tabulated in the table 4.1.3.1 As can be seen from the above table, the study area has a 75% or more probability of getting rainfall in the group range of 450-500mm. Probability of occurrence of rainfall equivalent to 75% of normal rainfall in the study area is only 89 per cent.

4.2.0 GROUND WATER LEVEL ANALYSIS

The change in storage of groundwater in an aquifer is reflected by change in groundwater level. Usually change in groundwater storage is a seasonal phenomenon. Representative wells uniformly distributed over the study area as shown in the figure 4.2.1 has been chosen for the analysis based on the availability of data. The analysis is carried out using quarterly data for the desired period depending on the data availability from 1985-1994. The representative groundwater level reduced to mean sea level has been shown in the figures 4.2.2 to 4.2.5

4.2.1 Average ground water level

The water levels in the wells have been reduced with respect to mean sea level. Average groundwater level has been calculated using Thiessen Polygon Method. For this purpose Theissen weights for all wells being considered for analysis were established and groundwater levels calculated with respect to mean sea level multiplied by respective Thiessen weight has been taken as average groundwater level for the study area. The average values (pre-monsoon and post-monsoon) of groundwater level computed for the study has been plotted against time unit(figure 4.2.1.1). The average fluctuations of the water levels between pre-monsoon and post-monsoon varied from 2m to 3m over a study period.

Table No. 4.1.3.1 Probability Analysis of Annual Rainfall

Sl No.	Class Interval	No. of Years	Perce-ntage	Cumulative Probability
1	250 - 300	2	5.55	100.00
2	300 - 350	-	0.00	94.45
3	350 - 400	2	5.55	94.45
4	400 - 450	3	8.33	88.90
5	450 - 500	5	13.89	80.57
6	500 - 550	5	13.89	66.68
7	550 - 600	5	13.89	52.79
8	600 - 650	5	13.89	38.90
9	650 - 700	2	5.55	25.01
10	700 - 750	3	8.33	19.46
11	750 - 800	1	2.78	11.13
12	800 - 850	1	2.78	8.35
13	850 - 900	-	0.00	5.57
14	900 - 950	-	0.00	5.57
15	950 - 1000	-	0.00	5.57
16	1000 - 1050	1	2.78	5.57
17	1050 - 1100	1	2.78	2.79

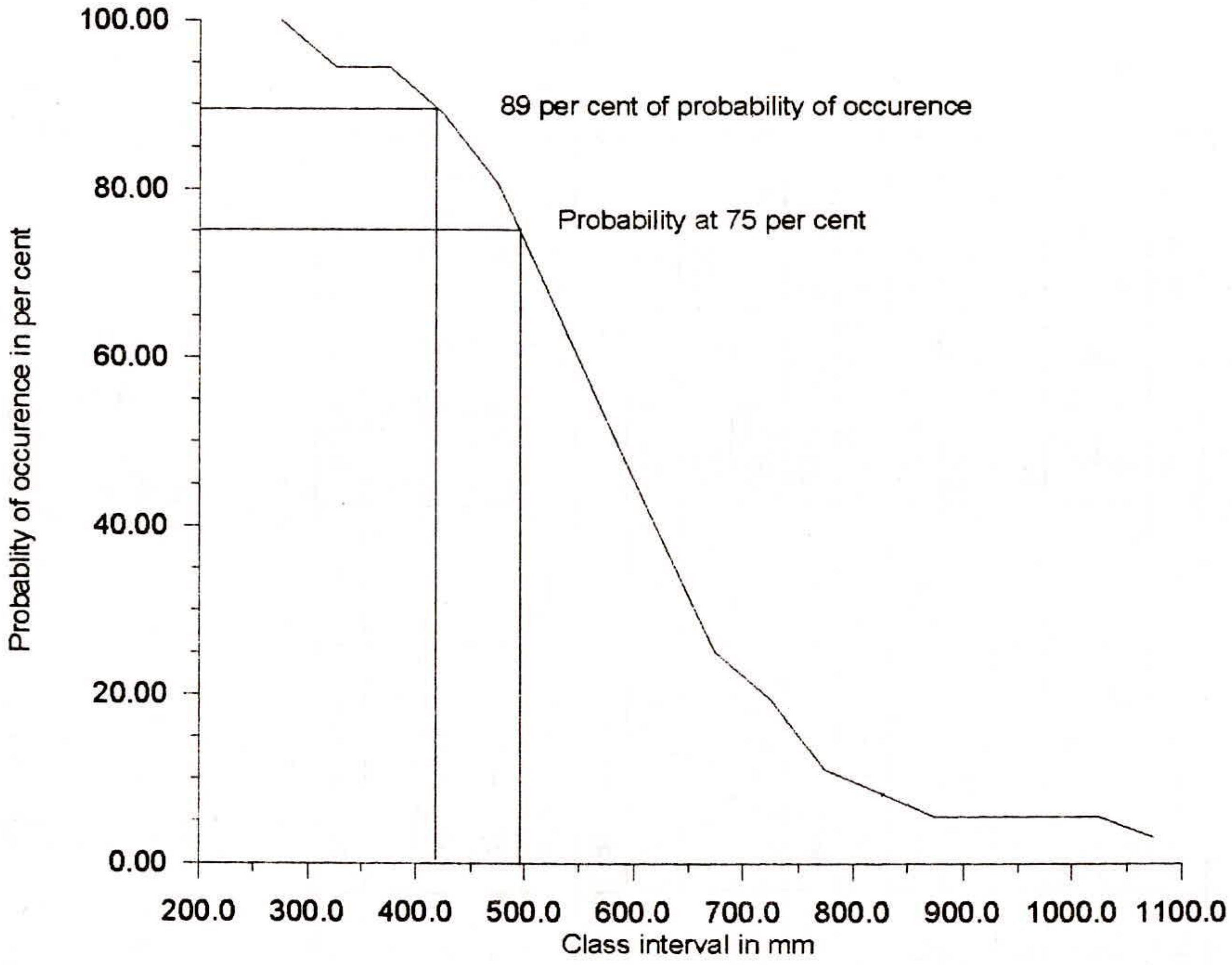

Figure 4.1.3.1 Probability Distribution Curve

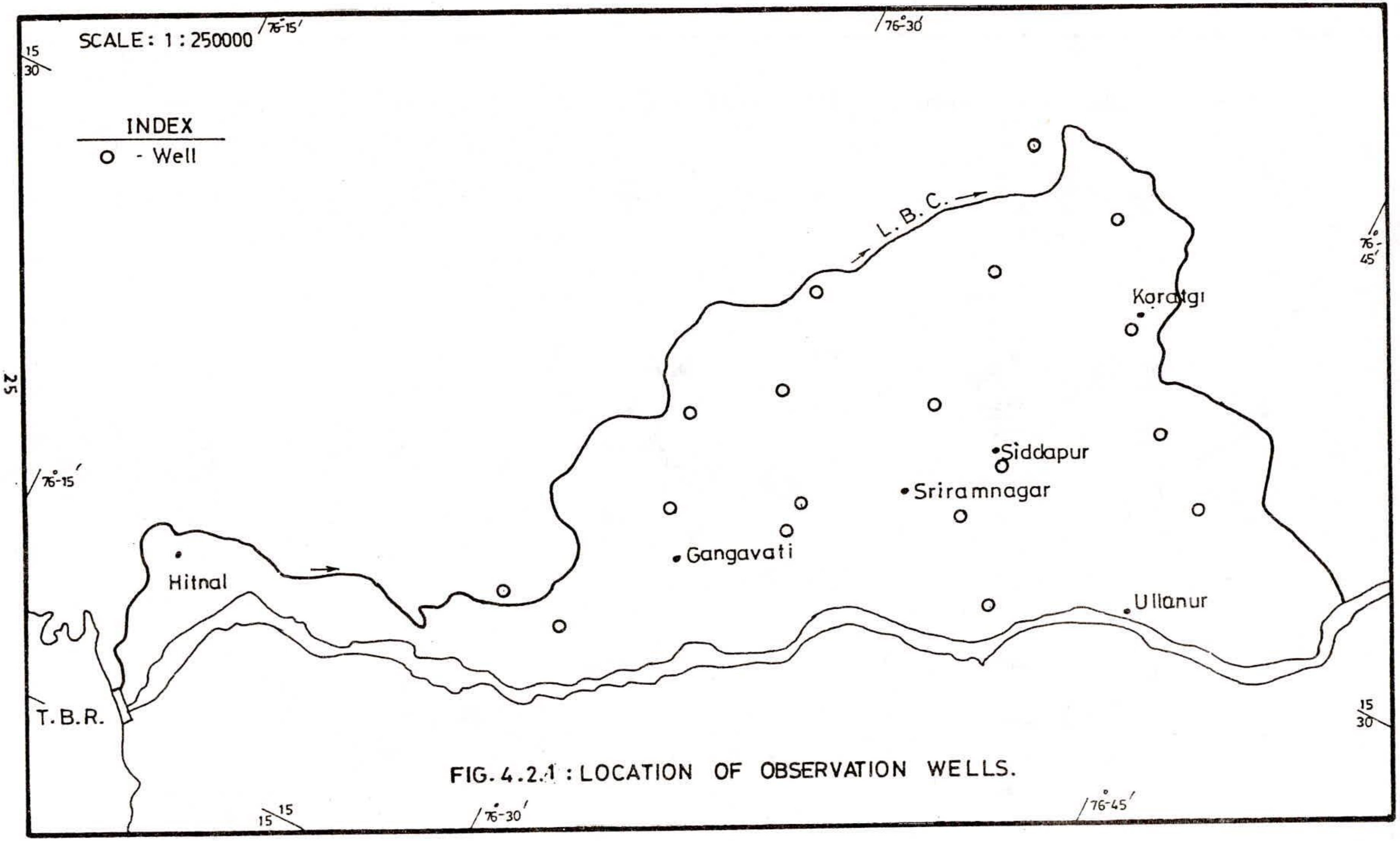

FIG. 4.2.1 : LOCATION OF OBSERVATION WELLS.

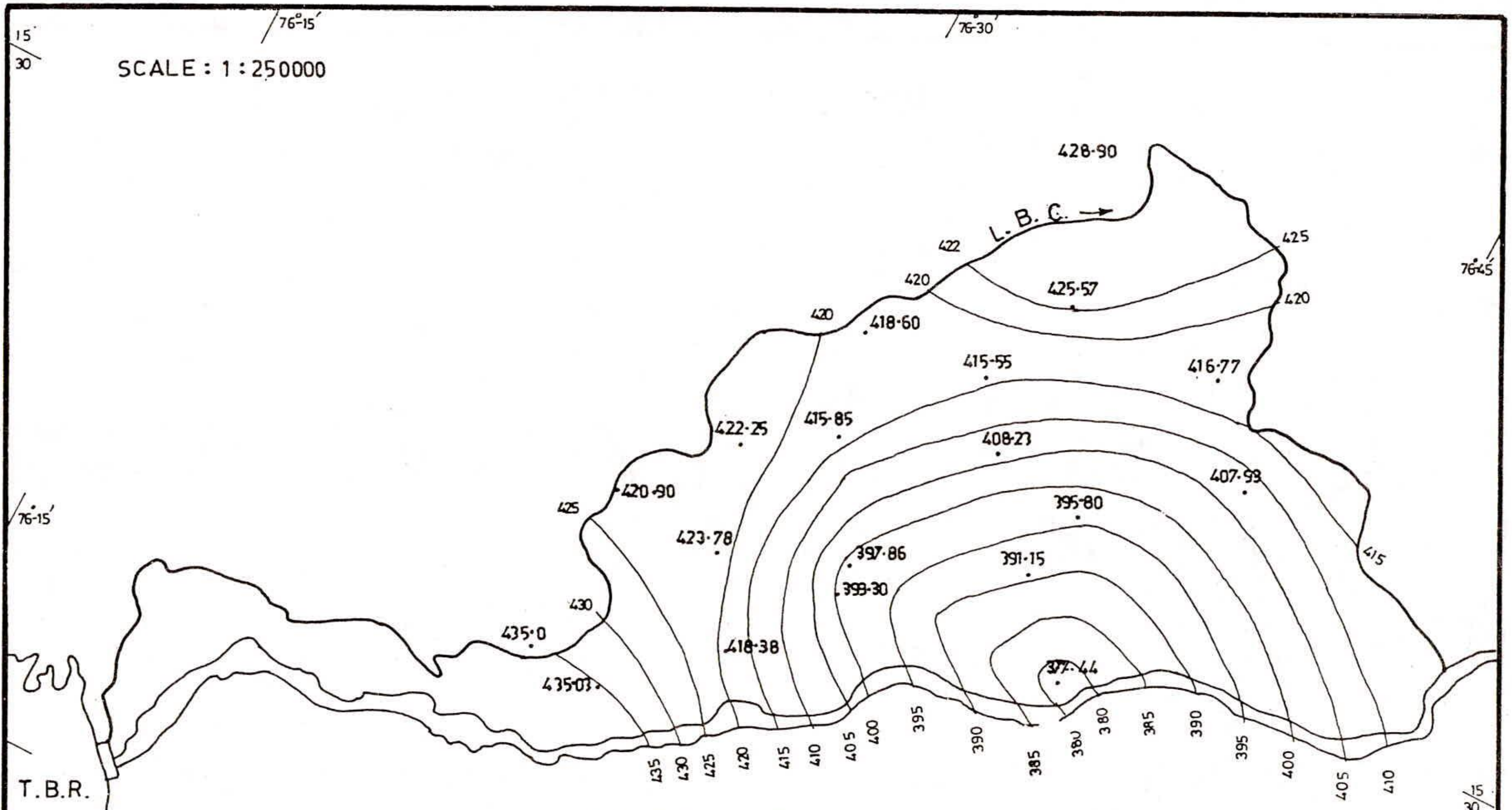

FIG. 4.2.2 : GROUND WATER LEVEL CONTOUR (MAY-1990)

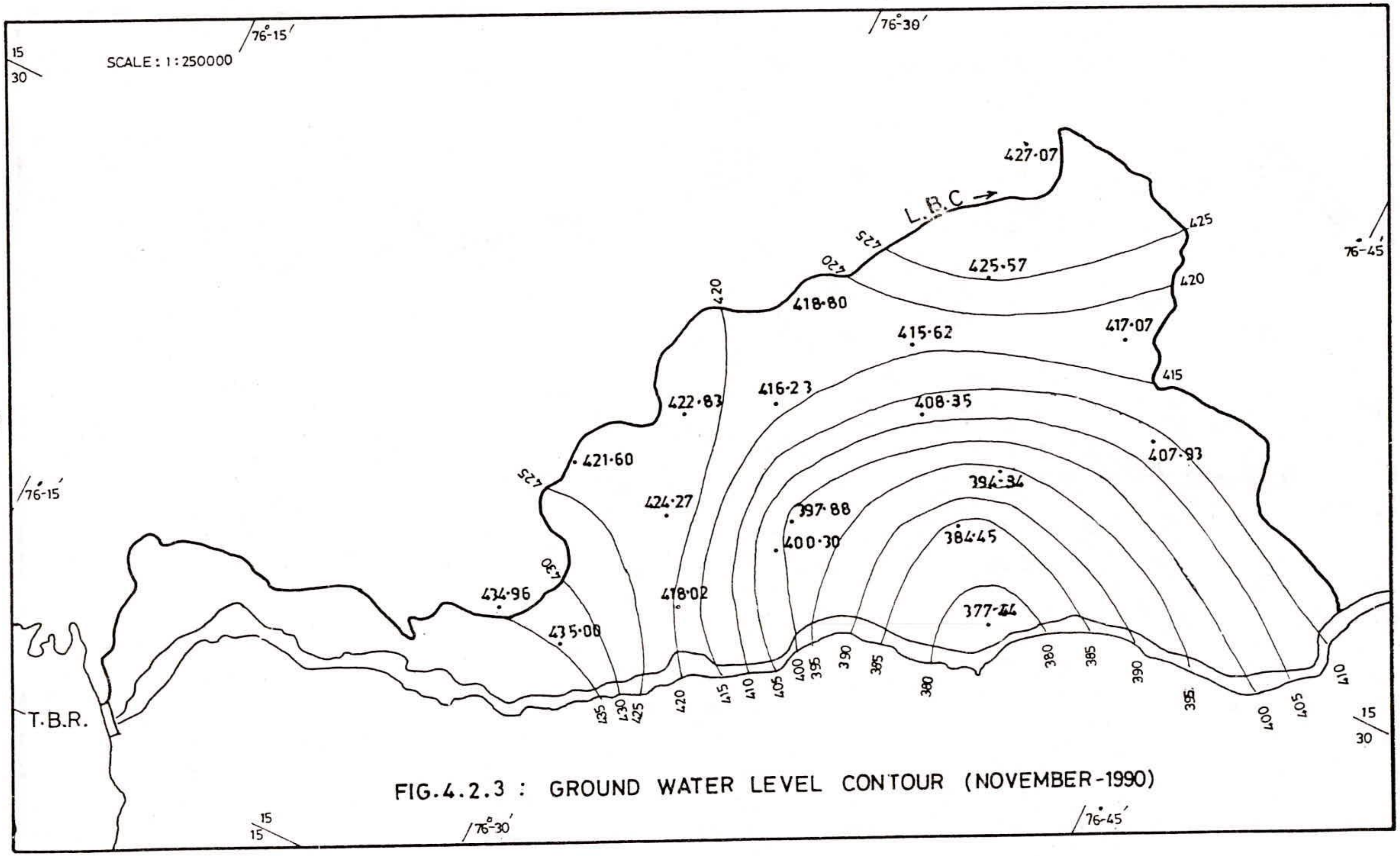

FIG.4.2.3 : GROUND WATER LEVEL CONTOUR (NOVEMBER-1990)

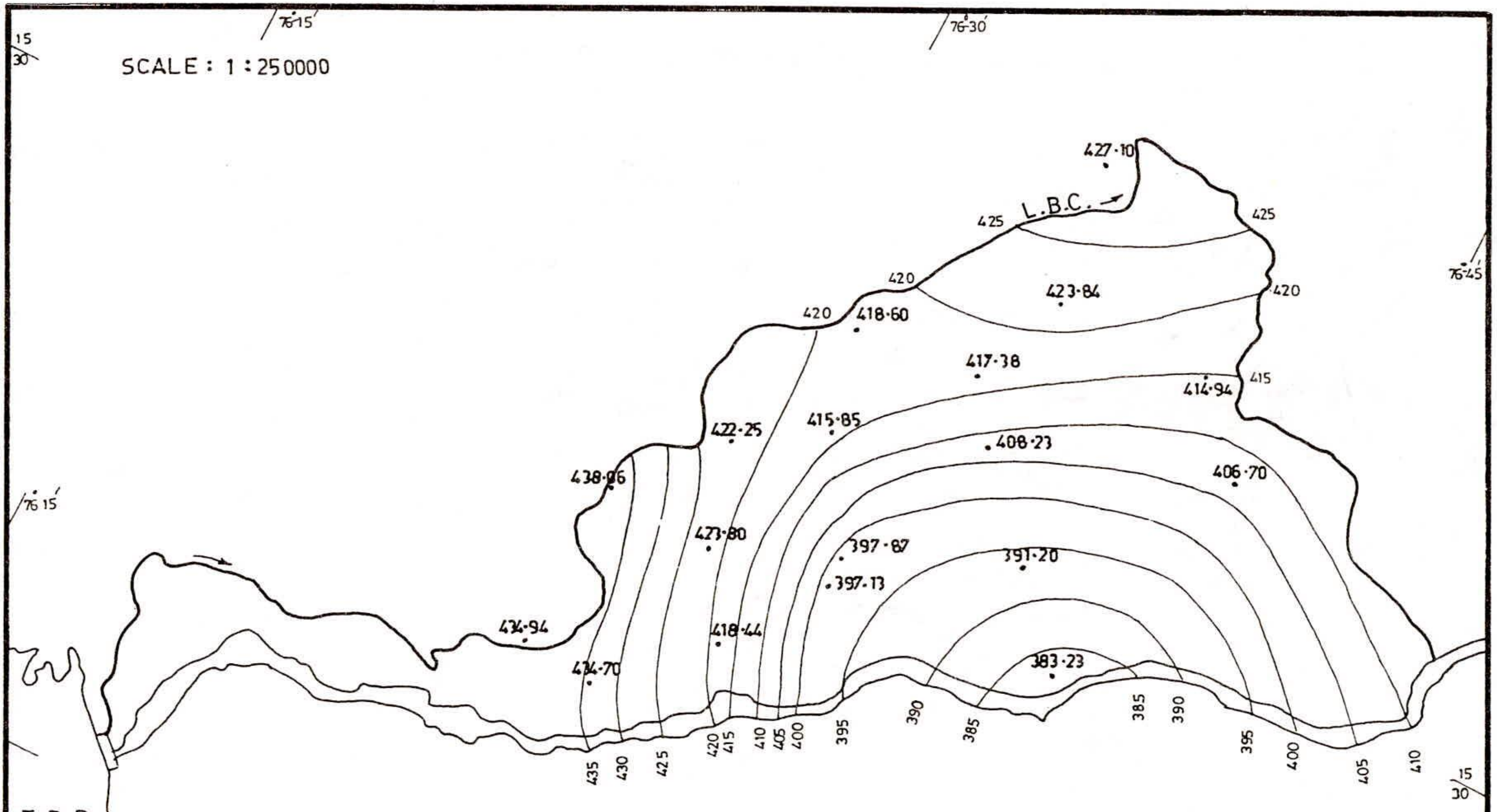

FIG. 4.2.4 : GROUND WATER LEVEL CONTOUR (MAY- 1994)

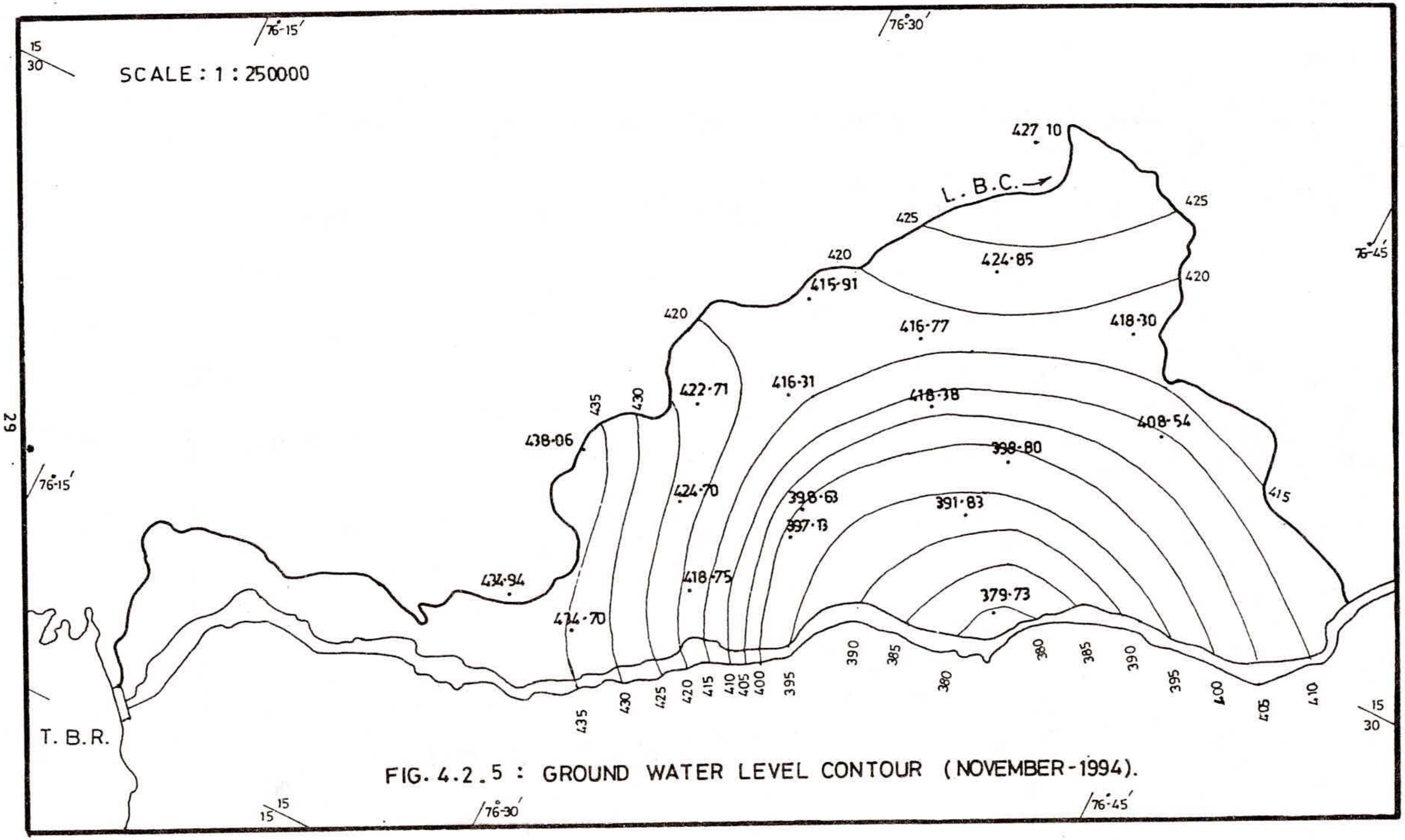

FIG. 4.2.5 : GROUND WATER LEVEL CONTOUR (NOVEMBER-1994).

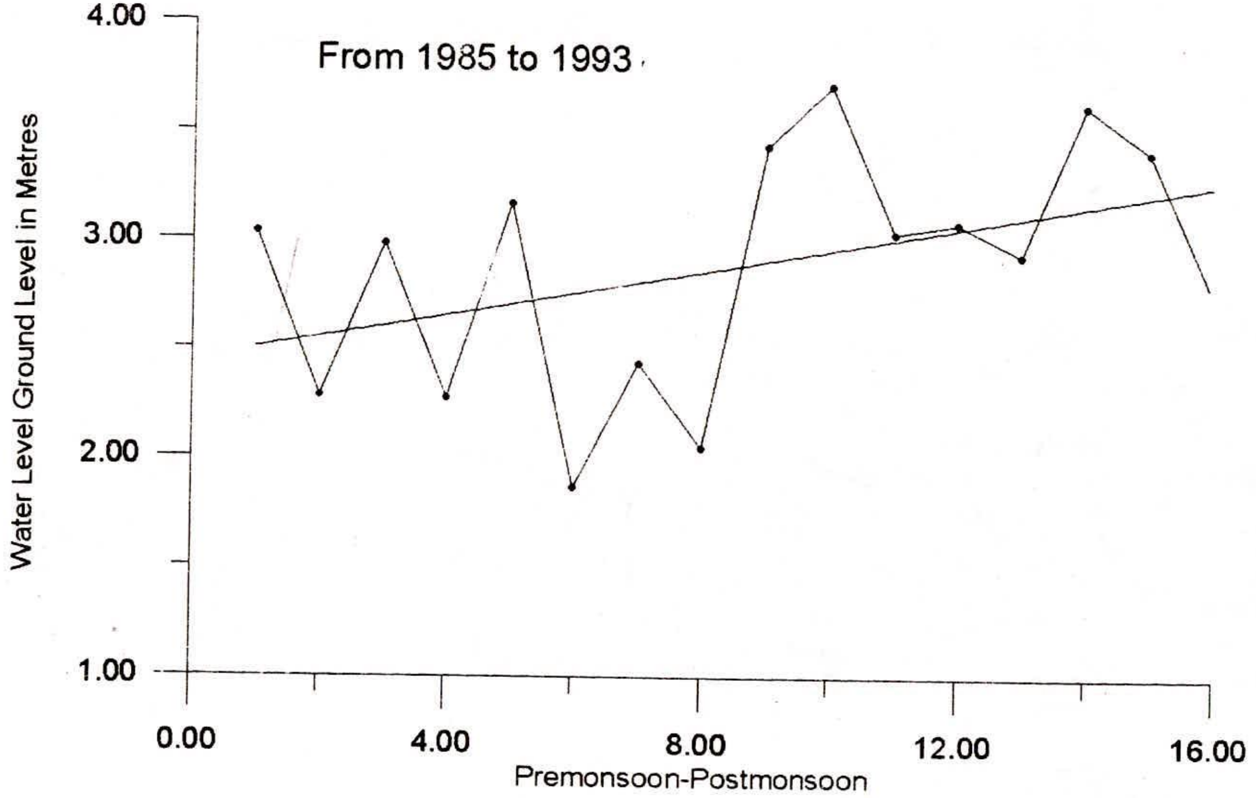

Figure 4.2.1.1 Average Groundwater Fluctuation in the Study Area

4.2.2 Trend analysis of groundwater level

The trend in groundwater level fluctuations was worked out by carrying out simple regression analysis. In order to work out the trend of groundwater level, the seasonal values (monsoon season) of groundwater level were plotted for each year of available data. A simple regression line was fitted to show the trend of groundwater level over the period. These graphs showing trends seasonal rainfall and groundwater levels over the periods of analysis. The graphs showing trends of groundwater levels over the period of analyses are shown in figures 4.2.2.1 to 4.2.11.

Wells have been selected such a way that, they are representative of head reach, middle reach, and tail end to find out the trend of groundwater regime. Groundwater levels have been plotted against time for the study area, which show rising of trend in groundwater level over the years especially in the head reaches, middle reaches, close to the canal and natural streams. The rate of increase of groundwater level in post-monsoon in the study area is noticeable and higher as compared with the pre-monsoon groundwater level. Since the groundwater is recharged mainly through precipitation and surface irrigation, the over-irrigation year after year has led to increase in the groundwater level. Apart from these indications, over the study period, the groundwater level has reached a saturation level as it can be seen from the figure 4.2.2.1 to 4.2.2.11. It is also noticed that irrespective of recharge and exploitation situation, groundwater regime attains the same level after the monsoon. This is due to the limited storage capacity of the granite aquifer compared to the recharge potential of the command area. The local topographic situation and the aquifer characteristics govern the groundwater levels during post-monsoon period in such situations. This kind of trend is seen especially in the head reaches and middle reaches.

4.2.3 Water logging Identification

Groundwater build up in the soil zone affects the air water ratio and has a adverse ill effect on the yield of the crops and other vegetation. The changes in ground water levels of the study area are to be monitored to find whether the area is affected by water logging or not. To identify the area subject to water logging, the ranges of the depth to groundwater level (below ground level) were drawn over the study area, for the year 1988,1990, 1992, and 1994 for pre-monsoon(June) and post-monsoon(November). The area were groundwater level is shallower than 2m below ground surface during pre-monsoon and post-monsoon season has been marked and is considered as water logged area.(fig 4.2.3.1 to 4.2.3.10).

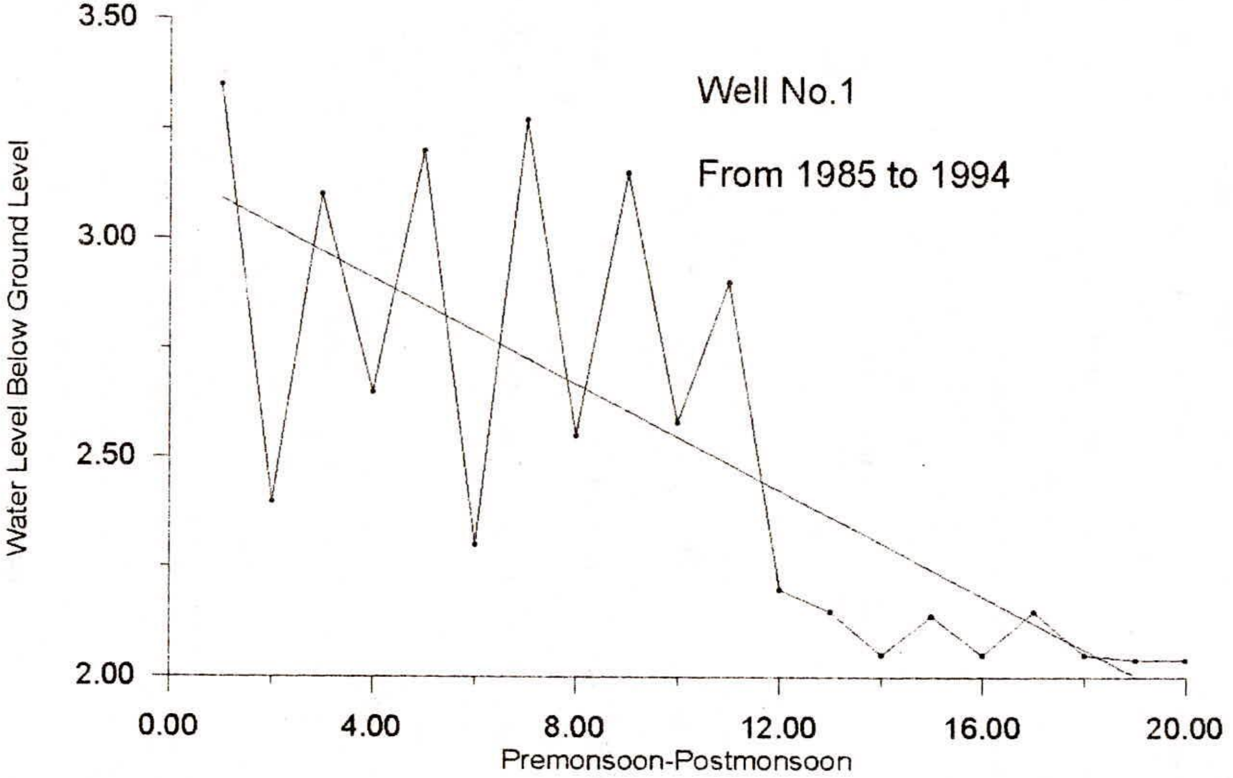

Figure 4.2.2.1 Variation of groundwater level of the study area

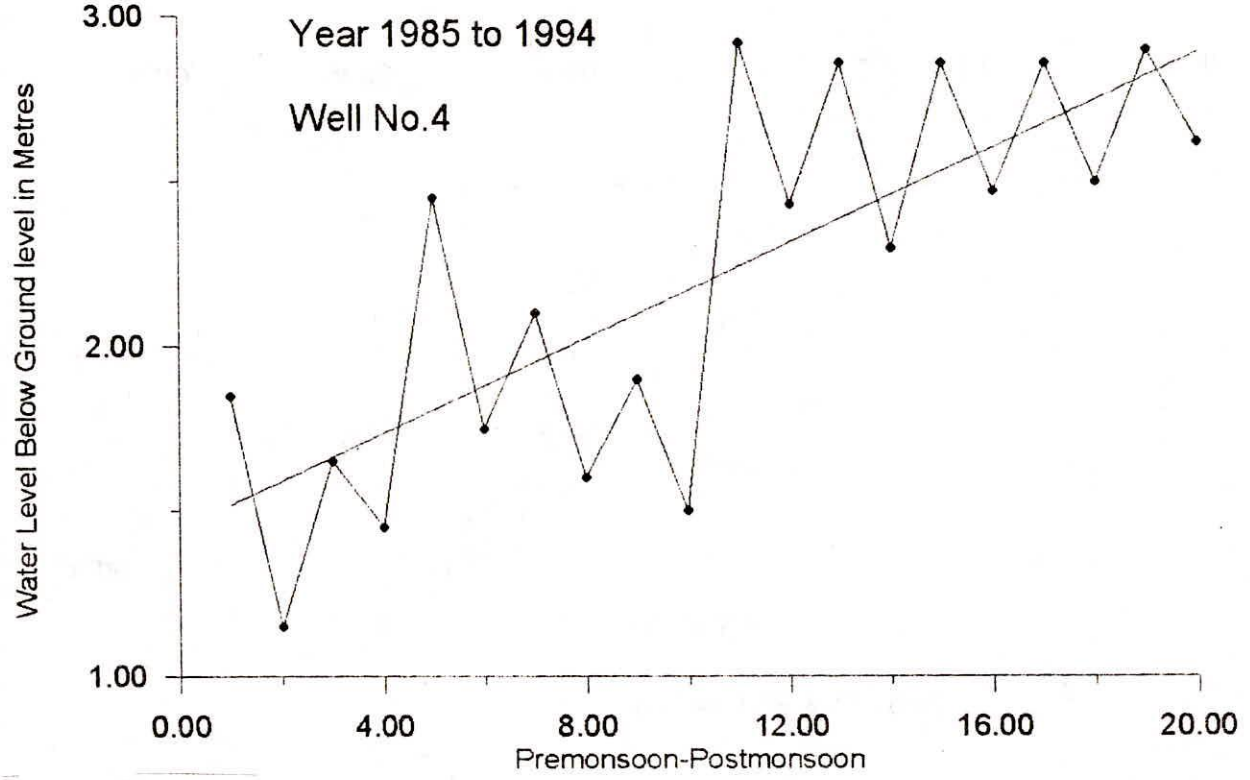

Figure 4.2.2.2 Variation of groundwater level of the study area

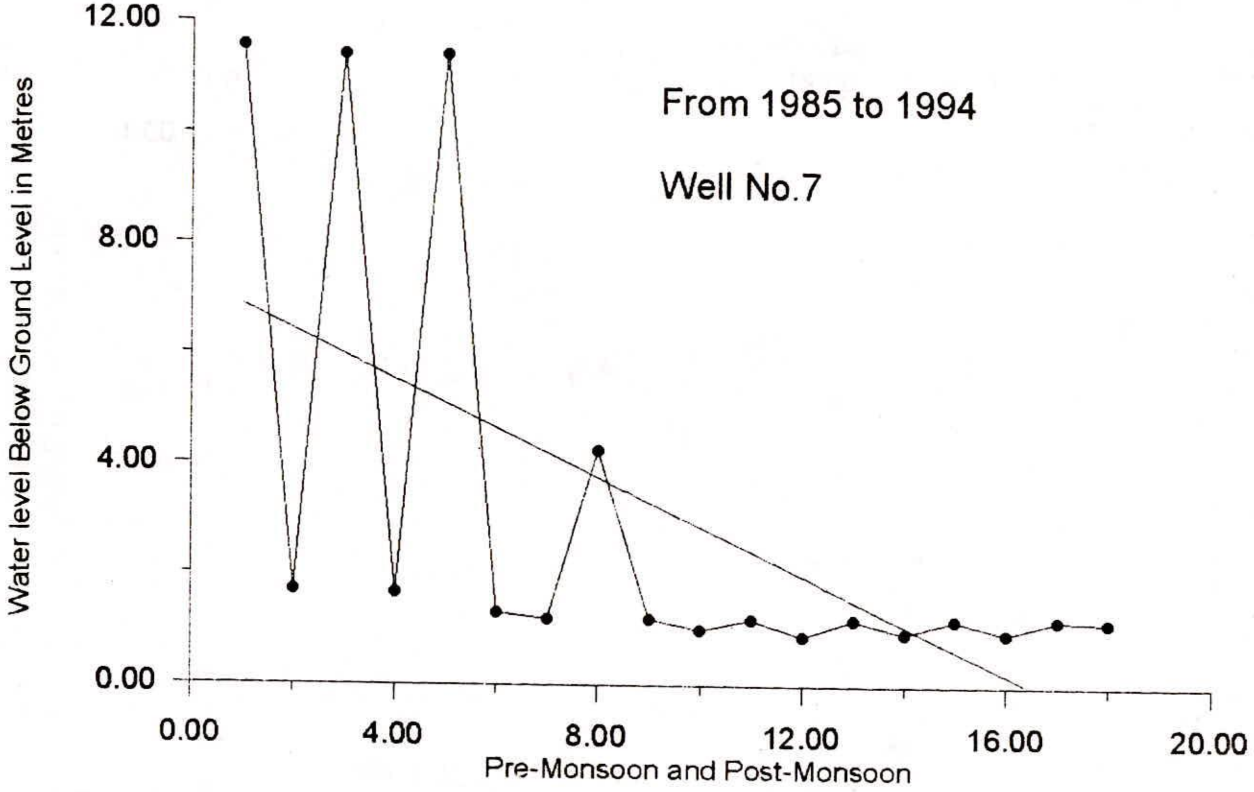

Figure 4.2.2.3 Variation of groundwater level of the study area

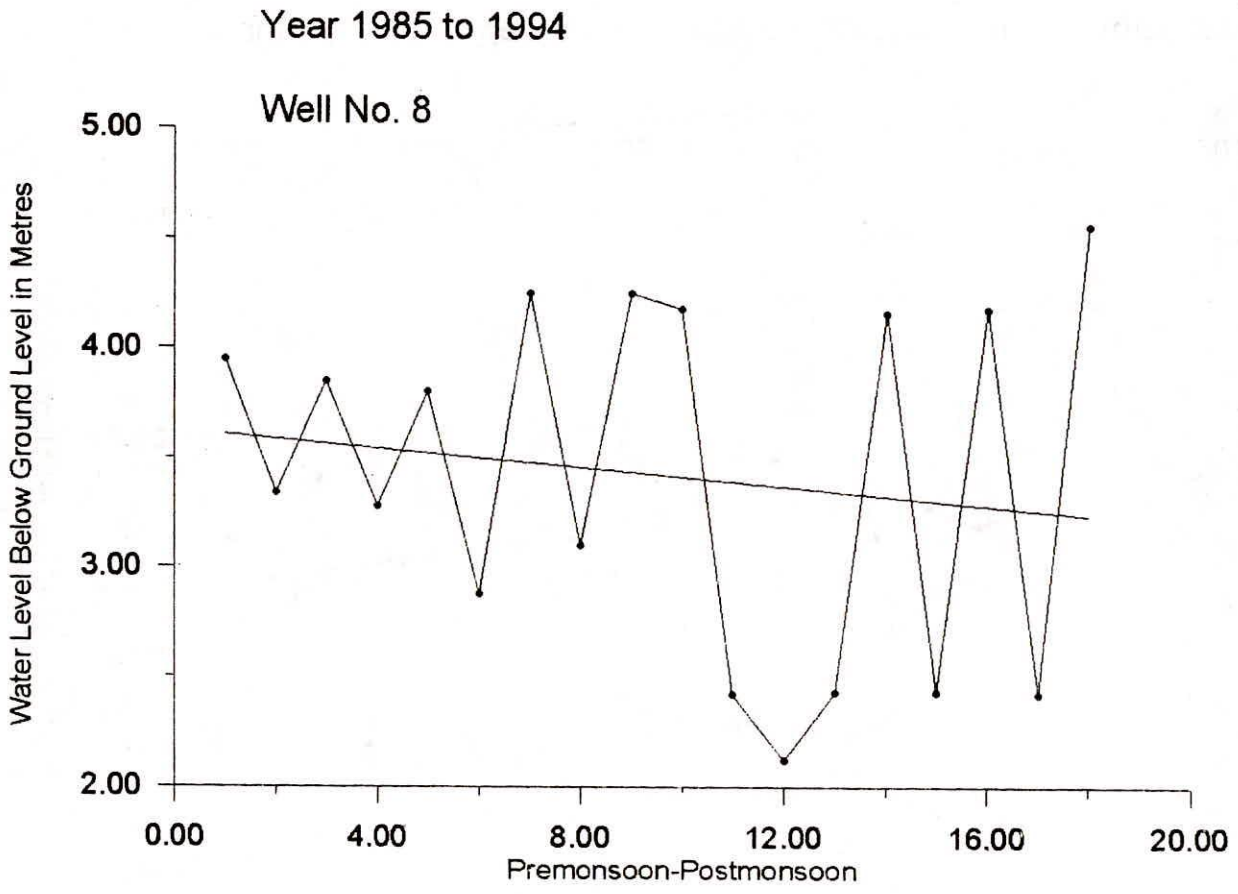

Figure 4.2.2.4 Variation of groundwater level of the study area

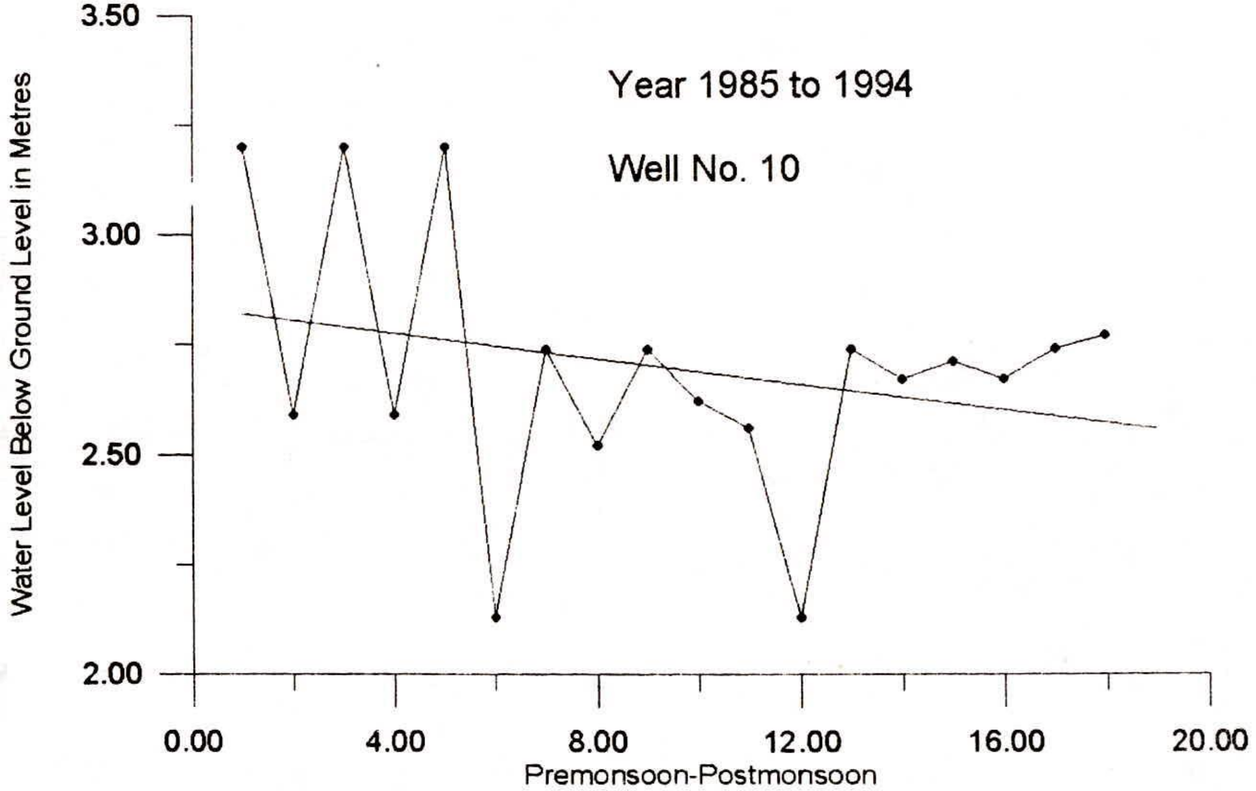

Figure 4.2.2.5 Variation of groundwater level of the study area

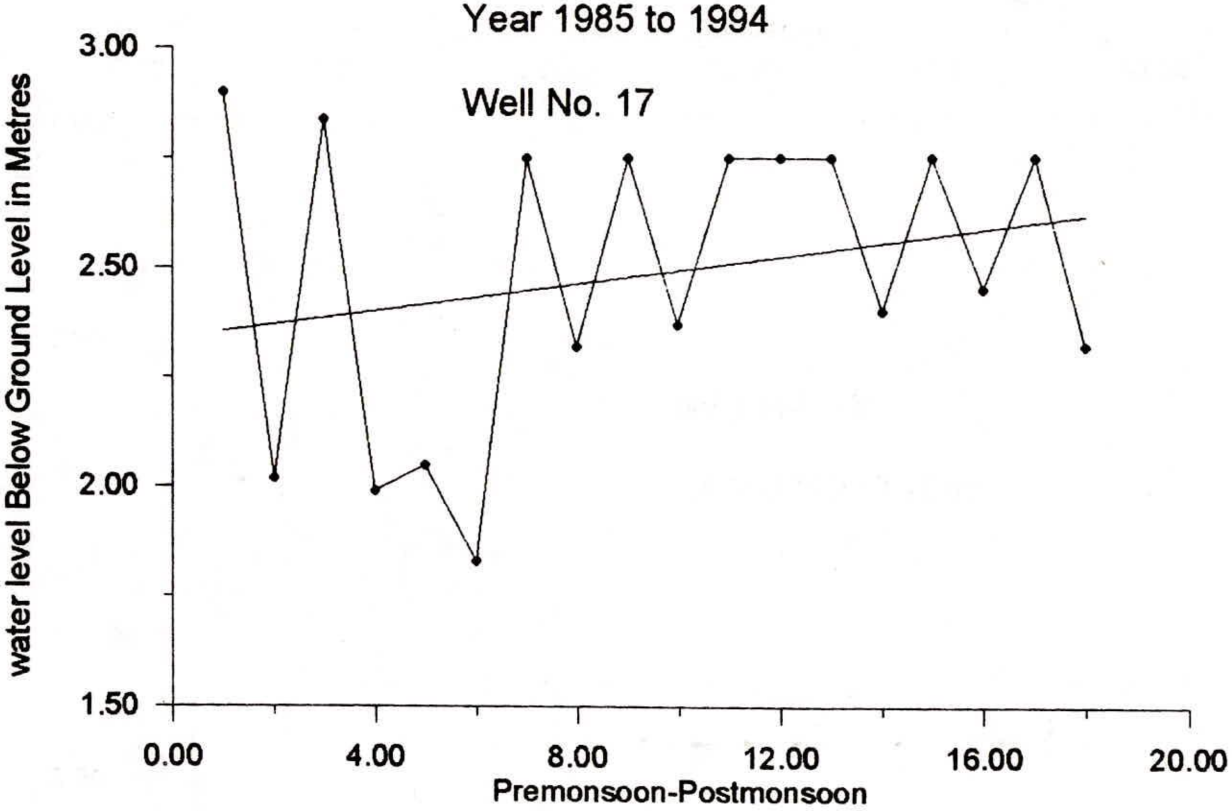

Figure 4.2.2.6 Variation of groundwater level of the study area

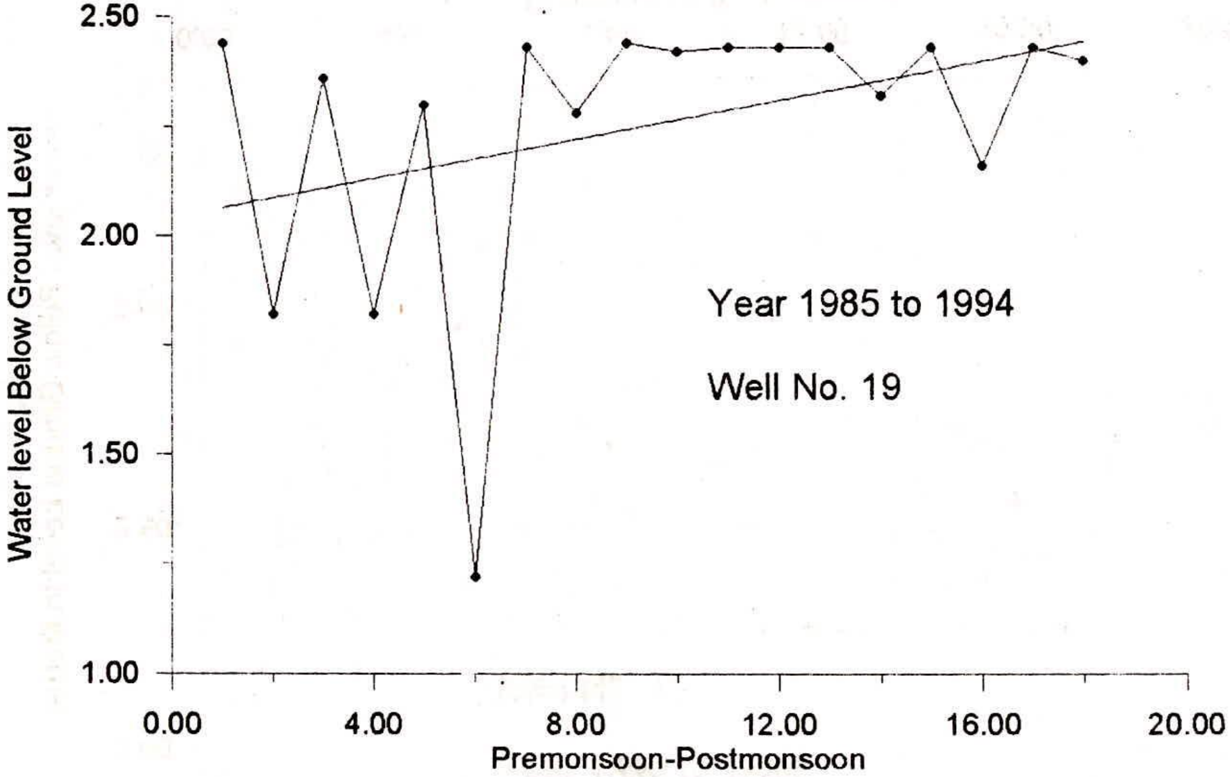

Figure 4.2.2.7 Variation of groundwater level of the study area

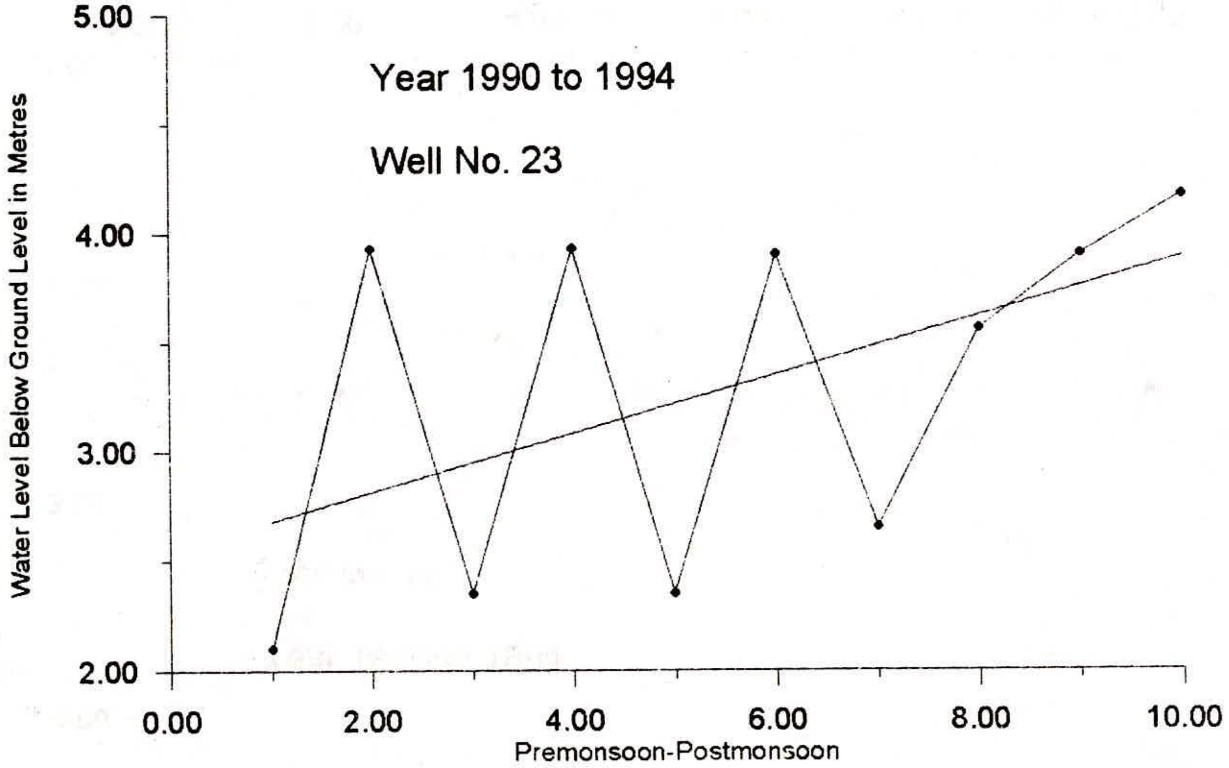

Figure 4.2.2.8 Variation of groundwater level of the study area

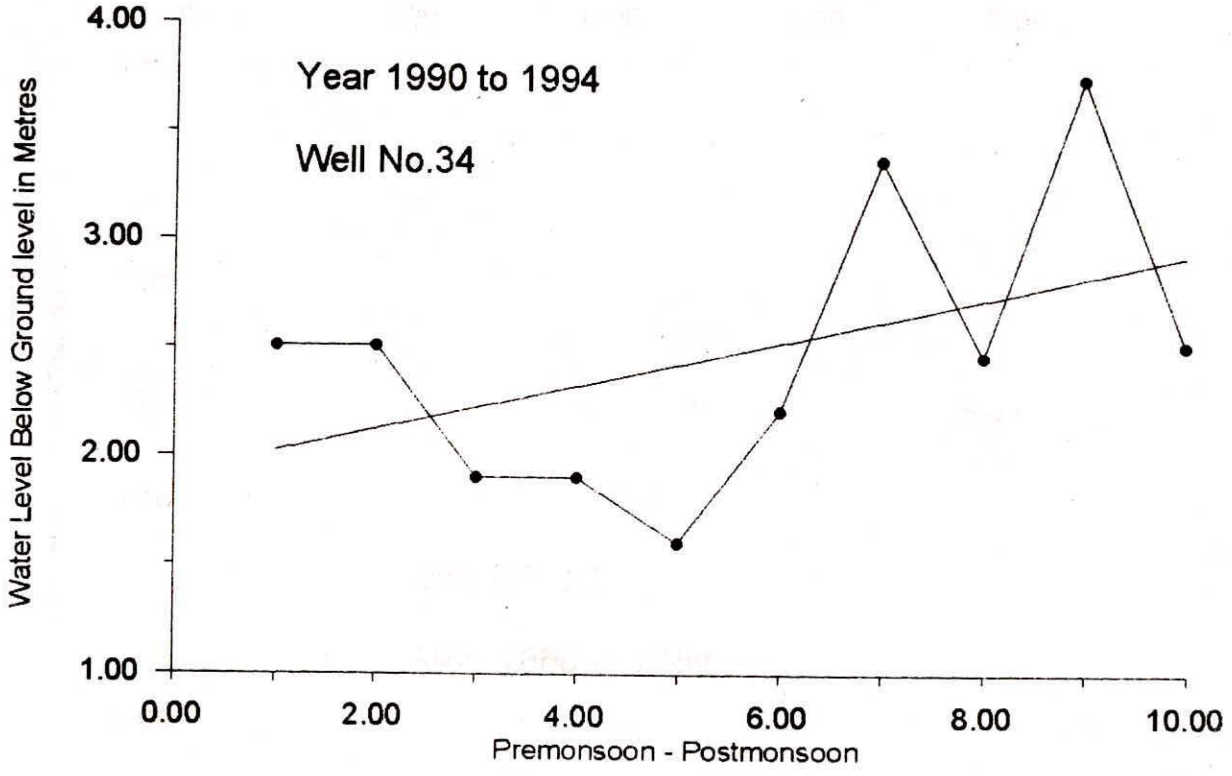

Figure 4.2.2.9 Variation of groundwater level of the study area

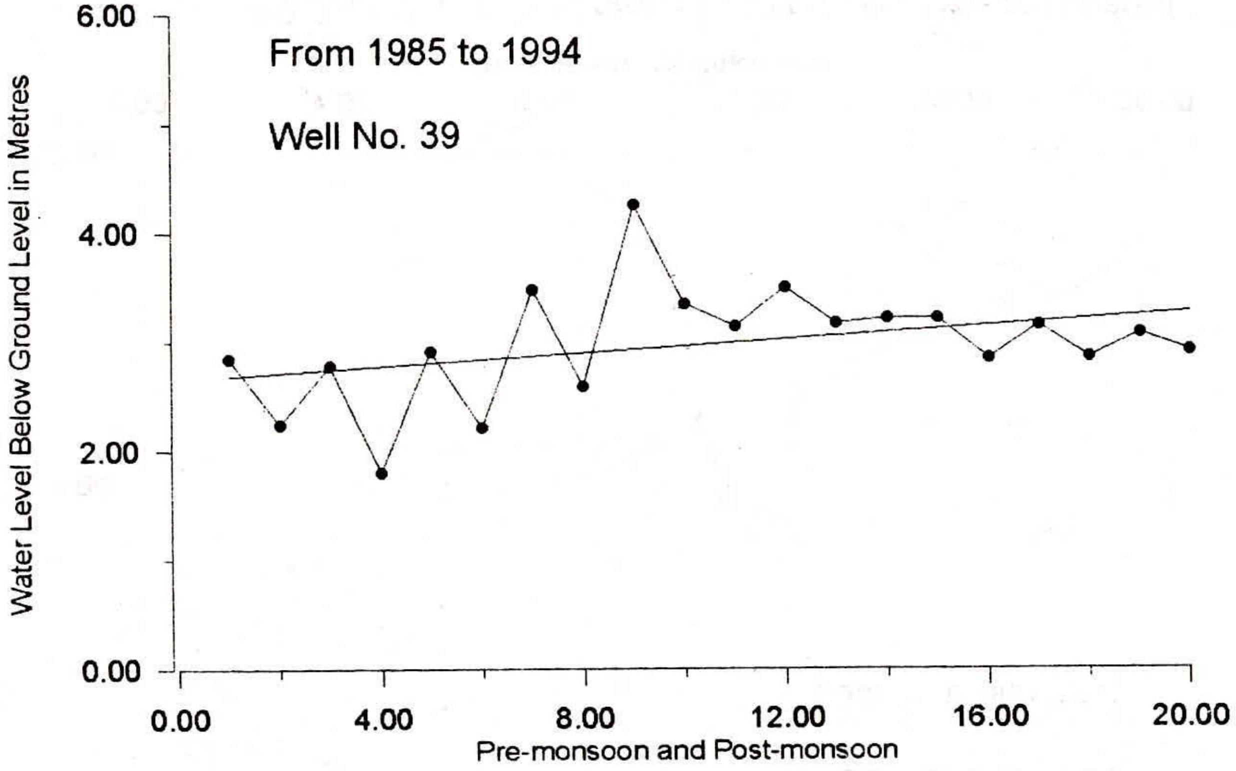

Figure 4.2.2.10 Variation of groundwater level of the study area

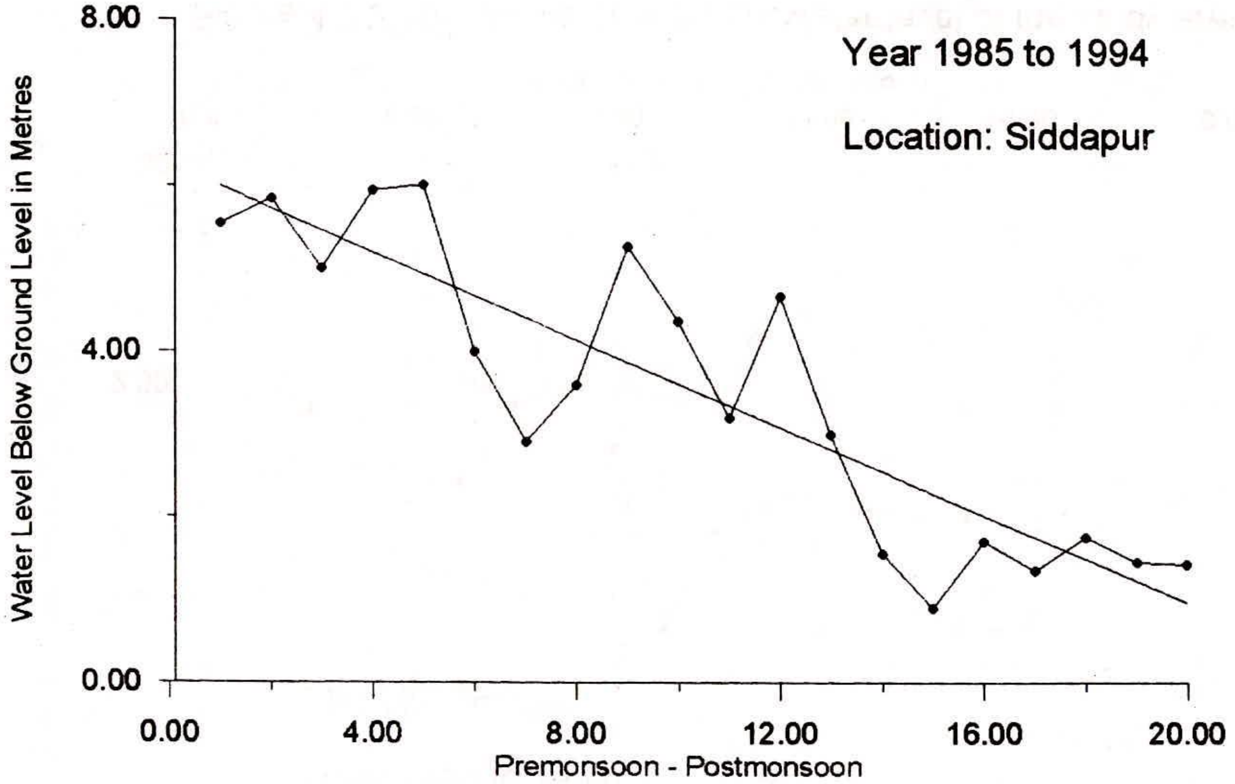

Figure 4.2.2.11 Variation of groundwater level of the study area

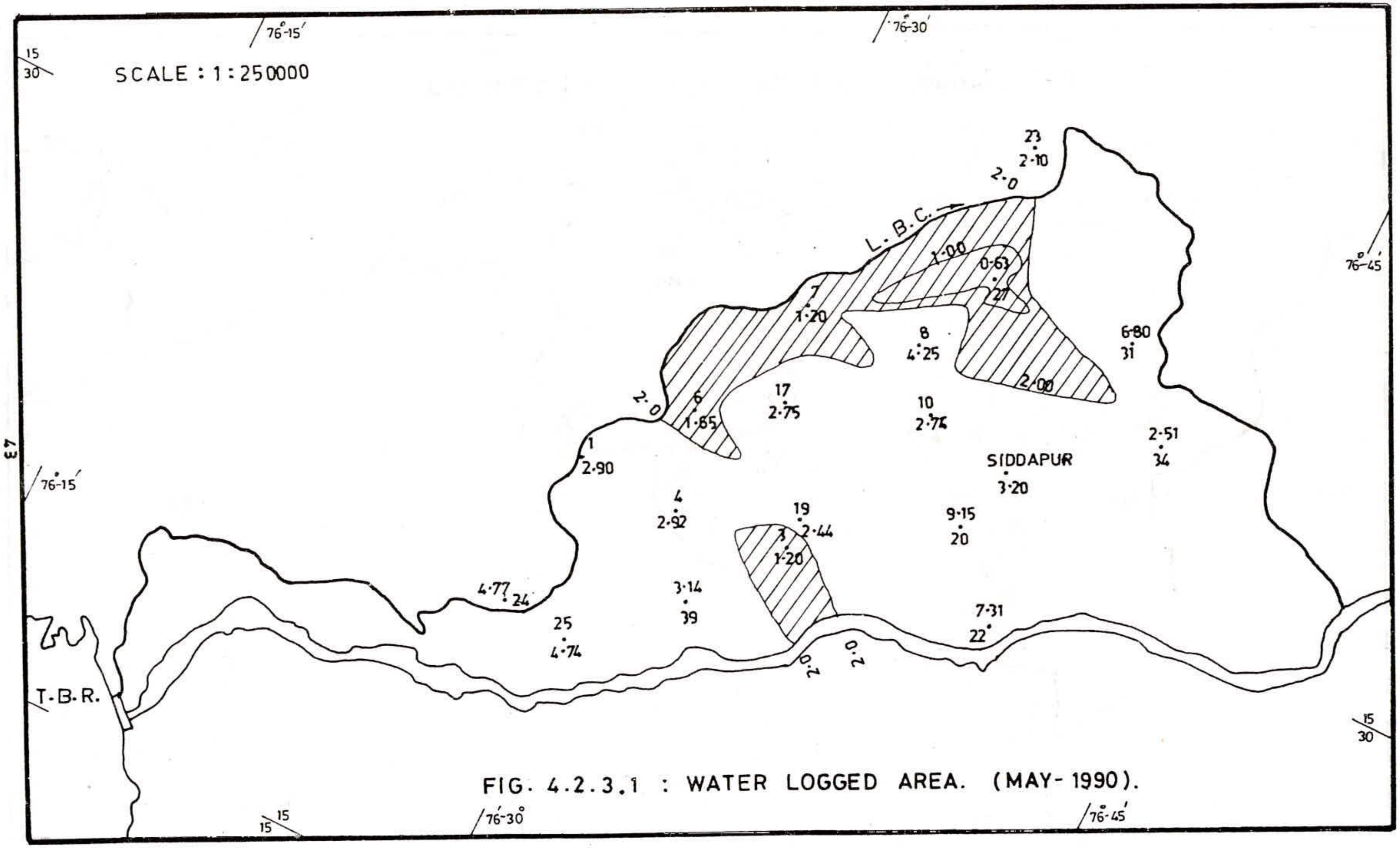

FIG. 4.2.3.1 : WATER LOGGED AREA. (MAY-1990).

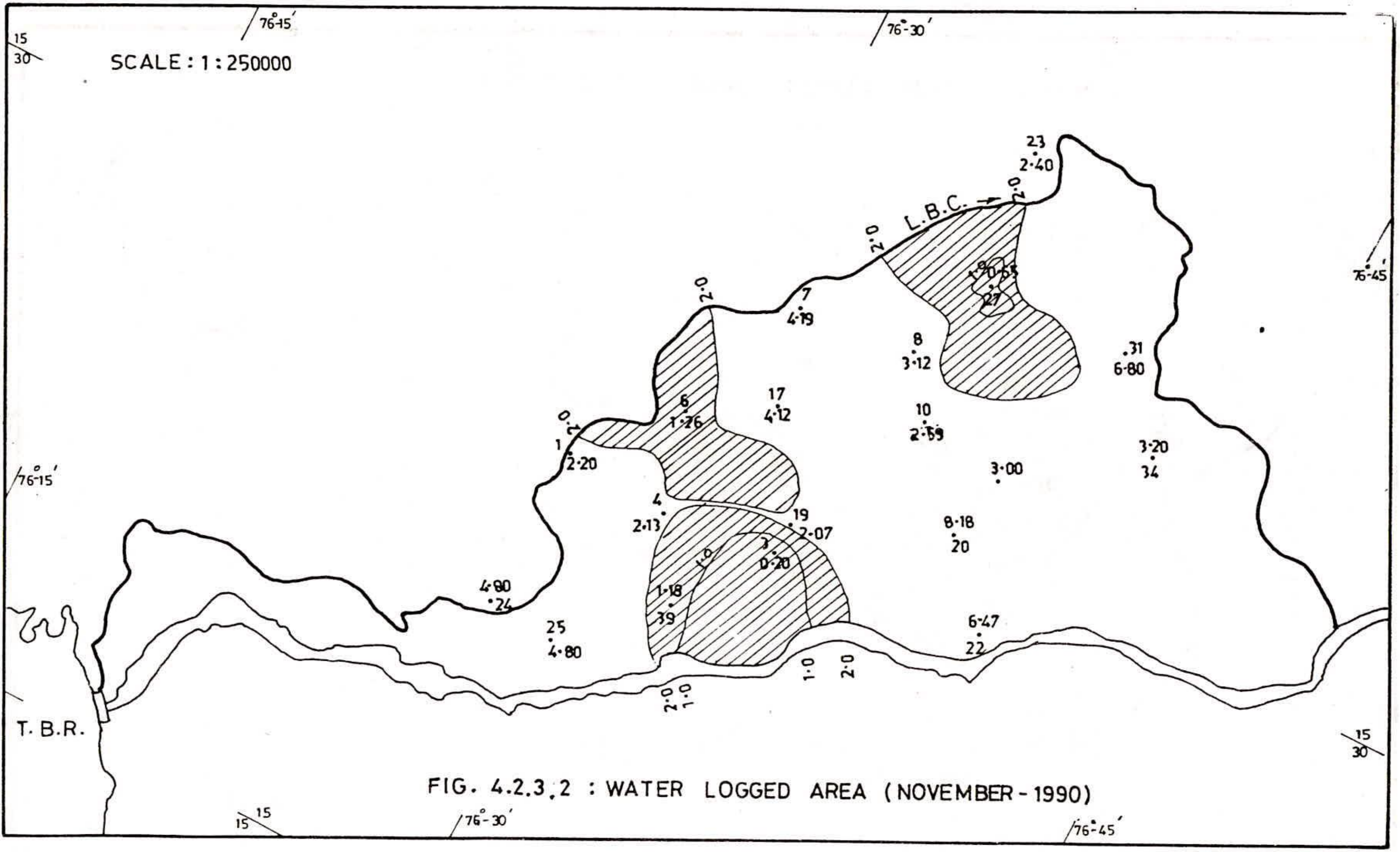

FIG. 4.2.3.2 : WATER LOGGED AREA (NOVEMBER - 1990)

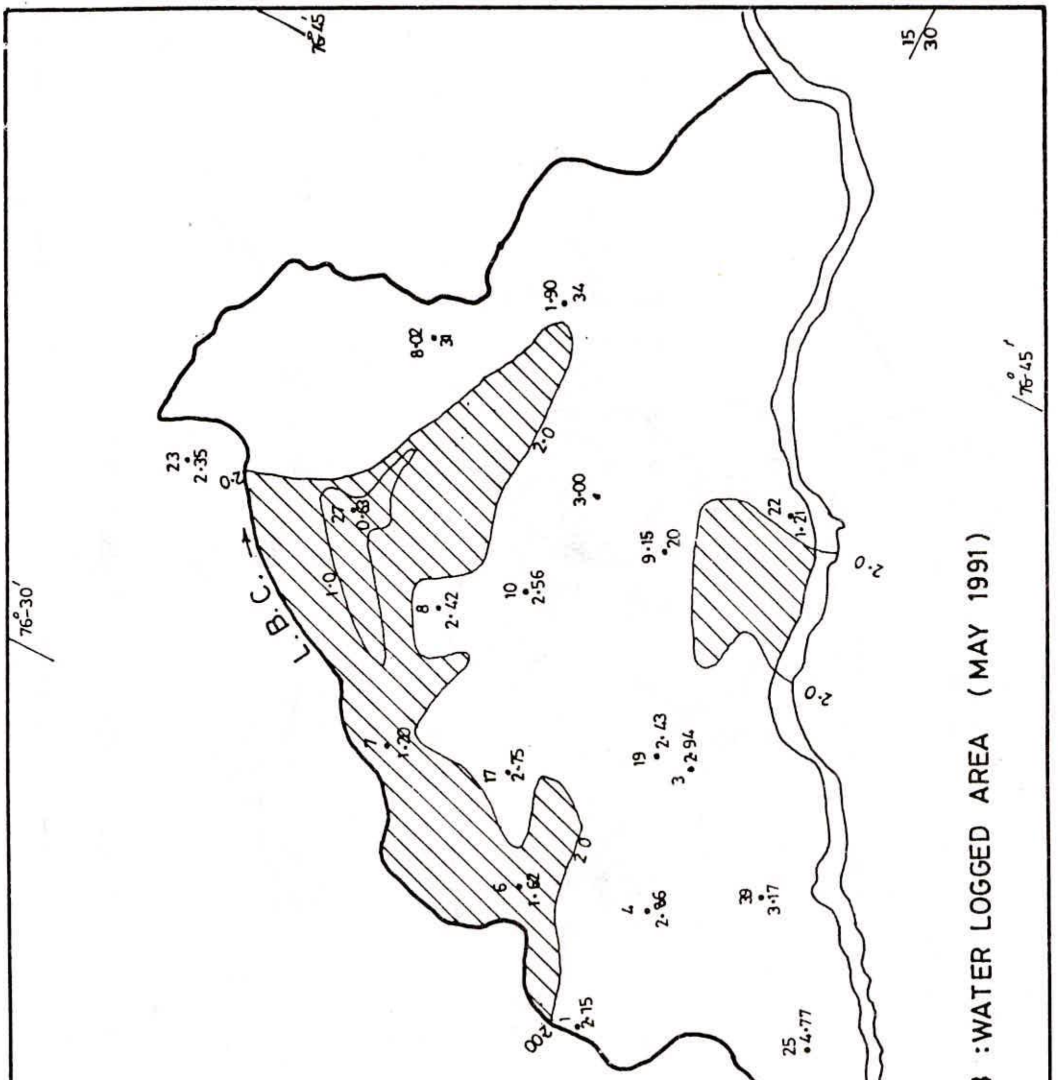

FIG. 4.2.3.3 : WATER LOGGED AREA (MAY 1991)

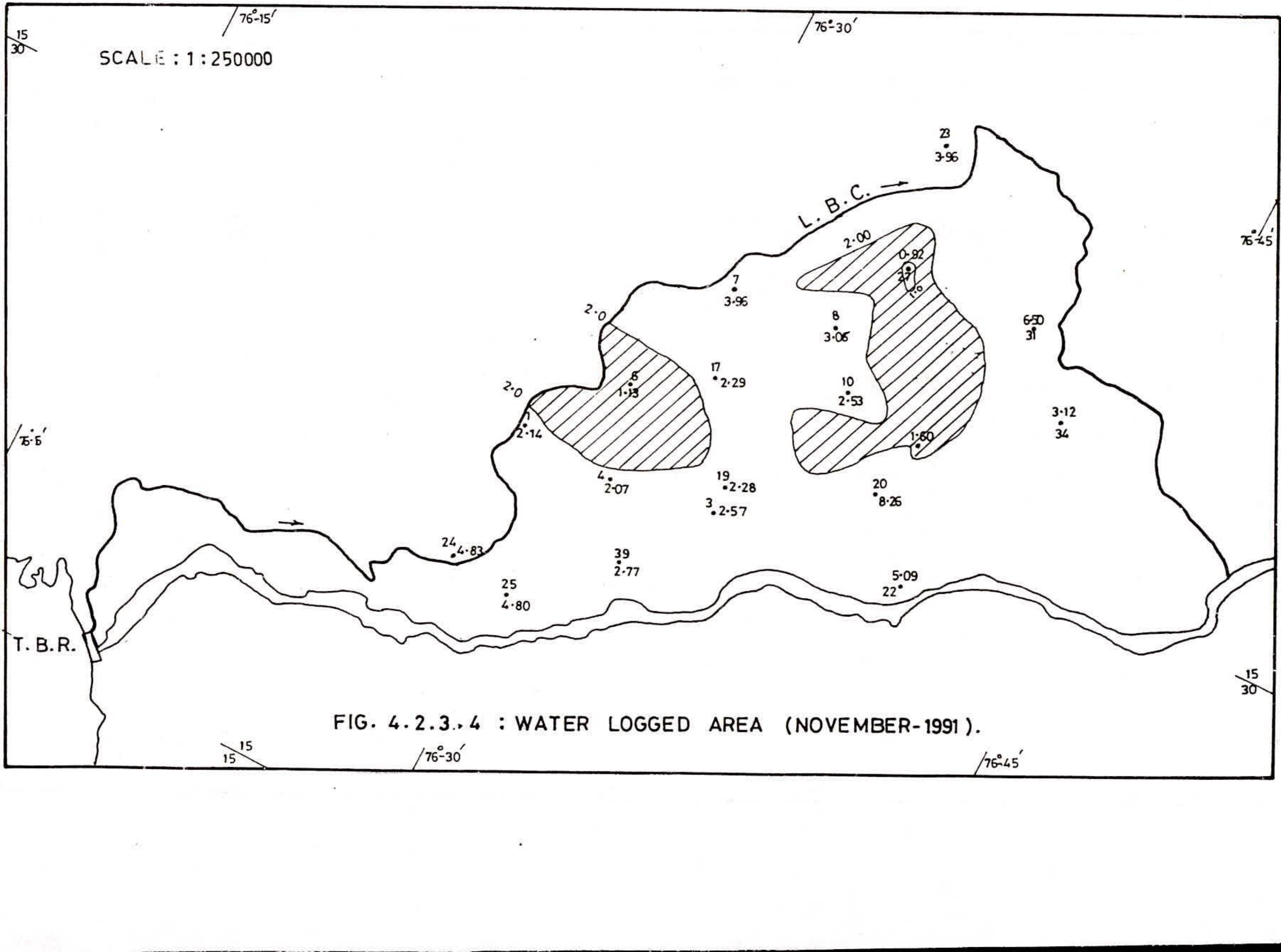

FIG. 4.2.3.4 : WATER LOGGED AREA (NOVEMBER-1991).

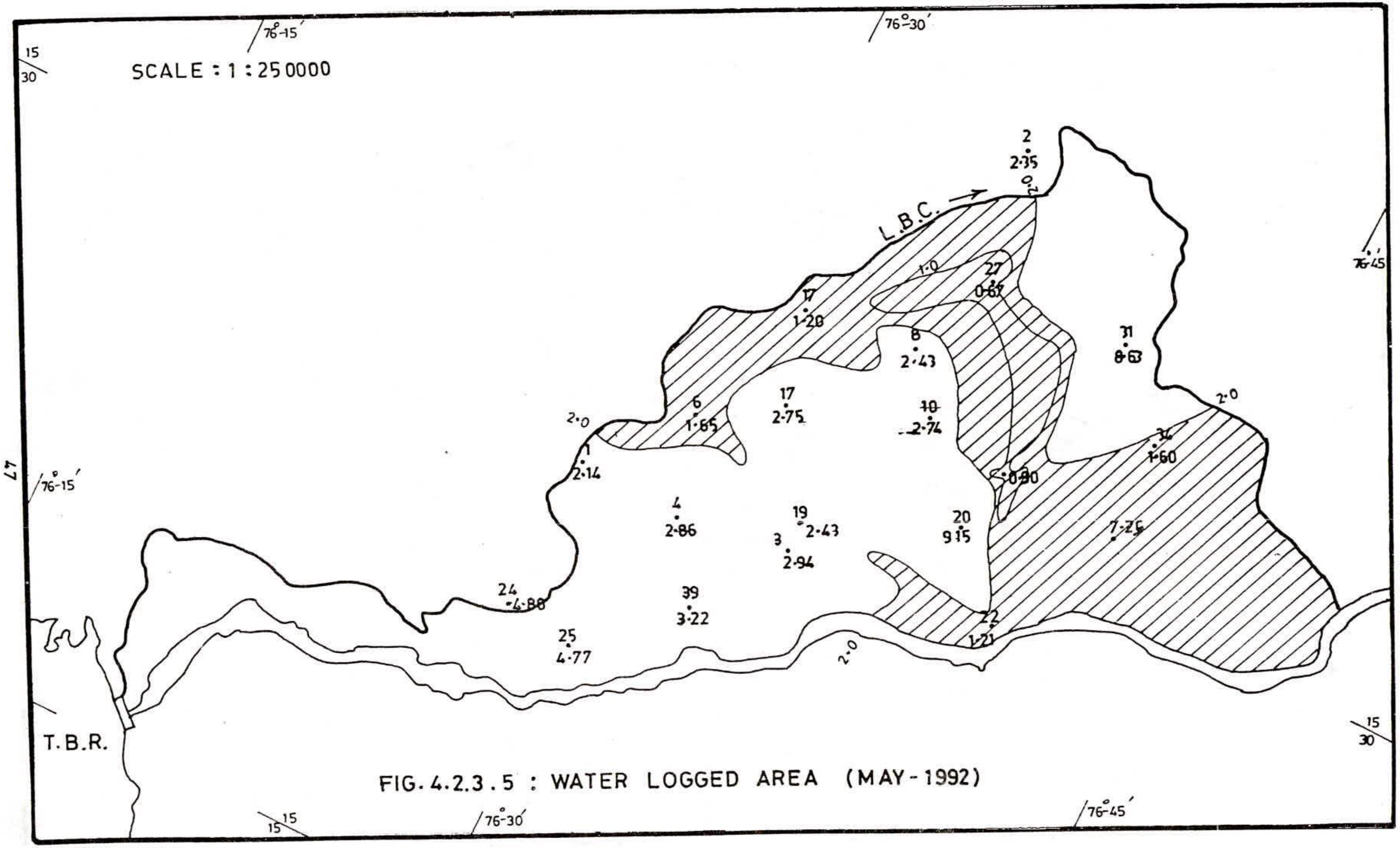

FIG. 4.2.3.5 : WATER LOGGED AREA (MAY-1992)

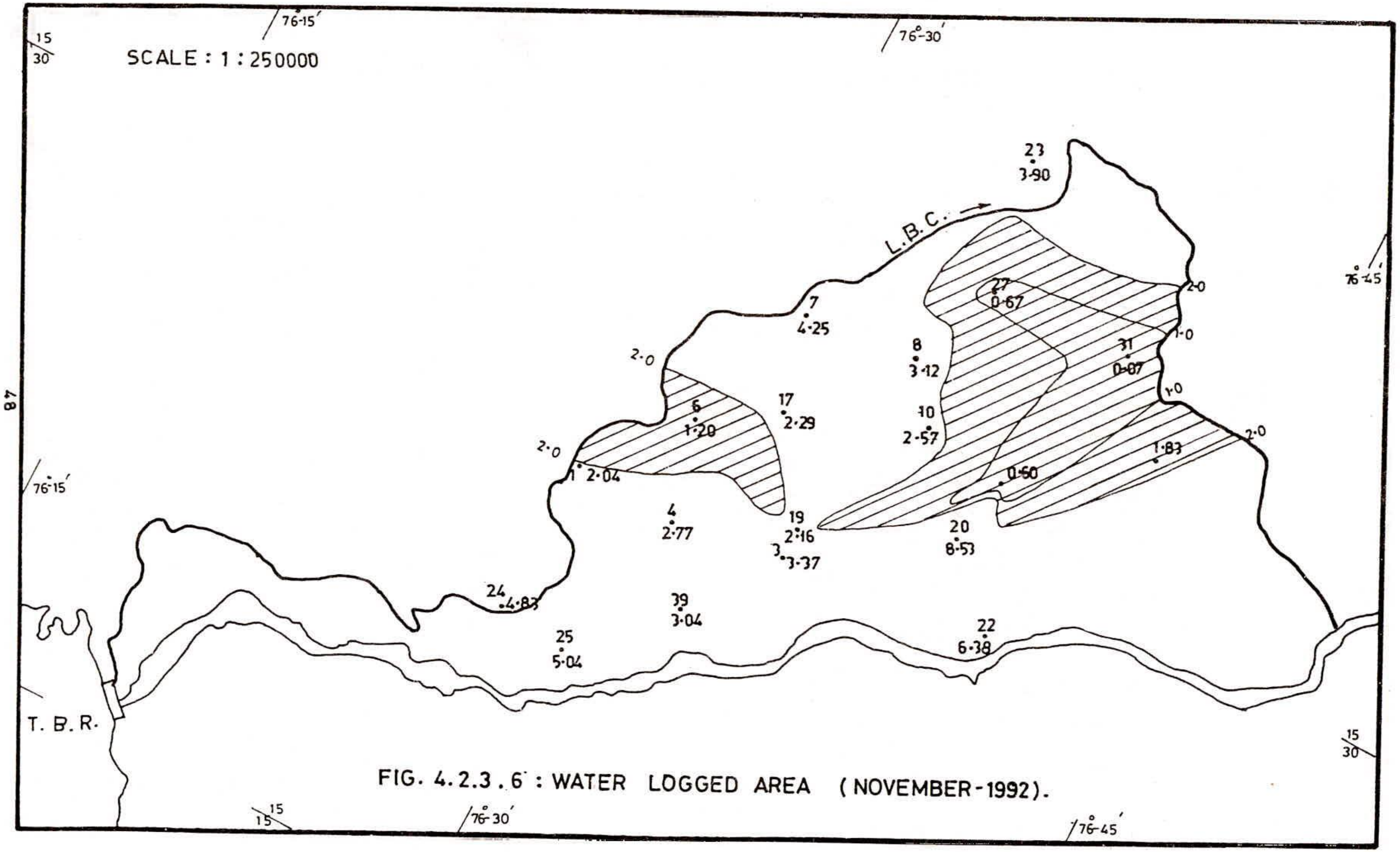

FIG. 4.2.3.6 : WATER LOGGED AREA (NOVEMBER-1992).

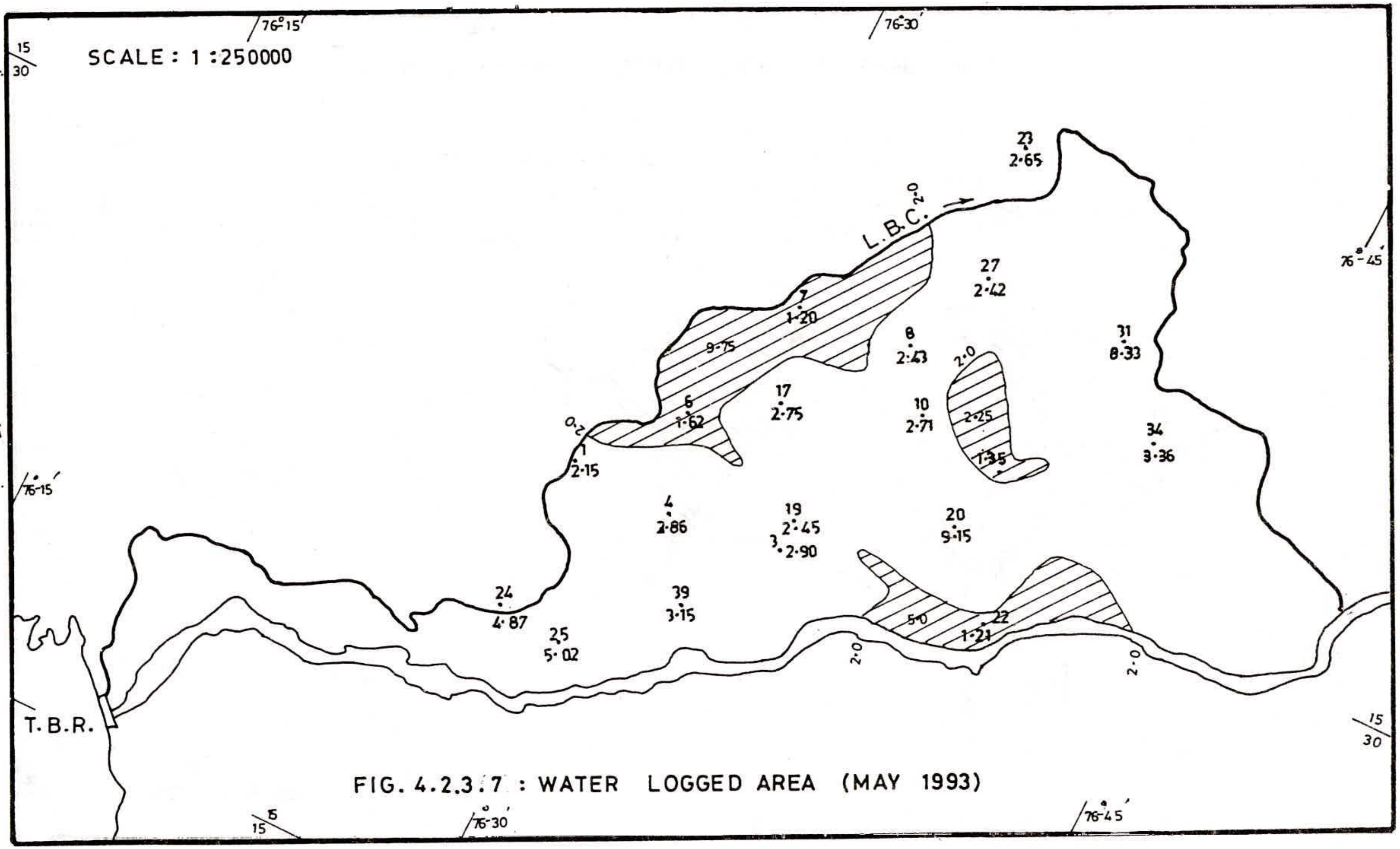

FIG. 4.2.3.7 : WATER LOGGED AREA (MAY 1993)

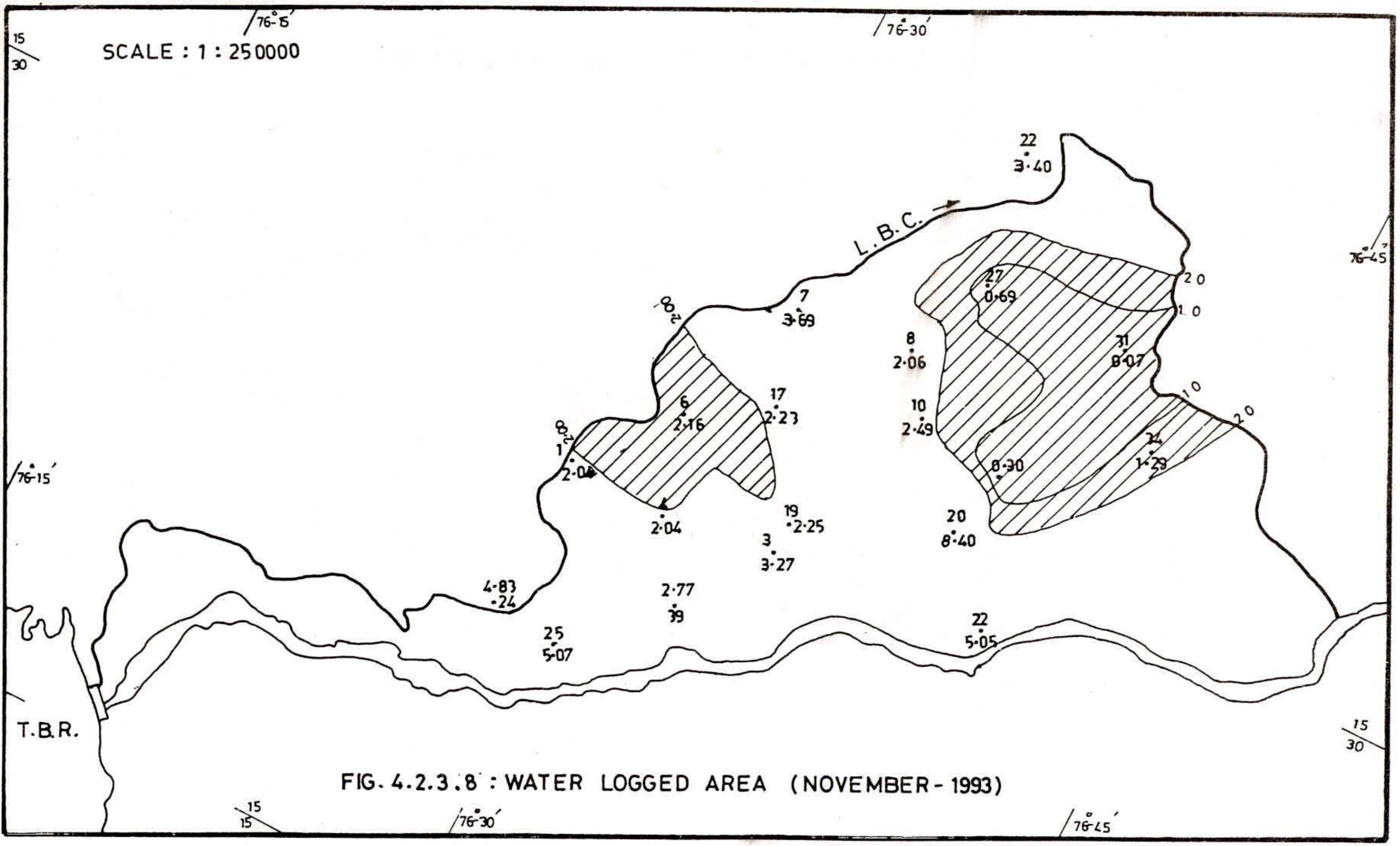

FIG. 4.2.3.8 : WATER LOGGED AREA (NOVEMBER - 1993)

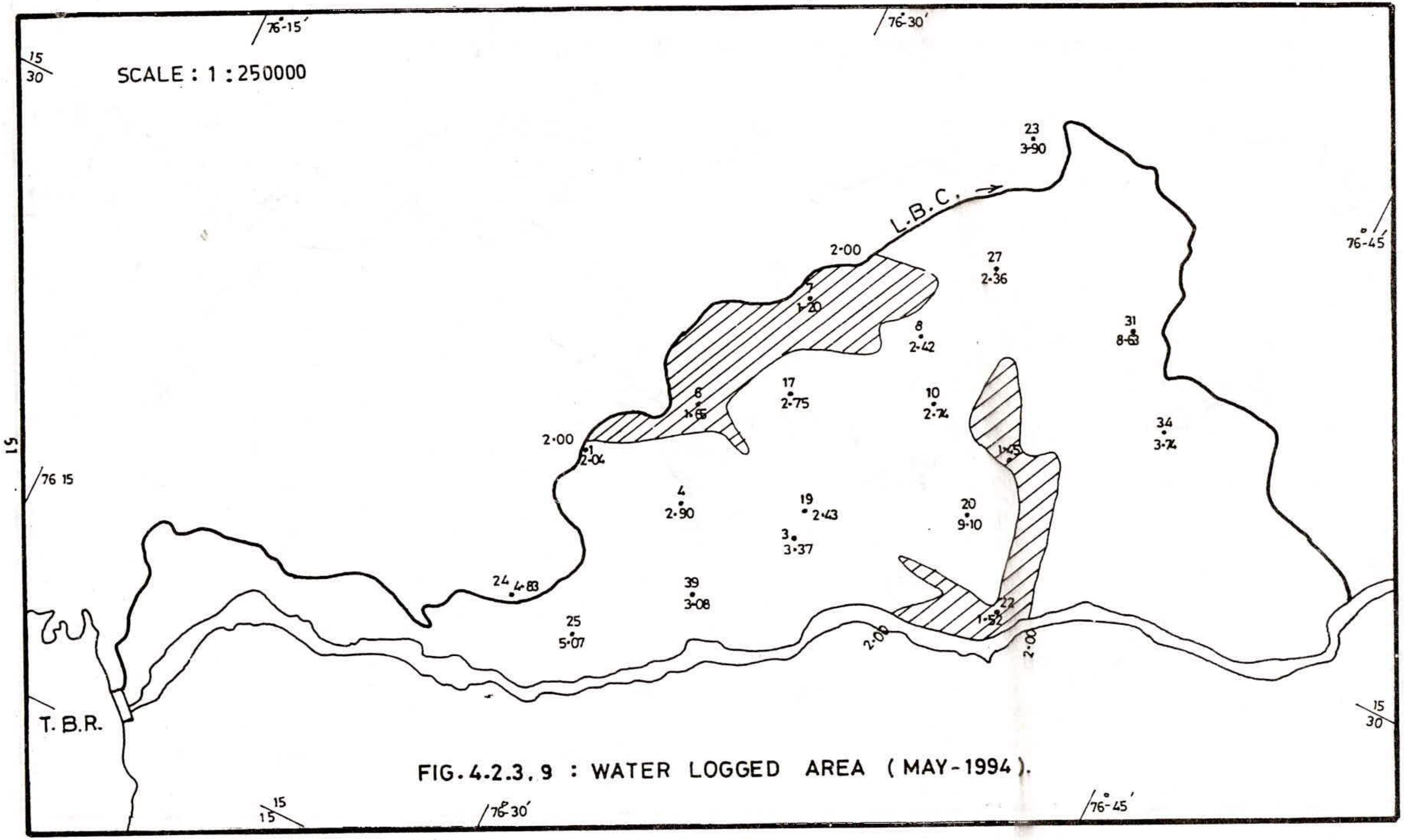

FIG. 4.2.3.9 : WATER LOGGED AREA (MAY-1994).

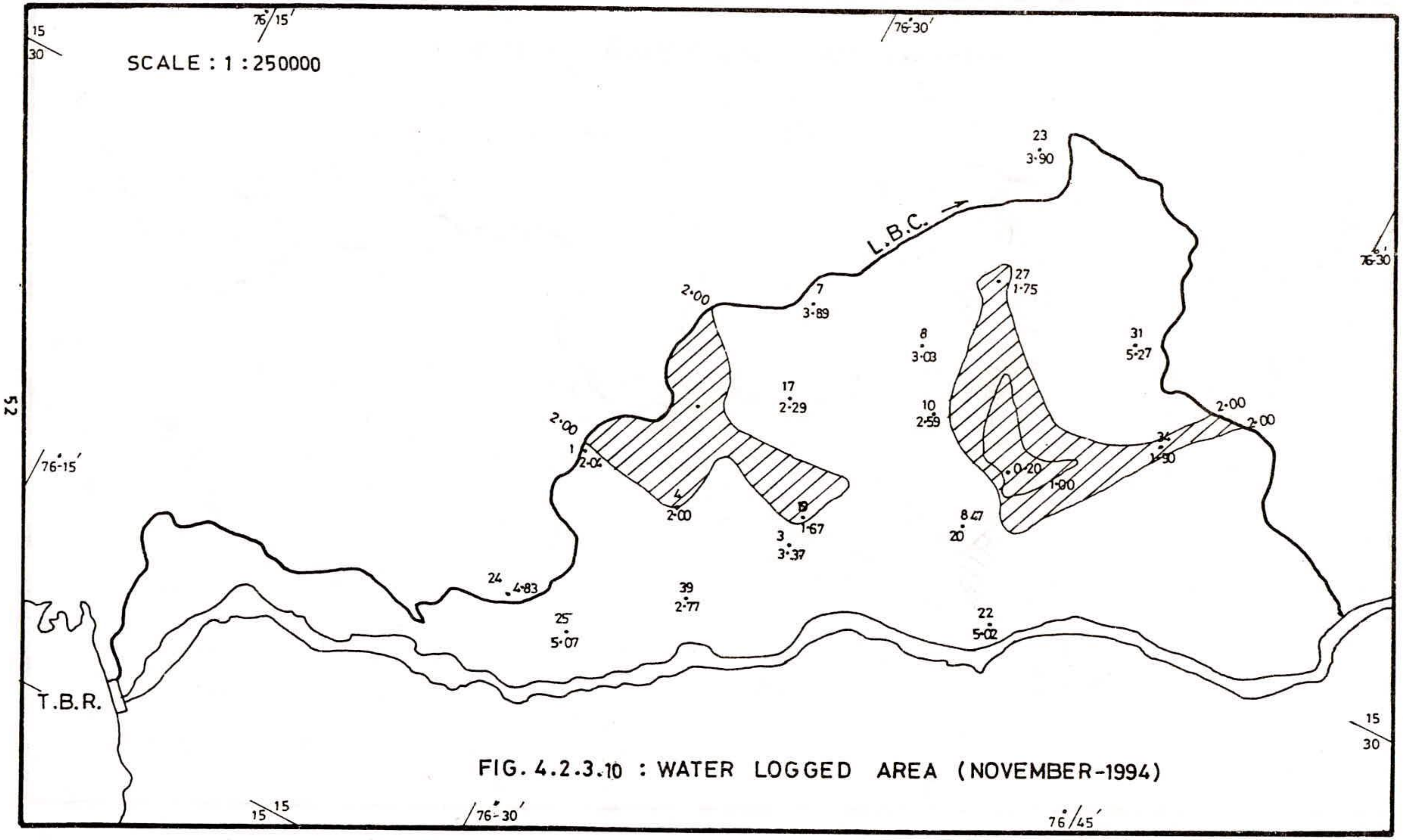

FIG. 4.2.3.10 : WATER LOGGED AREA (NOVEMBER-1994)

4.3.0 WATER REQUIREMENT

A rational planning and management of water resources is not possible without a comprehensive assessment of the need and the availability of water. In the assessment of water requirement that is, the irrigation water requirement, domestic water requirement which includes drinking water requirement and the requirement for Livestock and industrial water requirement have been considered.

4.3.1 Irrigation Water Requirement

The estimation of the water requirement of crops is one of the basic needs for crop planning of any irrigation project. Water requirement may be defined as the quantity of water, regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth under field conditions at a place.

The irrigation requirement for a crop depends on the irrigation need of the crop, the area occupied by the crop and the losses in the water distribution system.

Irrigation water requirement, IR is given by

$$IR = WR - ER + \text{Losses}$$

in which,

WR = Crop water requirement, and

ER = Effective rainfall.

4.3.1.1 Crop Water Requirement

Crop water requirement may be defined as the quantity of water, regardless of its source, required by the crop for its normal growth under field conditions at a place. Water requirement may be formulated as follows:

WR = Evapotranspiration + application losses + special needs

where,

ET = Evapotranspiration

Application losses include the loss of water during water application. These losses are unavoidable losses. Special needs include water required for land preparation, transplanting, leaching, etc,. Some part of the total water requirements of crop may be met by rainfall and hence it is calculated as follows.

4.3.1.2 Effective rainfall

Effective rainfall is that part of rain which enters the root zone and remains there as soil moisture. Crop water need can fully or partly be met by rainfall. All the rainfall is not effective. A part may be lost by surface runoff, and deep percolation and evaporation. In case of rainfall of high intensity only a part of the rain enters and is stored in the root zone and the quantity of effective rain is low. Frequent light rains on an area covered by a crop is more effective. With dry soil surface and little or no vegetative cover, rainfall upto 8 mm/day may be lost totally by evaporation. For rains of 25 mm to 30 mm per day with low percentage of vegetative cover only 60 percent of it is effective.

4.3.1.3 Estimation of effective rainfall

A number of empirical formulae can be used for estimating effective rainfall. The formula developed under a given set of conditions may not be applicable to different conditions elsewhere. However, in this study, consumptive use/precipitation ratio method which has been developed, by Soil Conservation Service of USDA (1969) has been adopted. In this method, the monthly effective rainfall is related to consumptive use. The effective monthly rainfalls which have been used are shown in table 4.3.1 The soil water storage capacity in the crop root zone at the time of irrigation is assumed to be equal to 75 mm.

4.3.1.4 Estimation of consumptive use

The consumptive use depends on the type and stage of growth of crop and the extent to which plants cover the soil moisture status, soil type and environmental conditions such as climate.

Consumptive use for a specific crop can be found using the relation

$$ET = K_C \, E_P$$

in which K_C = the crop coefficient

E_P = pan evaporation

The factors affecting the crop coefficient (K_C) are mainly the crop characteristics, crop planting, sowing date, rate of crop development, length of growing season and climatic conditions. Crop coefficient has been taken according to Water Management Division, Department of Agriculture, Irrigation, Govt. of India, 1971 as given in the table 4.3.2. The monthly crop water requirement has been calculated at net irrigation requirement, 80 per cent and 60 per cent efficiency from 1984-85 to 1993-94 for each principal crops (rice, sugercane, groundnut, cotton, sunflower, garden crop and pulses)

Table 4.3.1.1: Average monthly effective rainfall as related to mean monthly rainfall and mean monthly consumptive use (U.S.D.A. SCS, 1969)

Monthly mean rainfall mm	Mean Monthly Consumptive use, mm													
	25	50	75	100	125	150	175	200	225	250	275	300	325	350
	Mean monthly effective rainfall, mm													
12.5	7.5	8.0	8.7	9.0	9.2	10.0	10.5	11.2	11.7	12.5	12.5	12.5	12.5	12.5
25.0	10.0	16.2	17.5	18.0	18.5	19.7	20.5	22.0	24.5	25.0	25.0	25.0	25.0	25.0
37.5	22.5	24.0	26.2	27.5	28.2	29.2	30.5	33.0	36.2	37.5	37.5	37.5	37.5	37.5
50.0	25.0	32.2	34.5	35.7	36.7	39.0	40.5	43.7	47.0	50.0	50.0	50.0	50.0	50.0
62.5	at47.1	39.7	42.5	44.5	46.0	48.5	50.5	53.7	57.5	62.5	62.5	62.5	62.5	62.5
75.0		46.2	49.7	52.7	55.0	57.5	60.2	63.7	67.5	73.5	75.0	75.0	75.0	75.0
87.5		50.0	56.7	60.2	63.7	66.0	69.7	73.7	77.7	84.5	87.5	87.5	87.5	87.5
100.0		at80.7	63.7	67.7	72.0	74.2	78.7	83.0	87.7	95.0	100.0	100.0	100.0	100.0
112.5			70.5	81.5	87.7	90.5	95.7	102.0	108.0	115.0	121.0	112.0	112.0	112.0
125.0			75.0	81.5	87.7	90.5	95.7	102.0	108.0	115.0	121.0	125.0	125.0	125.0
137.5			at122.0	88.7	95.2	98.7	104.0	111.0	118.0	126.0	132.0	137.0	137.0	137.0
150.0				95.2	102.0	106.0	112.0	120.0	127.0	136.0	143.0	150.0	150.0	150.0
162.5				100.0	109.0	113.0	120.0	128.0	135.0	145.0	153.0	160.0	162.0	160.0
175.0				at160.0	115.0	120.0	127.0	135.0	143.0	154.0	164.0	170.0	175.0	175.0
187.5					121.0	126.0	134.0	142.0	151.0	161.0	170.0	179.0	185.0	187.0
200.0					125.0	133.0	140.0	148.0	158.0	168.0	178.0	188.0	196.0	200.0
225.0					at197.0	144.0	151.0	160.0	171.0	182.0				
250.0						150.0	161.0	170.0	183.0	194.0				
275.0						at240.0	171.0	181.0	194.0	205.0				
300.0							175.0	190.0	203.0	215.0				
325.0							at287.0	198.0	213.0	224.0				
350.0								200.0	220.0	232.0				
375.0								at331.0	225.0	240.0				
400.0									at372.0	247.0				
425.0										250.0				
										at412.0				
450.0	25	50	75	100	125	150	175	200	225	250				

TABLE 4.3.1.2

CONSUMPTIVE USE (EVAPO-TRANSPIRATION) COEFFICIENT K, OF CLASS A PAN EVAPORATION

Per cent	Crop Group							
	A	B	C	D	E	F	G	R
0	0.20	0.15	0.12	0.08	0.90	0.60	0.50	0.80
5	0.20	0.15	0.12	0.08	0.90	0.60	0.55	0.90
10	0.36	0.27	0.22	0.15	0.90	0.60	0.60	0.95
15	0.50	0.38	0.30	0.19	0.90	0.60	0.65	1.00
20	0.64	0.48	0.38	0.27	0.90	0.60	0.70	1.05
25	0.75	0.56	0.45	0.33	0.90	0.60	0.75	1.10
30	0.84	0.63	0.50	0.40	0.90	0.60	0.80	1.14
35	0.92	0.69	0.55	0.46	0.90	0.60	0.86	1.17
40	0.97	0.73	0.58	0.52	0.90	0.60	0.90	1.21
45	0.99	0.74	0.60	0.58	0.90	0.60	0.85	1.25
50	1.00	0.75	0.60	0.65	0.90	0.60	1.00	1.30
55	1.00	0.75	0.60	0.71	0.90	0.60	1.00	1.30
60	0.99	0.74	0.60	0.77	0.90	0.60	1.00	1.30
65	0.96	0.72	0.58	0.82	0.90	0.60	0.95	1.25
70	0.91	0.68	0.55	0.88	0.90	0.60	0.90	1.20
75	0.85	0.64	0.51	0.90	0.90	0.60	0.85	1.15
80	0.75	0.56	0.45	0.90	0.90	0.60	0.80	1.10
85	0.60	0.45	0.36	0.80	0.90	0.60	0.75	1.00
90	0.46	0.35	0.28	0.70	0.90	0.60	0.70	0.90
95	0.28	0.21	0.17	0.60	0.90	0.60	0.55	0.80
100	0.20	0.20	0.17	0.20	0.90	0.60	0.50	0.20

grown in the study area and tabulated in the table 4.3.3. The irrigable area under existing canal release and delta of the study area has been presented in the table 4.3.4a to 4.3.4e.

4.3.2 Drinking Water Requirement

Drinking water requirement includes the domestic water requirement and live stock water requirement. The water requirement for the domestic purposes normally taken as 135 LPCD and for the live stock 100 LPCD for urban population. For the rural area 40-50 LPCD is normally considered. The growth rate of population 1.75 per cent is considered on the basis of the actual growth of population between 1981 and 1991 census. The drinking water requirement of live stock and population is varies from 3.87 MCM to 4.67MCM over the study period. The industrial use is not considered in the study area.

4.4.0 GROUNDWATER BALANCE OF THE STUDY AREA

Water balance technique has been extensively used to make quantitative estimates of water resources and the impact of man's activities on the surface water and groundwater regimes. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system. After the water balance studies, modelling can be done for evaluating impact of alternative policies so as to select a safe abstraction policy.

The basin concept of water balance is :

inflow to the system - outflow from the system = change in storage of the system, over a period of time.

4.4.1 Ground water balance equation

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

$$R_i + R_c + R_r + R_t + I_g + S_i = T_p + E_t + O_g + S_e + \Delta S$$

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 ground water irrigation

R_t = recharge from reservoirs and tanks;

I_g = subsurface inflow to the study area;

S_i = influent seepage from rivers;

Table No.4.3.3.1 Average Monthly Crop Water Requirement(in cm)

Months	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94
June	19.81	15.00	7.57	4.90	16.07	11.70	4.66	7.15	7.95	13.90
July	4.78	9.60	19.60	20.54	12.33	11.84	13.03	15.46	21.20	12.23
Aug	24.65	21.55	12.61	18.00	4.62	20.72	12.33	19.47	17.56	4.77
Sept	15.45	18.46	10.20	6.81	4.45	5.75	21.35	16.76	10.46	5.40
Oct	7.82	15.55	20.54	8.58	20.35	22.91	6.20	21.05	11.32	7.30
Nov	10.05	10.31	1.41	2.02	9.98	9.27	4.62	7.44	-	4.65
Dec	16.98	19.40	17.14	7.68	14.50	14.73	16.15	16.84	13.73	5.56
Jan	26.63	25.19	25.32	21.65	25.64	25.93	26.44	26.50	24.51	21.74
Feb	23.78	24.10	23.44	24.52	24.18	23.22	25.23	24.45	21.83	22.19
Mar	43.18	47.83	43.00	44.97	39.10	46.28	42.25	44.14	40.64	41.98
Apr	36.72	33.16	37.04	32.33	35.04	37.37	26.65	30.90	35.72	25.76
May	26.17	24.25	33.36	27.47	31.57	10.90	22.88	17.67	28.24	31.84
Total	256.02	264.39	251.23	219.47	237.83	240.62	221.79	247.83	233.16	197.32

Table No. 4.3.4a Irrigable Area Under Existing Canal Release & Delta

	1985-86			1986-87		
Months	Crop water Requirement	Canal Release MCM	Irrigable Area Km^2	Crop water Requirement	Canal Release MCM	Irrigable Area Km^2
June	0.15	-	-	0.076	8.215	108.52
July	0.096	-	-	0.196	58.611	299.04
August	0.216	55.138	255.86	0.126	62.639	496.74
September	0.185	61.526	333.48	0.102	63.670	624.21
October	0.156	63.548	408.64	0.205	62.497	304.27
November	0.103	57.584	558.53	0.014	41.642	2953.35
December	0.194	50.509	260.35	0.171	56.836	331.60
January	0.252	57.968	206.30	0.253	58.978	232.93
February	0.241	46.223	191.80	0.234	56.927	242.60
March	0.478	52.167	109.07	0.430	61.592	143.24
April	0.332	9.870	29.760	0.370	28.248	76.26
May	0.243	-	-	0.334	1.762	5.28

Table No:4.3.4b Irrigable Area Under Existing Canal Release and Delta

	1987-88			1988-89		
Months	Crop water Requirement	Canal Release MCM	Irrigable Area Km^2	Crop water Requirement	Canal Release MCM	Irrigable Area Km^2
June	0.049	5.044	102.94	0.161	9.756	60.71
July	0.205	48.584	236.53	0.123	31.340	254.18
August	0.180	83.939	466.33	0.046	34.657	750.14
September	0.068	65.105	956.01	0.044	48.437	1088.47
October	0.086	49.615	578.26	0.203	52.656	258.75
November	0.020	22.323	1105.10	0.099	49.715	498.14
December	0.076	9.670	126.28	0.145	46.104	317.96
January	0.217	47.916	221.32	0.256	53.891	210.18
February	0.245	26.117	106.57	0.242	52.036	215.20
March	0.450	54.322	120.80	0.391	39.528	101.10
April	0.323	38.243	118.29	0.350	19.178	54.73
May	0.275	6.652	24.22	0.316	-	5.28

Table No:4.3.4c Irrigable Area Under Existing Canal Release and Delta

	1989-90			1990-91		
Months	Crop water Requirement	Canal Release MCM	Irrigable Area Km^2	Crop water Requirement	Canal Release MCM	Irrigable Area Km^2
June	0.117	-	-	0.047	-	-
July	0.118	42.742	361.00	0.130	92.073	706.62
August	0.207			0.123	77.059	624.97
September	0.057	66.717	1160.30	0.214	66.238	310.25
October	0.229	65.287	284.97	0.062	67.732	1092.44
November	0.093	50.725	547.20	0.046	46.822	1013.46
December	0.147	32.798	222.66	0.161	44.738	277.00
January	0.260	62.188	239.83	0.264	77.400	292.74
February	0.232	69.606	299.77	0.252	67.329	266.86
March	0.463	76.762	165.86	0.423	72.528	171.66
April	0.374	35.793	95.78	0.267	37.550	140.90
May	0.109	5.438	49.89	0.229	8.239	36.00

Table No:4.3.4d Irrigable Area Under Existing Canal Release and Delta

Months	1991-92			1992-93		
	Crop water Requirement	Canal Release MCM	Irrigable Area Km^2	Crop water Requirement	Canal Release MCM	Irrigable Area Km^2
June	0.072	59.038	825.71	0.080	116.134	1460.81
July	0.155	-	-	0.212	116.135	547.81
August	0.195	38.870	199.64	0.176	52.947	301.52
September	0.168	43.783	261.24	0.105	66.666	637.34
October	0.210	57.583	273.55	0.113	61.438	542.75
November	0.074	32.312	434.30	-	35.734	-
December	0.168	70.434	418.25	0.137	27.035	196.90
January	0.265	68.821	259.70	0.245	64.637	263.72
February	0.244	65.386	267.43	0.218	59.450	272.33
March	0.441	74.702	169.24	0.406	65.998	162.40
April	0.309	39.636	128.27	0.357	55.663	155.83
May	0.177	4.407	24.94	0.282	7.148	25.31

Table No:4.3.4e Irrigable Area Under Existing Canal Release and Delta

1993-94

Months	Crop water Requirement	Canal Release MCM	Irrigable Area Km^2
June	0.139	-	-
July	0.122	57.963	473.94
August	0.048	66.293	1389.80
September	0.054	58.988	1092.38
October	0.073	56.302	771.26
November	0.047	46.504	1000.07
December	0.056	3.763	67.68
January	0.217	65.082	299.37
February	0.222	62.270	280.62
March	0.420	50.858	121.15
April	0.258	48.112	186.77
May	0.318	12.514	39.30

T_p = draft from ground water
E_t = evapotranspiration losses
= $E_{tf} + E_{tw}$
E_{tf} = evapotranspiration losses from forested area,
E_{tw} = evapotranspiration losses from water-logged area;
O_g = sub-surface outflow from the study area;
S_e = effluent seepage to rivers; and
ΔS = change in ground water storage, positive for increase and -ve for depletion.

The estimation of the various inflow and outflow components and the methodology adopted for estimating each ground water balance component are discussed below.

4.4.1.1 Draft from Ground Water (T_p)

Draft is the amount of water lifted from the aquifer by means of various lifting devices. The withdrawal can be made by means of (i) Deep tubewells, (ii) Shallow tubewells, (iii) Pumping sets, (iv) Rahats and other means. An inventory of wells and sample survey data are prerequisites for computation of ground water draft.

The yearly draft is computed by multiplying unit draft with the number of devices. Seasonal draft values for monsoon and non-monsoon seasons have been taken as 20% and 80% of the yearly draft values.

The existing groundwater draft is worked out by considering the number of existing wells and adopting the probable draft in the study area.(on the basis of sample survey conducted by the state government Mines and Geology department of Karnataka State).

4.4.1.2 Evapotranspiration Losses (E_t)

Evapotranspiration is the amount of water loss by evaporation and that transpired through plants for a certain area. When this evapotranspiration is from an area where the water table is close to the ground surface, the evaporation from the soil and transpiration from the plants will be at the maximum possible rate i.e. at potential rate. This potential evapotranspiration will take place in a water-logged tract due to the rise in the water table or the forested or other tree vegetation area which has the roots extending to the water table or upto the capillary zone. The evapotranspiration from such area can be worked out by usual methods of computing evapotranspiration using the known data. In the present study area, the evapotranspiration losses from forested areas (E_{tf}) has been estimated by the total area covered by the forest area and pan evaporation value. From the observed water level data, the depth to water table below ground level is less than 2.0 metre throughout the study area has been considered as under water logged for the evapotranspiration loss (E_{tw})due to water logging.

4.4.1.3 Effluent and Influent Seepage (S_e and S_i)

The aquifer and stream interaction depends on the transmissivity of the aquifer system and the gradient of the water table in respect to the river stage. Depending upon the gradient, either aquifer may be contributing to the river flow (effluent) or river may be recharging the aquifer (influent).

For estimation of effluent or influent flows, all rivers coming in the study area have been divided into a number of small reaches and computations made for each segment. For every reach, at least one observation station nearest to the middle of the reach has been selected. The hydraulic gradient is computed as the ratio of the difference between the river stage at the point where the normal from the observation well meets river and the water level in the observation well, to the distance between the points under reference. Similarly observation wells are taken on the other side of the river and the hydraulic gradients computed.

The effluent or influent seepage can now be estimated as:

$$S_e \text{ (or } S_i) = \Sigma T \ I \ \Delta L$$

where, T is transmissivity, I is the hydraulic gradient and ΔL is the length of the reach. By considering sign of the gradient the influent and effluent seepages has been estimated over the entire reach for all the rivers coming in the area.

4.4.1.4 Sub-surface Inflow and Outflow (I_g or O_g)

Sub-surface inflow and outflow is governed mainly by the hydraulic gradient and the transmissivity of the aquifer. The whole boundary is divided into small segments and the gradient of water table calculated by using the ground water levels near the boundary for each segment. Net flows are calculated for each segment by using the relationship;

$$I_g \text{ (or } O_g) = T \ I \ \Delta L \text{ in which,}$$

T is the transmissivity, I_g (or O_g) is the discharge passing through a particular segment, I is the gradient and ΔL is the length of the segment concerned. Thus to get the total discharge passing across the study areas boundaries, the discharge values for each segment are summed up. Thus;

$$I_g \text{ (or } O_g) = \Sigma \ T \ I \ \Delta L$$

4.4.1.5 Recharge from Canal Seepage (R_c)

Seepage refers to the process of water movement from a canal into sub-surface strata. Seepage losses from surface water bodies often constitute a significant part of the total recharge to ground water system. Hence, it is important to properly estimate these losses for recharge assessment to ground water system.

The data related to running days in monsoon and non-monsoon seasons for canals in the study area are not available for the study area. The recharge from canal seepage in monsoon and non-monsoon seasons has been estimated as 10 per cent of the total water release in the canal in the respective season.

4.4.1.6 Recharge from Field Irrigation (R_i)

Water requirements of crops is met, in parts, by rainfall, contribution of moisture from the soil profile, and applied irrigation water. A part of the water applied to irrigated fields for growing crops is lost in consumptive use and the balance infiltrates to recharge the ground water. Infiltration from applied irrigation water, derived both from ground water and surface water sources, constitutes one of the major components of ground water recharge. For a correct assessment of the quantum of recharge by applied irrigation studies are required to be carried out on experimental plots under different crops in different seasonal conditions.

(a) Recharge from surface water irrigation (R_{rs})

Recharge from surface water irrigation has been taken as 20 percent of water delivered for application in the field. Data of irrigated areas in monsoon and non-monsoon seasons are available for the study period.

(b) Recharge from ground water irrigation (R_{rg})

Recharge from ground water irrigation has been taken as 40 percent of the water delivered (i.e 40 percent of the ground water draft).

4.4.1.7 Recharge from Reservoirs and Tanks (R_t)

Study have indicated that seepage from tanks varies from 9 to 20 percent of their live storage capacity when there is data on live storage capacity of large number of tanks available. The seepage from the tanks may be taken as 44 to 60 cm per year over the total water spread. If monthly water level data for tanks are available for the study period, the corresponding water spread areas may be estimated from area-elevation curves available. Then the monthly recharge values are computed by multiplying the seepage factor with the water spread areas. However no recharge due to tanks in this study considered as there is no data available in respect of tanks in the study area.

4.4.1.8 Change in Ground Water Storage (ΔS)

The change in ground water storage is an indicator of the long term availabilities of ground water. The change in ground water storage between the beginning and end of the non-monsoon season indicates the total quantity of water withdrawn from ground water storage, while the change between the beginning and end of monsoon season indicates the volume of water gone into the reservoir. During the monsoon season, the recharge is more than the extraction and hence the ground water storage increases, which can be utilised in the subsequent non-monsoon season.

To assess the change in ground water storage, the water levels are observed through a network of observation wells spreaded over the study area,. The water levels are normally highest immediately after monsoon in the month of October or November and lowest just before monsoon in the month of May or June. The change in ground water storage can be computed from the following equation.

$$\Delta S = \Sigma \Delta h \; A \; Sy$$

where

ΔS = change in ground water storage

Δh = change in water level

A = area influenced by that well and

Sy = specific yield.

In the present study, premonsoon and post-monsoon water level data are made available for the study period. Thiessen polygons have been drawn for the observation wells and the change in ground water storage in monsoon and non monsoon seasons were estimated by using the above relation. The values of specific yield has been used as provided concerned authority.

4.4.1.9 Recharge from Rainfall (R_r)

Part of the rain water that falls on the ground, is infiltrated into the soil. This infiltrated water is utilised partly in filling the soil moisture deficiency and part of it is percolated down reaching the water table. This water reaching the water table is known as the recharge from rainfall to the aquifer.

For the monthly rainfall data in the study area Thiessen polygons may be drawn and mean seasonal rainfall values are computed for the study period.

The methods for estimation of rainfall recharge involve the empirical relationships established between recharge and rainfall developed for different regions. Nuclear methods can also be employed to assess the rainfall recharge. However, in the present study, the recharge to ground water from rainfall is estimated by water balance approach. In this approach, all the components of water balance equation other than the rainfall recharge, are estimated using the relevant hydrological and meteorological information. The rainfall recharge for monsoon season is calculated by substituting these estimates in the water balance equation. Recharge coefficient i.e. recharge per unit rainfall is thus estimated. Since most of the rainfall occurs in the monsoon season only, it is assumed that in non-monsoon season all the rain water is used by crops and absorbed in the soil moisture zone with no recharge to ground water reservoir. Hence the recharge from rainfall has been taken as zero in the non-monsoon season. The table 4.4.1.9.1 shows the groundwater balance and its components for the study area from 1988-89 to 1993-94 with reasonable accuracy except a few years. The average rainfall recharge coefficient is found to be 9.0 per cent. The total groundwater recharge from recharge components has presented in the table 4.4.1.9.2. using estimated rainfall recharge coefficient from the groundwater balance approach.

4.5.0. WATER QUALITY OF THE STUDY AREA

The water quality data in respect pH, Electrical conductivity and Total dissolved solids, Calcium, Magnesium, Carbonates Bicarbonates and Sulphates have been collected for both canal water and groundwater from the State Agriculture department of Karnataka Government for the study area.

If we want to know the data of water quality, how big, diverse and symmetrical are they? , it can be found by the statistical measure mainly standard deviation and coefficient of skewness irrespectively. However, in this case , data available only for two years and it could not be any statistical analyses or trend analyses of water quality of the study area over the years. Analysed water quality parameters has been presented in the table 4.5.1 and 4.5.2.

The water quality has been checked for the above said parameters for the suitability of it's potability and irrigation purposes.

4.5.1 pH value of the study area

The pH value of water is a measure of hydrogen in concentration of the water sample. It may be noted that the pH of natural water is 7, acidic is less than 7, and alkaline water is more than 7. The pH value of the study is varying between 7.5 to 8.9.

Table.4.4.1.9.1 GROUNDWATER BALANCE OF THE STUDY AREA

ASSUMED SPECIFIC YIELD : .025
ALL UNITS IN MCM

GW BALANCE COMPONENTS	8889		8990		9091		9192		9293		9394	
	MN	NMN	MN	MNM	MN	NMN	MN	NMN	MN	NMN	MN	NMN
I. DISCHARGE COMPONENTS												
1. Groundwater Draft	.83	1.17	.85	1.19	.87	1.21	.88	1.24	.90	1.26	.92	1.29
2. ET Losses :												
i. Forested Area ;	14.11	30.33	13.55	26.95	13.00	27.85	12.21	29.51	14.32	28.00	14.49	27.37
ii. Water logged ;	35.28	47.40	27.10	44.92	26.00	49.31	22.89	67.63	35.79	43.75	32.61	45.61
3. Net Outflow	25.00	20.00	25.00	20.00	25.00	20.00	25.00	20.00	25.00	20.00	25.00	20.00
A. Total Discharge = 1+2+3 :	75.23	98.90	66.50	93.07	64.88	98.37	60.98	118.38	76.01	93.01	73.02	94.27
II. RECHARGE COMPONENTS												
4.Recharge from Canal Seepage Loss :												
a. Canal and Distribution ;	10.09	14.92	10.90	15.17	10.26	19.73	9.96	22.28	14.36	17.78	11.98	16.41
b. Surface water Irrigation ;	40.37	59.69	43.59	60.66	41.02	78.92	39.85	89.14	57.44	71.13	47.91	65.62
c. Groundwater Irrigation ;	.33	.47	.34	.48	.35	.48	.35	.50	.36	.50	.37	.52
d. Reservoir and Tanks ;	2.00	3.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	3.00
5. Net Influent Seepage :	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
B. Total Recharge = 4+5:	52.79	78.08	56.83	79.30	53.62	102.14	52.17	114.92	74.16	92.42	62.25	85.54
6. Change in Groundwater Storage ;	12.20	-12.66	9.76	-17.39	9.45	4.88	5.80	6.10	6.71	-7.63	11.89	-14.79
7. Rainfall ;	344.44	33.84	192.09	83.69	322.68	62.99	185.68	62.04	100.13	111.11	238.44	74.62
8. Recharge from Rainfall = 6+A-B;	34.63		19.43		20.71		14.61		8.56		22.66	
9. Recharge Coefficient = 8/7;	.10		.10		.06		.08		.09		.10	
10. Unaccounted Water = B-A-6;		-8.16		3.62		-1.11		-9.56		7.03		6 0

Table No: 4.4.1.9.2 Recharge components of the Study Area (in MCM)

	8889		8990		9091		9192		9293		9394	
RECHARGE COMPONENTS	MN	NMN	MN	MNM	MN	NMN	MN	NMN	MN	NMN	MN	NMN
Canal and Distribution	10.09	14.92	10.90	15.17	10.26	19.73	9.96	22.28	14.36	7.78	11.98	16.41
Surface water Irrigation	40.37	59.69	43.59	60.66	41.02	78.92	39.85	89.14	57.44	71.13	47.91	65.62
Groundwater Irrigation	.33	.47	.34	.48	.35	.48	.35	.50	.36	.50	.37	.52
Reservoir and Tanks	2.00	3.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	3.00
Recharge from Rainfall	34.63		19.43		20.71		14.61		8.56		22.66	
Total recharge	83.79	85.13	74.11	86.83	82.66	107.81	68.88	120.50	83.17	102.42	83.70	92.25

Table:4.5.1 Groundwater Quality of the Study Area

Sl No	Well Location	Date	Ca	Mg	Na + K	HCO_3	CO_3	Cl	Fl	NO_3	SO4	TDS	Hard ness	pH
1	Yerdona	10.1.84	42	1021/2	86	10	338	-	-	18	74	630	420	7.70
2	Karatgi	10.1.84	31	50/1	130	19	142	-	-	15	48	470	288	7.90
3	Siddapur	3.1.84	114	55	93/2	288	24	134	-	-	242	900	508	8.40
4	Hirebenkal	23.1.82	64	19	49/1	317	5	30	-	43	3	549	240	7.65
5	Siddapur	19.8.80	27	7	181	407	40	40	-	-	2.5	495	96	7.80
6	Gangawathi	28.10.94	160	30	248	368	28	294	-	30	220	1190	520	8.10
7	Chikbenkal	16.9.94	27	51	223	436	91	148	-	-	35	805	272	8.55
8	Rampura	16.9.94	102	44	86	281	308	168	-	28	125	685	432	8.25
9	Chikbenkal	06.09.94	48	20	95	312	19	73	-	15	-	430	200	7.95

(Source: Department of Mines and Geology, Karnataka)

Table: 4.5.2 Surface water quality of the study area

Sl No.	Distributary	EC dS/m	pH	Na^+	Ca^{2+}	Mg^{2+}	CO^{3-}	HCO_3^-	Cl^-	SO_4^{2-}	SAR $(m.mol/l)^{1/2}$	RSC (me/l)
1.	1 (LBC)	2.7	8.1	8.5	16.3	5.2	2.0	2.0	18.7	3.3	8.1	8.6
2.	2 (")	0.4	8.6	1.2	2.0	1.3	1.9	1.0	1.9	0.0	1.1	0.3
3.	3/A	6.4	7.5	26.0	2.5	6.3	3.4	2.9	32.6	2.2	12.3	-2.5
4.	5(")	0.9	8.4	8.7	1.8	3.5	1.9	1.0	1.9	0.0	5.4	2.4
5.	10/10A (LBC)	0.6	8.7	1.8	2.1	1.9	1.9	1.1	2.2	0.0	5.4	2.4
6	10A (LBC)	4.6	8.5	44.0	0.9	1.8	4.8	9.8	9.1	30.6	37.0	11.9
7.	11 (")	0.5	8.6	2.9	1.5	1.4	2.0	1.9	2.8	1.7	2.5	1.0
8.	11 (")	0.5	8.6	2.9	1.6	1.8	1.9	1.9	2.6	0.4	2.2	0.3
9.	16 "	0.7	8.7	3.0	1.2	2.7	1.9	3.3	2.6	0.1	1.5	1.3
10.	16 "	0.6	8.7	3.0	1.2	2.7	1.9	3.3	2.6	0.1	2.1	1.3
11.	18 "	0.4	8.9	0.0	1.5	1.3	1.0	2.0	0.8	0.0	-	0.2
12.	19 "	0.8	8.9	4.6	0.7	4.2	3.2	1.9	3.3	2.6	3.1	0.2
13.	21 "	0.7	8.5	4.7	1.1	1.1	2.5	3.5	2.5	0.0	4.7	3.8
14.	25 "	2.3	8.2	18.9	0.9	2.4	3.5	4.1	9.4	6.4	8.6	3.5

(Source: University of Agricultural Sciences, ARS, Gangavathi)

4.5.2 Electrical Conductance

The ability of a cube of one centimetre side water to conduct an electrical current is called specific electrical conductance or electrical conductivity. The relationship between conductivity in micromhos/cm and TDS ppm TDS = 0.64 micromhos/cm (Hart Bary T. 1974). For rainwater, conductance vary from 5 to 20 micromhos/cm for ocean water varies from 45,600 to 55,000 micromhos/cm.

In the present study the conductivity of groundwater and canal water samples range from as low as <u>150</u> micromhos/cm to 1859 micromhos/cm.

4.5.3 Total Dissolved Solids

It is an indicator for the total solid present in the water. The presence of total dissolved solids in the collected samples over study period range from <u>221</u> to 1190 PPM.

4.5.4 Calcium(Ca)

Calcium occurs in calcareous rocks, such as lime-stone, dolomite, gypsum and basic igneous rocks. Because of it s wide spread occurrence in rocks and soils and its ready solibility, calcium is resent in nearly all waters. Calcium causes most of the hardness and scale formation properties of water. Analysed samples for calcium in the study area is in the range from 0.9 to 160.0 ppm.

4.5.5 Magnesium(Mg)

The common sources of magnesium are dolomite, olivine, serpentine, talc etc. They also occur in conjunction with calcium minerals. Calcium and magnesium causes most of the hardness and scale formation properties of water. The presence of the magnesium in the range of 1.1 and 1021 ppm.

4.5.6 Sodium(Na)

The primary source of most sodium in natural water is the weathering of plagioclace feldspars. Ancient brines, sea water, industrial waste and sewage may add some sodium. All natural water contain measurable amounts of sodium. Actual concentration of the study area range from about 0.8 ppm to about 248ppm.

4.5.7 Potassium(K)

Potassium is derived during the process of weathering of rocks. Potassium is commonly less than one tenth of concentration sodium in natural water. All natural water contain measurable potassium. Result from tested samples of the study area range from 0.0 to 2.0ppm.

4.5.8 Chloride(Cl)

Chloride is the main constituent of the earth's crest, but a major dissolved constituent of most natural waters. Usually, water high in chloride is also high in sodium. Chloride contents varies between 0.1ppm in arctic snow and 1,50,000ppm in brines. Shallow groundwater in regions of heavy precipitation generally contains less than 300ppm of chloride. Concentration of 1000ppm or more are common in groundwater. 0.8 to 294ppm is the range of values for analysed samples in the study area.

4.5.9 Sulphate(SO_4)

Sulphur occurs in water largely in oxidised form of sulphate. It may also be present as sulphide. In the present analyses, sulphate is found in the samples from 0.1 to 242ppm.

4.5.10 Nitrates(NO_3)

Although rocks contain small amounts of nitrates, most nitrate in natural water come from organic sources or from industrial and agricultural fertilizers. Nitric oxides produced in atmosphere by lightning discharges are added in the form of nitrate to water. Normal water contains only 0.1 to 10.0 ppm of nitrate. Nitrate compounds are highly soluble and encourages the growth of primitive plants. Concentration in the nitrate in the study area is about 15ppm to 43.0ppm.

4.5.11 Hardness

Hardness is conventionally considered to be the quality of water which normally destroys the property of soap to form lather. Hardness is mainly due to the presence of calcium and magnesium compounds. Usually in the form of bicarbonates, sulphates and chlorides. Hardness determinations are usually reported as, total hardness, carbonate hardness, non-carbonate hardness.

Carbonate hardness is caused by soluble bicarbonates of Ca and Mg and can removed by precipitation of these salts by boiling. Non-carbonate hardness is caused by dissolved salts of Ca and Mg (other than bicarbonate) and other minor constituents. This part of hardness cannot be removed by boiling. Total hardness is formed in the range of 96 to 520 ppm in the study area.

5.0 RESULTS AND DISCUSSIONS

The analysis of rainfall trend over study area has been carried out by annual departure analyses and probability analysis of rainfall. The study area recorded annual rainfall deficit of the order of 50% in the year 1985 and 1989. The range of rainfall group for the study area which have a probability occurrence of 75% or more probability of getting rainfall in the group range of 450-500 mm. The probability of occurrence of rainfall equivalent to 75% of normal rainfall in the study area is only 89 per cent. Rainfall over the years ranges from 1075mm to 288mm with standard deviation 166.86. The symmetry of the rainfall pattern is +0.573 with variability +0.287. The normal annual rainfall is estimated to be 582.0mm. However the study area receives 12 per cent of rainfall from January to May, 83 per cent from June to October and 5 per cent from November to December. The overall situation of the rainfall in the study area is dependable and can be considered as good.

Since the groundwater is recharged mainly through precipitation and surface irrigation, the over-irrigation year after year has led to increase in the groundwater level. The increase in trend of groundwater level shows in those wells which are close to canal and natural streams especially in the head reaches and middle reaches of the command. Apart from these indications, over the study period, the groundwater level has reached a saturation level as it can be seen from the figure 4.2.2.1 to 4.2.2.11. Well No.1, 7, 8, which are very close to main canal and having rising trend of water table. Well no. 10 and well at Siddapur which are very close to natural stream and it has trend of rising water table. Well no. 23, 34, and 39 are at the tail end is having lowering trend of water table. It is also noticed that irrespective of recharge and exploitation situation, groundwater regime attains the same level after the monsoon. This is due to the limited storage capacity of the granite aquifer compared to the recharge potential of the command area. The local topographic situation and the aquifer characteristics govern the groundwater levels during post-monsoon period in such situations. This kind of trend is seen especially in the head reaches and middle reaches.

The mean ground water level trend of the study area shows a little decrease in trend. The built up of groundwater table is taking place only in the head reach and middle reach where as water table is decreasing in the tail end region.

The water table has been built up in the head reaches and some part of the middle reaches. It is observed that even in premonsoon (April-May) the water table lies below 2 to 3 metres from the ground level.

The indication from figure 4.2.3.1 to 4.2.3.11 is that, there is a little decreasing trend of groundwater levels or water logging in the tail ends of the command area. However, head reaches and middle reaches have increasing trend of groundwater level or water logging area which was inferred also from the groundwater trend analyses.

The principal crops grown in the area are rice, sugarcane, groundnut, cotton, sunflower, garden crop and pulses . Crop water requirement has been estimated from year 1984-85 to 1993-94 separately for the kharif season and rabi season. The efficiency of the irrigation are 60 per cent during respective years.

The irrigation water requirement for paddy crop in the Kharif season is estimated as 188 cm to 231 cm at 60 per cent efficiency. With the same efficiency, irrigation water requirement for the rabi season is found to be in the range of 260 cm to 299cm. The crop water requirement for sugar cane in kharif season is 24cm to 61cm and 130 to 164cm in the rabi season. In other words total water requirement is in the range of 154cm and 225cm. The irrigation water requirement has been estimated for the groundnut crop and is found to be in the range of 10 to 46cm in the kharif season and for rabi 75cm to 99cm, and for pulses, it is 0 if there is a good amount of rainfall, however under the worst condition of rainfall, upto 25cm is required. In the rabi season, irrigation water requirement is in the range of 34cm to 50cm. Irrigation water requirement for cotton is estimated 2cm to 45cm in kharif period and for rabi 40cm to 67cm(total is from 42cm to 112cm). Demand of sunflower crop is in the range of 14 and 74cm for kharif and for rabi crop 38cm to 63cm. Garden crop which requires 37cm to 74cm for the kharif period and 148cm to 185cm for the rabi period. However, the total crop water requirement is from 185cm to 259cm.

The average annual crop water requirement or delta at 60 per cent efficiency for the existing cropping pattern is in the range of 1.9m to 2.6m. The monthly canal release and monthly crop water requirement presented in·the table 4.3.3.1. The monthly crop water requirement shows that maximum from January to May and minimum during October and November. The irrigable area corresponding to estimated monthly delta of the cropping pattern with the actual monthly canal releases are in the range; June: 0.0 to 1460 km^2, July: 236.0 to 706.0 km^2, August: 199.0 to 1389.0 km^2, September: 261.0 to 1160.0 km^2, October: 258.0 to 1092.0 km^2, November: 434.0 to 2953km^2, December: 67.0 to 418.0 km^2, January: 206.0 to 331 km^2, February: 106.0 to 300.0 km^2, March: 101.0 to 171.0 km^2, April: 29km^2, to 186km^2 and May: 0 to 49km^2. These results highlighting the arbitrary release of canal water irrespective of the demand in the command area agianst the 49 per cent of the command area under development.

The recharge coefficient has been estimated from groundwater balance approach of the study area and is found to be 9.0 per cent. The total recharge from different groundwater balance components from 68MCM to 84MCM for monsoon season and 81MCM to 120MCM for non-monsoon season. The recharge from surface water irrigation in the range of 39MCM to 57MCM for monsoon and 59MCM to 89MCM, canal seepage loss for monsoon is 9MCM to 14MCM, where as non monsoon loss varies from 14MCM to 22MCM. The major part of recharge taking place from these two components. However, groundwater draft is very negligible. The main discharge of the study area taking place via evaporation due to waterlogging. It is in the range of 22MCM and 36MCM for the monsoon and for non-monsoon is in the range of 43MCM to 62MCM. The above result calls an urgency for reducing the evaporation loss especially in the head reaches and middle reaches of the study area by lowering down the water table.

The water quality for potability is judged on the basis of the standard for physical and chemical qualities of water for drinking purpose, by the recommendation of World Health Organisation (WHO) and Public Health Engineering Department(PHE) of India as given in the table 5.1. Based on the salinity classes C1, C2, C3, & C4 and its irrigation suitabilities are given in the table 5.2. The quality of the ground water is found to be good. No hazardous constituents are found for domestic or irrigation purposes. The groundwater is fit for direct use and need for mixed water management or treatment of water is not required before either for domestic or irrigation use.

CONCLUSIONS

The analyses of geohydrological data of the study area shows that, there is an 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 inter-relationship 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 head reaches and middle reaches. The following measures may be adopted for the proper and productive utilization of surface and subsurface water resources conjunctively:

Table: 5.1.0 Standards for Physical and Chemical of Potable Water

	International Standards Reccommended by WHO		Recommendation of the PHE Committee of Govt Of India	
	Maximum acceptable concentration	Maximum Allowable limit	Permissive	Excessive
(1)	(2)	(3)	(4)	(5)
PHYSICAL:				
Turbidity	5	25	5	25
Colour(Units on platinum Cobalt Scale)	5	50	5	25
Taste and Odour	Unobjectionable		Nothing disagreeable	
CHEMICAL:				
pH range	7-8.5	Less than 6.5 or greater than 9.2	7-8.5	Less than 6.5 or greater than 9.5
Total solids (ppm)	500	1500	500	1500
Total hardness (ppm)	-	-	300	600
Calcium(Ca) (ppm)	75	200	75	200
Magnesium(Mg) (ppm)	50	150	50	150
Chloride(Cl) (ppm)	200	600	250	1000
Sulphate(SO4)	200	400	250	400
Nitrate(ppm)	-	45	2 50	

Table 5.2 WATER QUALITY FOR IRRIGATION USE

Sl. No.	Conductivity (micromhos/cm)	Quality	Irrigation Use
1.	Less than 250(C1) (low salinity)	Entirely safe	Can be used for Irrigation for almost all crops and soils
2.	250 to 750(C2)	Safe for most soils	Can be used, if a moderate amount of leaching occurs. Normal salt tolerant plants can be grown without such salinity control.
3.	750 to 2250 (C3)	Safe if soils are permeable or are rendered permeable by leaching techniques	Cannot be used on soils with restricted drainage. Only high salt tolerant crops can be grown.
4.	Greater than 2250 (C4) (Very highly saline)	Unsuitable	Generally not suitable for irrigation.

1. Canal release should be on the basis of actual cropwater requirement depending on the existing cropping pattern.

2. The cropping pattern may be changed to reduce the surface water irrigation where the area is prone to get waterlogged.

3. Canal release may be regulated at sub-distributory level in accordance with the crop water requirement.

4. Tail end command area may fully irrigated by canal supply.

5. Open wells may be dug in the head reaches and middle reaches to develop subsurface water resources to avoid the surface water irrigation.

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