CS /AR / 2005-06

Artificial Recharge Studies: Identification of Potential Underground Reservoir in Tirupati Sandstone Formations

National Institute of Hydrology

Deltaic Regional Centre

Kakinada

2006

PREFACE

According to the sub committee on ground water management of committee on ground water and irrigation and drainage division of ASCE, the term 'ground water reservoir' (GWR) is a widely and loosely used to denote places where ground water is accumulated under condition that make it 'suitable' for 'development' and 'use'. According to them, GWR is an excellent term for general use and is parallel in concept to 'surface water reservoir' (SWR) as it conveys the concept of storing water.

The scale or level of artificial recharge towards water conservation i.e., individual or locality or watershed or basin is an important characteristic along with the purpose for which it is intended, i.e., domestic, agriculture or industrial and the method adopted i.e., natural or artificial. Every water resources system requires storage especially when its replenishment or supplies and diversions or uses are fluctuating or intermittent. Planning proper storage is a solution in such cases. In recent past, artificial recharge techniques are undertaken in 'as is where is basis' towards water conservation as proper planning is not done in advance to adopt such practices.

In uniform aquifers, such as sandstone, the water table is a smoothly contoured surface intersecting the ground at rivers and lakes. Water table is the top surface of a body of slowly moving ground water that fills the pore spaces within a rock mass. Above it lies the freely draining vadose zone, and below it lies the permanently saturated phreas. As groundwater development takes place unchecked in such potential aquifers and crosses the dynamic resource potential, the water table in sand stone aquifers gradually and continuously falls at about 3 to 4 m per year. The same is being experienced in most of the tertiary sand stone formations along the east coast since middle of 1980's. So such emptied aquifers can be best used as underground reservoirs by undertaking appropriate artificial recharge techniques. It will help in not only rejuvenate the aquifer but also to exploit the advantages of underground reservoirs. The objective is to conduct investigations in such formations and to identify potential sites for undertaking Artificial recharge measures to improve groundwater reservoirs in Sandstone / Lateritic formations. In this report analysis and results of the hydrological investigations taken up in the upland Tirupati sand stone aquifer are discussed.

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DIRECTOR

ABSTRACT

Variation in groundwater level has been analyzed to understand the process of groundwater recharge and its flow in upland Tirupati Sandstone Aquifer. The Deuterium and Oxygen-18 isotopes are used to understand the contribution of different recharge sources and also the most important groundwater recharge source for the study area. The present paper describes the ground water condition in the region and gives detailed account of stable isotope characteristics of the aquifer. The analysis presented the variation of local meteoric precipitation line with respect to groundwater line as δD vs. $\delta^{18}O$ plots for 2004 and 2005.

In this study a relationship is established to understand the characteristics of groundwater recharge in an upland sandstone aquifer with respect to rainfall. Studies and analysis of data for 15 villages illustrates that the ground water table has fallen to depths of about 30 to 50 meters below ground level in the area, which has about 2200 electric motors with an average installed capacity of 10HP capacity. It indicates that the area is underlain by a huge underground reservoir from which about 120 MCM of groundwater is withdrawn annually and need to be recharged artificially for the survival and development of those who depend on the success of this infrastructure.

Also, it is observed that the $\delta^{18}O$ values of the groundwater of the aquifer are changing from pre monsoon to post monsoon even at large depth indicating the porous nature of the aquifer and the presence of rainfall recharge in the aquifer. The results on spatial variation of the $\delta^{18}O$ values in the study are useful in identifying suitable locations for undertaking artificial recharge measures in the aquifer to supplement the natural recharge to groundwater aquifer. The suitability of upland aquifers for undertaking groundwater recharge is discussed for a sand stone aquifer from observed piezometer data.

The study of rainfall recharge in the study area during the wet rainy season of September and October 2005 indicated that on the average a daily rainfall of 17mm can yield in a rise of about 29 cm of groundwater level in the aquifer. This is a positive signature of the aquifer to take up appropriate natural or artificial water conservation measures. Such application undertaken at other upland areas may help in evolving suitable relationship of rainfall and recharge

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1.0 INTRODUCTION

Water conservation is the practice of preserving whatever available water for the best use of society. Its importance is known to us since ages, as ours is one of the famous and prosperous civilization in the world. All that is being said and done about water conservation is just to remind, recollect and revise such knowledge. Conservation is basically intended to meet the increased demand or value of water in rural and urban areas. Thus, all the available experience, data and scientific information about occurrence and distribution of rainfall, surface water and groundwater systems need to be considered to plan and adopt suitable water conservation practice, whether it is rain water harvesting to supplement surface water storage or recharge of groundwater. The scale or level of water conservation i.e., individual or locality or watershed or basin is also an important characteristic along with the purpose for which it is intended, i.e., domestic, agriculture or industrial and the method adopted i.e., natural or artificial. Every water resources system requires storage especially when its replenishment or supplies and diversions or uses are fluctuating or intermittent. Planning proper storage is a solution in such cases. In recent past, artificial recharge techniques are undertaken in ‘as is where is basis’ towards water conservation as proper planning is not done in advance to adopt such practices.

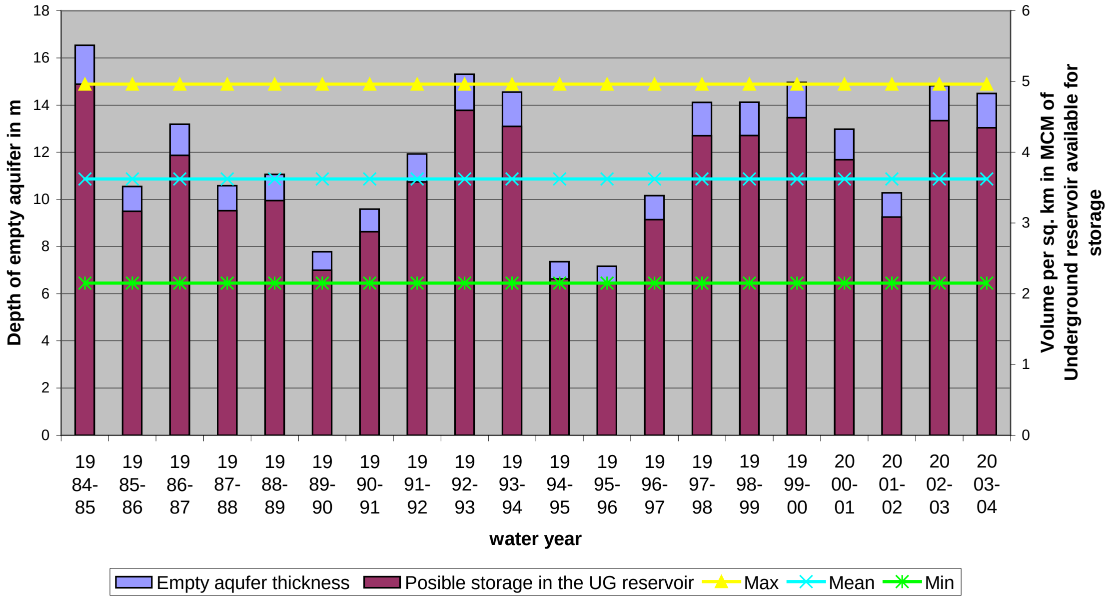
Since 1980s groundwater has acquired importance as its development and utilization has increased many folds for meeting the demands for the rapidly expanding urban, industrial and agricultural water requirements. A dried up large diameter dug well shown in Fig. 1. This resulted in continuous fall of groundwater levels due to which some of the well structures like open wells, shallow tube wells and some deep tube wells have to be abandoned as they dried up. This has caused great loss to the economy of such regions. If unchecked for or not restored many such regions may be under threat. Such water resources systems need to be restored by utilizing surplus floodwaters to supplement the dwindling storages especially when their replenishment is not possible or when natural replenishment is insufficient.

Groundwater can be more systematically exploited to the fullest extent with artificial recharge techniques. Therefore, ground water recharge is but one phase of the management of ground water basins. Generally artificial recharge means intentional replenishment of ground water bodies. It is a means of augmenting the natural infiltration of surface water into a ground water reservoir at a rate that vastly exceeds that occurring naturally. Most water resources development is related to the maximum use of storage either over ground in reservoir or underground water bodies. Surface reservoir being man made is restricted to the design capacity. Under most natural conditions, underground storage is more extensive and generally more conveniently located than the artificial surface storage. The former is also devoid of losses due to evaporation and has very less degree of quality deterioration due to pollution etc.

Fig. 1. A dried up dug well in a Upland Area

Artificial Recharge to groundwater basin is a solution to increase the natural supply of water to wells in aquifers where the water table is under continuous decline. It can be defined as augmentation of natural infiltration of rainfall or ponded water into underground formations. It can be undertaken by spreading of water or by artificially changing the natural conditions like recharging through pits, excavations wells and shafts or by pumping to induce recharge from surface water bodies. The actual design depends on the extent of empty underground reservoir and the aquifer characteristics of the formations and depends on local topographic geologic and soil conditions as well as the availability of water for recharge and the ultimate water use in such areas. It is well known how important it is to identify a suitable site for building a dam and forming a reservoir while planning and managing water resources of a basin. Even the best site has some disadvantages on the environment of the upstream and the down stream accompanied by rehabilitation and resettlement of the basin whereas the an underground reservoir can minimize such draw backs and help reduce construction of canal networks as the water is available every where in the aquifer system. The water temperature is regulated in underground reservoir and helps minimize evaporation losses. Thus it is necessary to take advantage of benefit of underground reservoir wherever it is feasible. Such underground reservoir have to be integrated as part of water resources planning in a basin so that the excess flood waters can be used to recharge the formations suitable for storage of water.

Fig 2 **Aquifer thickness at Kavali and potential storage in MCM per 10 sq km at Sy 3%**



In Andhra Pradesh, only about 14 percent of rural households have access to piped water schemes to meet drinking and domestic water needs. Most use water from tube wells or open wells, while a small minority use tanks and springs. Hence there is a high dependence on groundwater for drinking and other domestic purposes. Nearly 90 percent of rural households collect water from community sources, which are often remote and suggesting that a substantial amount of time and effort goes into water collection in rural AP. By 1993, only about 60 percent reported access to safe drinking water. Only 11 percent had these sources within their own premises (WHIRL, 2001). The rocks of Achaeans, Limestones, Quartzites and shales of Pre-

Cambrian and massive Deccan Traps are grouped together as consolidated hard rocks in Andhra Pradesh. Semi-consolidated sedimentary formations of Gondwanas, Intra and Inter trappeans, Rajahmundry Sandstones and the unconsolidated alluvium are termed as soft rocks. According to Sakthivadivel (2001), once a global picture and trends are identified, then more refined methodologies can be adopted to design the system up to an accepted level for local scale system, such as an irrigation system or sub-system level underlain within an aquifer system. In many a cases aquifers are anisotropic. This happens when the sediments of the aquifer are deposited such that the resulting porous medium has a higher permeability in one direction, usually horizontal, than in the other direction.

In the flat uplands of East Godavari district where the drainage is poor the Sand stone appears as out crop and extend to large depths of about 250 to 300 m. In the aquifer water table was falling at a rate of 3 m per year since 90's due to pumping and existing rainfall recharge is not able to arrest such a fall. As canal is under construction, the recharge processes in this deep aquifer are to be understood.

In uniform aquifers, such as sandstone, the water table is a smoothly contoured surface intersecting the ground at rivers and lakes. Water table is the top surface of a body of slowly moving ground water that fills the pore spaces within a rock mass. Above it lies the freely draining vadose zone, and below it lies the permanently saturated phreas. As groundwater development takes place unchecked in such potential aquifers and crosses the dynamic resource potential, the water table in sand stone aquifers gradually and continuously falls at about 3 to 4 m per year. The same is being experienced in most of the tertiary sand stone formations along the east coast since middle of 1980's. The thickness of empty aquifer in a laterite formation near Kavali during 1984 to 2004 and the potential storage possible in MCM is shown in Fig. 2. So such emptied aquifers can be best used as underground reservoirs by undertaking appropriate artificial recharge techniques. It will help in not only rejuvenate the aquifer but also to exploit the advantages of underground reservoirs. The objective of this study is to conduct investigations in such formations and to identify potential sites for undertaking Artificial recharge measures to improve groundwater reservoirs in Sandstone / Lateritic formations. In this study analysis and results of the hydrological investigations taken up in the upland sand stone aquifer are discussed.

2.0 REVIEW

In a proper aquifer, large volume of storage is available and according to Bear and Verruijt (1992), a storage of 15 MCM of water is possible in a portion of aquifer of 10 km by 10 km size, with a storativity of 15 % by rise of water table by one meter. According to Sakthivadivel (2001), once a global picture and trends are identified, then more refined methodologies can be adopted to design the system to accepted level for local scale system, such as an irrigation system or sub-system level underlain within an aquifer system.

According to the sub committee on ground water management of committee on ground water and irrigation and drainage division of ASCE, the term 'ground water reservoir' (GWR) is a widely and loosely used to denote places where ground water is accumulated under condition that make it 'suitable' for 'development' and 'use'. According to them, GWR is an excellent term for general use and is parallel in concept to 'surface water reservoir' (SWR) as it conveys the concept of storing water. Traditionally, GWR where first encountered have been filled with water by nature, some times to over flowing condition ASCE (1987).

In many a cases aquifers are anisotropic. This happens when the sediments of the aquifer are such that when deposited the resulting porous medium has a higher permeability in one direction, usually horizontal, than in the other direction. Both sedimentation and stress produced by the material cause the flat particles to be oriented with their longest dimension parallel to the plane on which the formation lies. An inhomogeneous material composed of different textures is equivalent to its overall behavior to an homogeneous anisotropic porous medium (Bear, 1972), provided the thickness of individual layers is much smaller than the lengths of interest within the porous medium domain. The resistance of the layers governs the flow in vertical direction (recharge) (Bear and Verruijt, 1992). The layer of highest resistance, is important and not by hydraulic conductivity or thickness of individual layers as in horizontal flow.

In 1997 the European Union (EU) initiated an 'Integrated Water Resources Management System (IWRMS) project "INCO-DC, 1996" to prepare a decision support system for application in semi-arid regions which would assist in the identification and resolution of a number of topical issues faced by water resource managers. For the project, Taylor et. al. (2000) reported that the final product of the project is envisaged as being an "innovative computer based toolset designed as an assembly of tested, validated and well documented procedures comprising techniques of database management, remote sensing, aerial photograph interpretation, GIS analyses, process modelling, Graphical User Interface (GUI) and GIS-based decision support”.

Advances in information technology, including GIS and satellite hydrology, provide improved methods for hydrologists, planners, agronomists and decision makers dealing with watersheds and river basins. According to experts, Numerical simulation modeling, geo-statistics and GIS are indispensable technologies for spatial characterization of water resources in terms of all the important attributes. The effective application of GIS as a spatial analysis tool requires further research in order to produce more useful information for catchment management without necessarily having to perform more basic measurements. The recent developments in GIS augur a good sign to understand the regional and basin level variability of groundwater situations. Once the global picture and trends are identified, then one can use a more refined methodology to track down the variables to acceptable level of accuracy at a local scale such as an irrigation system or sub-system level underlain with an aquifer (Sakthivadivel, 2001). According to Oki (2003), many international organizations will have to play a pro-active and supporting role in the endeavor to promote and use of RS and GIS technologies. Karanjac (1995) quoted that billions of cubic meters of water could be available for various developments if information gaps were filled and provided by application of GIS and information systems. Combining hydrological models with GIS can link remote sensed data on land use/land cover, soils, weather and hydrology to topographic location and GIS has emerged as an extremely effective tool for analyzing and prioritizing natural resource management alternatives (Luijten, 1999). Prinz (2002) applied RS and GIS to determine areas suitable for water harvesting for dry land agriculture.

The unsaturated zone ranges in thickness from zero in very humid region to hundreds of meters in arid region. In addition the thickness varies temporally depending on environmental conditions such as climate. A capillary fringe of meters thickness is subtended below unsaturated zone and over the saturated zone or the aquifer. Water to the unsaturated zone is added from the surface as precipitation. This water percolates or drains downward into the soil to depths determined by factors such as amount of water and its time, the particle size distribution the type of material, extend and type of vegetation, antecedent soil moisture condition and temperature etc. Water may also enter the unsaturated zone by lateral flow caused by gradients in water potential. Further water may be available in the unsaturated zone via the capillary fringe above the saturated zone. Processes such as evaporation, evapotranspiration, lateral outflows, deep infiltration and some downward diffusion of water vapor remove the water in unsaturated zone.

In most arid regions soil water is recharged by occasional precipitation events. Most of the precipitation infiltrates into relatively dry soil while evaporation and transpiration depletes the soil water content. If the infiltrating water is greater than that transpired deep downward or lateral percolation happens. If the unsaturated zone is thin or the percolation rate is high the recharge rate will approach the rate of percolation over a long time periods. However, the unsaturated zone is very deep and the percolation rates are low, then the recharge rates may be out of time phase with current near surface conditions. In such cases it is important to differentiate between measurements of deep percolation in the unsaturated zone and estimates of recharge at the water table. Thus simple measures of infiltration or percolation rate do not necessarily represent the aquifer recharge rate.

The extent to which infiltration contributes to the recharge is determined by the time during which the water remains with in the surface layer. Most rainfall penetrates only the top few meters of unsaturated zone from where it is systematically removed by the efficient arid zone vegetation and by soil evaporation following capillary rise. Rarely a major event penetrates beneath the root zone. Advecting solutes along with the waterfront. For areas shallow water table the infiltrating water reaches the water table quickly causing rapid fluctuations in the water table. In areas of deep unsaturated zones even extreme events do not result in sufficient water entering the soil to significantly alter the water content of the whole profile, and the recharge front slows down as its water supply is exhausted. The result is that recharge velocity reaches a nearly constant value equal to the long-term mean recharge averaged across a period that increases with increase in depth.

Soils hydraulic conductivity i.e the ability of unsaturated soil to conduct water is directly related to its water content and size of pores. At saturation soils have highest hydraulic conductivity as soil dries the larger pores empty first, causing the hydraulic conductivity to decrease in an exponential manner (Gardner 1958). Thus a decrease in water content by only a few percent can produce a ten fold or hundred fold decrease in hydraulic conductivity. Therefore, the very low water content found in the subsoils of vegetated areas in warm and arid regions suggest very low hydraulic conductivity and correspondingly lower recharge rates.

Recent opinion is that virtually all precipitation falling in arid regions was utilized by plants with extensive root systems. This is because of evapotranspiration exceed precipitation on an annual basis. Mann (1976) stated that there is no direct recharge by rainfall through the vadose zones of arid region. Falconar et all (1982) stated that in regions where evaporation and runoff exceeds precipitation solutes are retained in vadose zone. Further, Lysimeter data from a arid regions in Washington and New Mexico demonstrated that the potential for vegetation to remove soil water for deep percolation in bare sandy soils ranged between 10 % greater than 15 % of the annual precipitation (Gee et al 1994). However, numerous studies have documented flow through vadose zone (Allison 1983, Walker et al 1991, Wood and Sanford 1995, Phelps 1994) which suggests our previous understanding of water flux through the arid regions, vadose zones was limited.

There has been increasing interest in understanding and predicting the flow of water and solutes in arid and semi arid regions, the water supply demand of growing urban areas have focused attention on long term water supplies and thus mechanisms of soil water movement and groundwater recharge.

Isotope techniques

Isotopes are supplementary tools for hydrological investigations and need to be employed as an integral part of groundwater studies. Environmental traces are good tools to study the interaction between waters, i.e. precipitation, surface water, groundwater etc as part of the processes of hydrologic cycle. It is understood that all hydrogeologic, hydrochemical, hydrodynamic and isotopic interpretations have to be space and time related. Therefore, necessary steps have been taken to include the related aspects along with water sampling for isotopes as per the prevailing hydrogeologic conditions in a study area.

Stable isotopes are the atoms of an element, which are satisfied with the current arrangement of proton, neutron and electron. According to Clark and Fritz (1997), stable isotopes such as D and ^{18}O can be used as conservative groundwater tracers since their values remain constant as long as there is no phase change or fractionation along flow path. The concept that the hydrological cycle system can be viewed as a global distillation column of waters fed by evaporation from the ocean as moisture which condenses as a result of cooling of air masses as it rises to higher levels. The degree of depletion of heavy isotopic water species of hydrogen and oxygen is correlated in the residual waters, provided equilibrium exists between the condensed phases and the vapors at all times. For stable isotopes, their differences in isotopic species in water play an important role in the variation that is observed in the atmospheric water cycle by promoting fractionation effects during vapor/liquid and vapor/solid phase changes. Thus, isotope fractionation occurs at each phase change except sublimation and melting of compact ice.

Dansgaard (1964) described in detail the process of formation of stable isotopes in Precipitation. Munnich (1968) has studied the moisture movement and recharge using isotope techniques and prepared guidelines for IAEA. Nair et. al. (1979) conducted groundwater recharge studies in Maharashtra using isotope techniques. Athawale et. al. (1980) estimated recharge to the phreatic aquifers of the Lower Maner Basin, using the tritium injection method. Saxena (1984) studied seasonal variation of ^{18}O in soil moisture and estimated recharge in moraine formations. Bhandari et. al. (1986) conducted hydrogeological investigations in Sabarmati and Mahi basins and Coastal Saurashtra using radioisotope and chemical tracers. Singh and Kumar (1993) explained the process of soil moisture movement and questioned whether it follows piston flow, as believed.

Artificial recharge techniques

Artificial recharge techniques have been used throughout the world for more than 200 years for a variety of purpose. Occasions arise where it is desirable to artificially recharge water underground to stem the decline of water levels; to supplement existing supplies; to remove suspended solids by infiltration through the soil; to store cyclic water surpluses for use in dry periods; to prevent loss of land surface resulting from excessive ground water or oil exploration; to use the aquifer as a distributary system e.g. in densely populated areas recharge in one area and withdraw in another; to decrease the size of areas needed for water supply system to increase the stream flow; to inhibit sea water intrusion that threatens to ruin fresh water bore wells in coastal areas; to replenish an area where the draft of water from underground source far exceeds the water which is being recharged on a natural basis

Storage of water within the earth's crust is dependent upon geological process that have produced voids capable of absorbing, transmitting, storing and yield water. Voids are numerous in most earth materials. Some are large enough to transmit water freely, whereas others are so small that surface tension exceeds hydrostatic pressure and the transmission of water is prevented. Useful groundwater storage capacity is not measured by the porosity of the reservoir but by the amount of water that the reservoir will yield by gravity drainage. This is commonly termed as specific Yield. It is the difference between porosity and filed moisture capacity. Potential aquifers below the one of soil moisture are already at field capacity. Therefore, most of the recharge water either can be recovered or will move to natural discharge areas.

The success of an artificial recharge project may depend largely on its location. Because the physical and hydrologic characteristics of the subsurface deposits determine recharge rates, selection of a new site or an evaluation of an existing one requires detailed knowledge of the local geologic and hydrologic conditions. Sites underlined by highly permeable sand and gravel deposits have higher recharge rates than sites underlined by poorly permeable materials like silt and clay. Each recharge site poses a unique set of problems, that must be thoroughly investigated, when one considers the variation among (1) Soils (2) Physical and Hydrologic characteristics of subsurface deposits (3) Depths to ground water and (4) Chemical quality of raw water and reclaimed water in addition to all other factors that affect the movement of water into and through soils and underlying materials it is little wonder that no two recharge projects are likely to proceed in the same way.

Water used for recharge purposes is always surplus water that has already been used for some purpose, or water from high flow periods of river, which is not needed for use exactly at that season. Such water, if not stored in surface or underground water reservoirs, would just run down to the sea and be lost for beneficial use by man. The water commonly used for artificial recharge purposes include natural stream flow, high flow directed from a near by watercourse, or cooling waters. In some places storm drainage water has been collected and then allowed to infiltrate through basins or wells. Also, sewer effluent either treated or untreated has served a major source of recharge water. This seems more attractive both technically and economically because water that would normally flow to waste can be effectively treated by means of land disposal systems from where it infiltrates eventually to become ground water.

As part of natural hydrologic conditions, the water table is nearly parallel to ground surface and in equilibrium with natural recharge and with losses occurring by surface and subsurface outflows or by uses. Dead storage includes ground water that cannot be economically extracted and or is of inferior quality. After initial development by pumping, the water table is lowered and water in storage is decreased. Surface loss and non-beneficial consumptive use are substantially eliminated. Finally when the basin fully managed, natural recharge is augmented by artificial recharge and water table ranges within relatively wide limits depending upon the seasonal variation of recharge water and demands for pumped ground water.

Artificial recharge techniques may be divided into direct and indirect methods. Many operations include more than one method of recharging and the methods may grade into one another. Each has certain advantages and disadvantages. The selection of a method, as said earlier, is based on the consideration of several factors, viz, climate, topography, soil, geology, water quality, purpose of recharge quantity of water involved, cost, land use etc.

Artificial recharge includes a variety of methods such a as well or other specialized construction, water spreading or changing natural conditions,. Other than induced infiltration, the two major techniques of artificial recharge are surface spreading and injection wells, In surface spreading methods. Large areas of land may be flooded, basins constructed, ditches or furrows excavated or existing channels might be modified. Water is diverted into these catchments structures and allowed to infiltrate. Recharge or injection wells might consist of shallow, relatively large pits or shafts that permit direct access from the surface water source to the ground water reservoir, Geology , soils and its selection are much more critical for spreading or infiltration recharge systems than for well recharge system. Some of the artificial recharge techniques suitable for deep aquifers are mentioned here.

Recharge pits and shaft

Water spreading cannot be effective in areas where subsurface strata restrict the downward passage of water. Further from regional point of view, condition that might permit surface spreading methods for artificial recharge is relatively rate. In situations such as these artificial recharge systems must penetrate the less permeable strata in order to provide direct access to the dewatered aquifer. This may be accomplished with pits, shafts or well. These structures also permit construction of artificial recharge facilities in relatively small areas. Recharge pits are simply excavations of variable dimensions that are sufficiently deep to penetrate less strata. Construction and maintenance are relatively simple and generally in expensive. In many places abandoned gravel pits have served as recharge pits.

Unfortunately, pits used for storage or treatments of liquid wastes provide a significant source of inadvertent recharge, which lead to complete and widespread problem of ground water pollution. Example includes sewerage treatment lagoons, industrial waste holding or disposal ponds and oil field brine evaporation pits, to mention only a few of an exceedingly large number.

Recharge shafts are generally deeper and of smaller diameter than pits. Their purpose is also to penetrate low permeability layers. Shafts may be line or unlined, open or filled with coarse materials and larger or smaller. Commonly recharge shafts are used in conjunction with pits. Both pits and shafts suffer from decreasing recharge rates with time due to the accumulation of fine-grained materials and to the plugging effect through about by microbial activity. For this type of project provision should be made for rapid removal of silt from the bottom of the pit.

Rates through recharge pits may be maintained by periodically allowing the facility to become dry or by scarping and removing the accumulated materials from the sides and bottom. Shafts are easy to maintain owing to their smaller diameter and greater depth. In some cases the costly material used to fill the shafts must be replaced. The initial design cost of pit is generally small since the major facility required is conveyance system for delivery of water leading to the pit. Water is usually brought to the pits by means of a pipe, open ditch for chute. Although infiltration rates are high in sandy and gravelly material, relatively non-silty water should be used unless, provisions are made to provide for economical removal of silt from the pits. Shafts can be used only to a limited extent, unless silt free water is available. If storm water is to be recharged through shafts, provision for special facilities of silt removal need to be considered.

Recharge wells or injection wells

Recharge wells are used to tap deep aquifers. A recharge well may be defined as well which admits water fro the surface to the underground formations. In many respects they are similar to water supply wells except water is pumped into rather than out of them recharge wells are cased through the material over lying the aquifer and if the earth materials are unconsolidated a screen is placed in the well in the zone or injection. The purpose of the screen is to prevent the aquifer from caving into the bore hole and to permit access to the water bearing materials. In some cases several recharge well may be installed in the same bore hole.

A gauge sampling pipe, manometer, water meter shut off valve, compressed air connection, and discharge line and if possible a length of transparent pipe in the injection pipe complete the well accessories. In general, water cannot be recharged by free fall into the borehole because this technique will entrap air bubbles that subsequently become lodged in the pores of the aquifer and effectively clog them. Sometimes air bubbles shake the rock with explosive force, when they escape and destroy the rock. For these reasons the water should be conducted to an outlet, below the water level through a specially inserted column of pipe.

For economical as well as hydrogeological reasons it is advantageous to use extraction wells intermittently for recharge purposes. The simplest way is to inject water through the pump column and the pump, applying some breaking in order to keep the pump from turning. It has been found that hydraulic resistance in the pump restricts the injection rates to about two thirds of the discharging capacity of the pump and this practically secures the elimination of suction effects at reasonably high rate of injection. Alternatively the pump can be drawn and replaced by an injection pipe. In this way somewhat higher injection rates can be achieved and the rather remote possibility of damaging the pump can be excluded. On the other hand, the procedure is time consuming, some what risky and costly.

Another method being tried in Israel utilises the annular space, between the column and the casing for injection. This is done by means of the installation of a simple by pass or by replacing the pump by an injection cap. Injection can be carried out simultaneously through the annular space and injection rates can be stepped up to the limits imposed by the properties of the aquifer without pulling out the pump.

One effective system for recharge consists of drilling injection wells into the aquifer downstream from a dam. Water is then conducted from the spillway to the wells. The released rate or the number of wells is varied to contract the rate and movement of recharge. In areas of cavernous limestone and gypsum, recharge wells may be placed upstream from a flood water retarding or other structures. The intake should be well below the crust of principal spillway elevation but several meters above the bottom to aid in desilting. When compared to other techniques of artificial recharge, injection wells are generally both expensive to construct and to maintain. The major advantages lie in their ability to tap deep reservoirs and in the fact that space requirements are small. Except in very permeable reservoir their major disadvantage, other than the cost, is their tendency to become plugged by the accumulation of fine grained sediment in the aquifer adjacent to the well and the build up of slime brought out by the action of microbes. Thus water quality is a major control factor in the use of wells for artificial recharge.

3.0 METHODOLOGY

Identification of suitable underground reservoirs is very important for success of artificial recharge projects that are being undertaken as part of water conservation programmes by different state and central agencies. A number of RS approaches to delineate such potential areas from hydro-geological and other aspects are under practice and most of such areas are extensively demarcated and mapped already. Despite this, the success stories are limited.

In recent years the demand for storage, analysis and display of complex and voluminous resources data has led to the use of computers for data handling and the creation of sophisticated information system. Geographic Information System (GIS) is a new technology, which is becoming an essential tool for analysis and great diversity of data (spatial and non-spatial) in a short time. Thus, a digital base generated under GIS environment can find applications in various fields related to natural resources viz. land, water, vegetation/forest, minerals, urban and rural development and specific area necessitating management of natural/anthropogenic hazards, development and management of facilities, transport etc.

Now, a study is undertaken with the support of State Groundwater Department to demonstrate that apart from hydrogeology the information on infrastructure combined with qualitative aspects can also be brought under GIS to support the delineations made from RS. The superposed results indicate that immediate benefits should be enormous and achieve in not only arresting the depleting groundwater table but also to build the vast underground reservoir from unused surface water when appropriate methods are adopted.

If surplus surface water is available is available near an area, using the monitored data on hydrology, soils and other statistical information at micro level suitable sites can be sensed for the occurrence of potential underground reservoirs. Bouwer (2002) discussed the whole process of artificial recharge of groundwater in detail and on the quantity and quality aspects of the recharge phenomena. Some of the important parameters like Rainfall, drainage density, grain size for d_{85}, Aquifer thickness, Depth to Water Table (DTW) in unconfined aquifer, well density, Average load in HP as indicator for energy for each structure, EC as indicator of groundwater quality can be considered with due weights to recognize the aquifers that can be potential underground reservoirs. The general methodologies for undertaking artificial recharge investigations and the concept followed is discussed here.

Application of Remote sensing and GIS techniques

An effective and integrated utilization of remote sensing and other data using any standard GIS software can handle both spatial and non spatial data. A processing system that can transform such integrated information into usable information for decision making is very helpful. Such a GIS system can provide capability such as reduction in redundancy and the inconsistency of data, provide integration of various data for specific purpose, promote ease and efficiency in data storage; provide capabilities for querrying.

The interpretation of data and information from various sources on geology, geophysics, geography, topography, thematic data and remote sensing data is essential for groundwater exploration. The data types from investigations are in different formats such as point data, maps, tables, graphs etc. It is difficult to integrated and interpret such diverse type data using manual overlying techniques. Integration of remotely sensed data and GIS can serve as a useful guide for the assessment of spatial and temporal dynamic phenomena and can collectively interpret the different groundwater data. Multi spectral classification of remote sensing data facilitates quantitative estimates of land cover type, land use pattern and water use by vegetation. Enhancement techniques like rationing, principal component analysis, spatial filtering, contrast stretching, lead to better interpretability and extraction of thematic information from images.

Land use using R/S

Groundwater Resource Evaluation needs the knowledge of the areal extent of phenomena related to groundwater movement. Remote sensing data have proven their importance as an additional tool in prospecting of groundwater from the identification of recharge and discharge areas from the recognition of spectral characteristics and spatial features of the groundwater flow phenomena from the remotely sensed data Remote sensing is an extremely an invaluable tool for mapping land use and land cover which are essential for proper water resources planning and management. This application is based on the fact that the images aid the investigator in locating morphological and structural features that influence groundwater flow.

The land use and land cover mapping reflects the availability of groundwater in a particular area. Some other direct indicators are presence of canals, ponds, lakes rivers etc which influence groundwater occurrence. Vegetation indicates the availability of adequate water where the groundwater may be close to the surface. The remotely sensed drainage information of rivers, tanks etc indicates the presence or absence of groundwater as the surface and subsurface drainages are inversely related. For instance absence of well defined drainage network over large areas subject to good rainfall indicate the occurrence of groundwater water. Information on soils and topography gives idea on groundwater replenishment by rainfall. The infiltration of rainfall and evaporation are greatly influenced by permeability of the soil. The lineaments are straight to slightly curvilinear feature formed in different types of land scapes. In hard rock terrains, the lineaments have considerable bearing on subsurface water resources. Faults, fractures and intersection of lineaments can be mapped using remotely sensed data.

The advantage of satellite image interpretation are scene optic view of over a large areal extent; reduction in field work time and expenditure as the conventional data collection methods are slow and expensive. Identification of potential areas for more detailed study; up to date information.

Criteria for land cover classification

The generation of remotely sensed image by various types of sensors flow aboard different satellites at varying heights at different times requires a classification system to come out with appropriate land cover map. A general classification is referred as USGS Classification system and has about 37 sub categories from 9 categories. However, for hydrologic purpose NRSA has come out with NRSA Hydrological Land Use Classification Scheme having 14 subcategories under seven categories. These categories and subcategories are also called Level 1 and Level 2 Classifications. While undertaking such classification, ground truth data plays an important part in remote sensing studies. In practice, it is difficult to obtain synchronous data for over large area. This limitation has related effect on the image classification as well.

Application of Isotope techniques

Elements that contain atoms with required number of protons but different numbers of neutrons are called isotopes. The concept that the hydrological cycle system can be viewed as a global distillation column of waters fed by evaporation from the ocean as moisture which condenses as a result of cooling of air masses as it rises to higher levels. The degree of depletion of heavy isotopic water species of hydrogen and oxygen is correlated in the residual waters, provided there exists equilibrium between the condensed phases and the vapors at all times. But, according to Fritz and Fontes (1980), evidently evaporation from the ocean does not produce vapor in isotopic equilibrium with it. For stable isotopes, their differences in isotopic species in water play an important role in the variation that is observed in the atmospheric water cycle by promoting fractionation effects during vapor/liquid and vapor/solid phase changes. Thus, isotope fractionation occurs at each phase change except sublimation and melting of compact ice (Fig. 3).

The Meteoric Line:

Water and solutes found in various segments of the hydrological cycle or the same segments during different seasons or under different climatic conditions, would show useful variation in their concentrations because of the isotope fractionation process as discussed above. One can notice measurable differences in isotopic character and reasonable explanations are at hand for such observation of variations in the nature. Dansgaard (1954, 1961,1964) conducted one of the earliest studies of the $\delta^{18}O$ in precipitation. It is observed that $\delta^{18}O$ in precipitation collected at high latitude coastal weather stations showed that a linear relationship with mean annual air temperature and the temperature coefficient was about 0.7 δ / ^{o}C. Here δ value is the most common way to express the difference in isotopic composition between a sample and a reference with a ratio of R-value, which is a reference standard for the substance. This difference is most commonly expressed in terms of parts per thousand or permil ($\%_o$) and is symbolized by δ. Note that permil is algebraically and symbolically similar to %. $\delta_{x / reference} = (R_x/R_{reference} - 1)10^3$. 'Permils' ($\%_o$) can be approximately (or not exactly) additive like 'percentages' (%).

Stable isotope characterization of groundwater

The δD and $\delta^{18}O$ analyses help in understanding the contribution of different recharge sources and also to pinpoint the most important recharge source. Dansgaard (1964) conducted one of the earliest studies of the $\delta^{18}O$ in precipitation. The δ value is the most common way to express the difference in isotopic composition between a sample and a reference with a ratio of R-value, which is a reference standard for the substance.

Measurements of stable isotopes are done in terms of abundance ratios i.e. atomic mass of heavy atom to the atomic mass of light atom. However, the absolute abundance ratio of isotopes is not usually measured in natural waters and in other components. Only the relative difference in the ratio of the heavy isotopes to the more abundant light isotope of the sample with respect to a reference is determined. The difference is designated by a Greek letter δ and is defined as follows:

$$\delta = (R_{sample} - R_{reference}) / R_{reference} \qquad (1)$$

where, R's are the ratios of the $^{18}O/ ^{16}O$ and D/H isotopes in case of water. The difference between samples and references are usually quite small, δ values are therefore, expressed in per mille differences (‰) i.e. per thousand, δ (‰) = δ x 1000. It is called as 'del'.

$$\delta (‰) = [(R_s - R_r) / R_r] \times 10^3 \qquad = [(R_s / R_r) - 1] \times 10^3 \qquad (2)$$

If the δ value is positive, it refers to the enrichment of the sample in the heavy-isotope species with respect to the reference and negative value corresponds to the sample depleted in the heavy-isotope species.

The reference standards normally considered are SMOW (Standard Mean Oceanic Water) and VSMOW (Vienna Standard Mean Ocean Water). VSMOW has the same ^{18}O content as defined in SMOW but its D-content is 0.2 ‰ lower. Over the period of use, the old standards have been consumed. Therefore, other reference standards have been developed in due course of time. These are SLAP (Standard light Antarctic precipitation), NBS-1 and NBS-1A (National Bureau of Standard) and GISP (Greenland ice sheet precipitation).

The relation between δD and $\delta^{18}O$ that has been observed in global precipitation is expressed mathematically by the equation known as Global Meteoric Water Line (GMWL)

$$\delta D‰ = 8\, \delta^{18}D + 10 \qquad (3)$$

The relation between δD and $\delta^{18}O$ can be written in a standard form as a linear equation

$$\delta D‰ = A\, \delta^{18}O + d \qquad (4)$$

Where A is the 'slope' and d is the 'intercept' of δD Vs $\delta^{18}O$ line of fresh global meteoric waters. One can develop regional and local meteoric water lines on the pattern of standard relationship between δD and $\delta^{18}O$ valid on regional or local levels. The 'slope' of the line corresponding to $\delta^{18}O$ versus δD of water undergoing evaporation decreases as humidity decreases. That is the slope of standard meteoric line of 8 can range between 8 and 3 in the case of evaporation depending on the relative humidity. The result of this is that residual liquid water that has undergone evaporation plots to the right of the meteoric water line following a slope of 3 to 8. Waters that have experienced the greatest evaporation factor are farthest from the meteoric line. The slope of this divergent line indicates that relative humidity during the evaporation process. Waters of Closed Basins must have undergone evaporative fractionation.

Craig (1961) measured both $\delta^{18}O$, δD in precipitation and surface water collected from a climatically and geographically wide range of localities. He showed these two measured parameters are linearly related to each other. The equation has the form $\delta D = a\ \delta^{18}O + b$ the approximate values of the constant 'a' is 8 and 'b' 10, according to his analysis. With these values for the constants this equation is known as the "Craig's Meteoric Line" or the "Global Meteoric Water Line" (Fig. 4). This is an appropriate but potentially misleading designation because not all $\delta^{18}O$ and δD values in natural precipitation, surface and groundwater plot on this line.

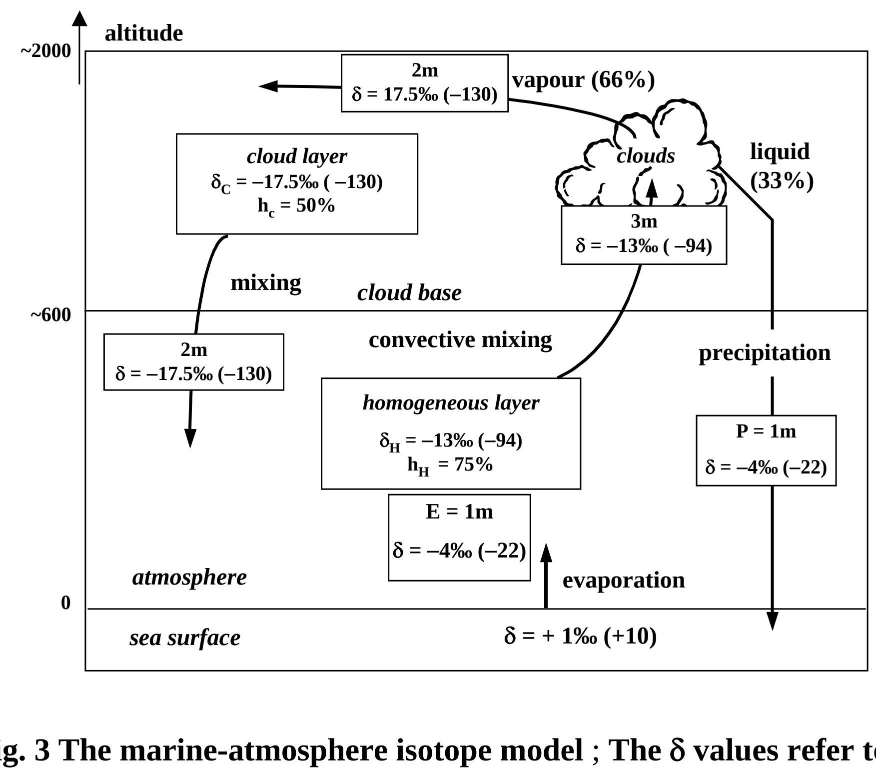


Fig. 3 The marine-atmosphere isotope model ; **The δ values refer to $\delta^{18}O$; [δD is shown in parenthesis]. The water transport fluxes are given in amounts of liquid water equivalents units of metre/year**

Deviation in Meteoric Line

A complicating factor for deviation in meteoric line is the cloud formation and precipitation. During cloud formation and during precipitation droplets becomes sufficiently large to descent, they may evaporate and exchange water molecules with the air below the clouds. Low-level moisture may be isotopically distinct from upper level moisture. In addition, on its way down through the air the droplet is likely to encounter air with the humidity less than 100%. Thus evaporation from the droplets occurs which is a fractionating process. Thus, the first precipitation droplet to fall through dry air is likely to show kinetic isotopic enrichment. Their values would fall to the right of the global meteoric line. Dansgaard (1964), Jouzel and Merlivat (1984) and Jouzel et. al(1987) discussed in detail the complexities of the models of isotope process in clouds and in droplets. Water in solid phase (Snow) is unlikely to exchange molecules with the surroundings while falling through. If snow evaporates by sublimation as it falls, no fractionation takes place and its isotopic composition will most likely retain a record of cloud temperature. Indian Meteoric Water Line is

$$\delta D = 8.2\ \delta^{18}O + 9.8\ ‰ \qquad (5)$$

Groundwater Dating

Determining residence time for shallow groundwater is also possible using environmental tracers such as $T/{}_3He$ (Schlosser et al.1989; Cook and Solomon 1997). Most of the tritium, a radioactive isotope of hydrogen currently in the environment, was released to the atmosphere in the late 1950s and early 1960s during above ground nuclear bomb tests. The tritium concentration in precipitation reached a maximum in the mid-1960s, 2–3 orders of magnitude higher than natural levels. Since then, its concentration has decreased quasi-exponentially. The age of the groundwater can be calculated using the radioactive decay relationship between

tritium and its daughter isotope, ${}_3He$

$$t = t_{1/2} / \ln(2)[1 + {}_3[He]_{tri} / [T]] \qquad (6)$$

where

t=time (apparent groundwater age);

$t_{1/2}$=half-life of tritium (12.43 years);

[T]=measured tritium content; and

$[{}_3He]_{tri}$ =concentration of ${}_3He$ derived from the decay of tritium.

Radioactive isotope of hydrogen, ^{3}H (tritium or T), originates (as does ^{14}C) from a nuclear reaction between atmospheric nitrogen and thermal neutrons (Libby, 1946):

$$^{14}N \rightarrow {}^{12}C + {}^{3}H$$

^{3}H enters the hydrologic cycle after oxidation to $^{1}H^{3}HO$ and finally decays according to:

$$^{3}H \rightarrow {}^{3}He + ß^{-}$$

with $E_{\beta max}$ = 18 keV and a half-life of 12.430 years (Unterweger et al., 1980). According to a recent re-evaluation, a more preferable value is 4500 ± 8 days (equivalent to 12.32 year). Under undisturbed natural conditions the ^{3}H concentration in precipitation was probably about 5 TU, which is equivalent to a specific activity of about 0.6 Bq/L (Roether, 1967). However, tritium is also produced in the atmosphere due to testing of atomic devices similar to cosmogenic tritium. It is also produced articificially under controlled conditions in laboratory/ reactor.

Isotopes in subsurface zone

A water molecule in groundwater travels from a point of recharge to a point of discharge and does gains age this travel time can be estimated by a number of physical and chemical techniques indirectly. From the point of collection or discharge zone water molecules recharge at different distances over a broad area get collected due to variations in thickness, porosity and permeability with space. The water flow path is changing and is not well defined in an aquifer. Variable texture of the aquifer affects the conductivity and thus the travel time of particles in an aquifer. Fractures falls and volcanic or rheological intrusions also divert or enhance the water pathways. Hydrodynamic dispersion is also another phenomena and includes at least three processes at microscopic level. These are tortuosity molecular sieving and adsorption. A fourth microscopic process molecular diffusion may not be an important dispersive process in most cases. Because diffusion is relentless but usually over whelmed by other mobilization processes. Thus these processes, each important in different proportion in different setting contribute to the fact that any groundwater sample is a mixture of molecules that have resided in the ground for a wide range of times. Hence a hydrogeologist must not only determine the average age but must evaluate the possibility that the sample consist of portions of water from different ages. Thus a good knowledge of the hydrogeologist system under evaluation needs judicious selection of sampling sites and sampling depths. Complete knowledge of the system is like subject of day dreams desirable but impossible. Consequently one is compelled to develop the most reasonable model of a system under study based on information obtainable with in the available time and resources.

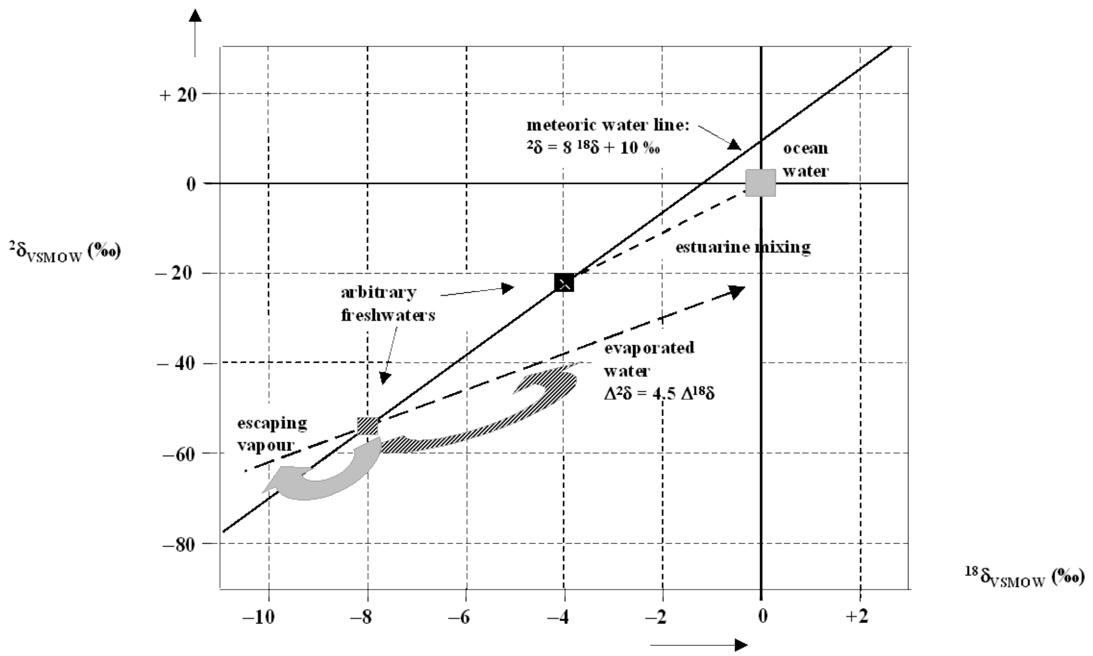


Fig. 4 Relation between the (d^{18}O, dD) values of meteoric water which undergoes evaporation and seawater mixing

The advantage of the environmental isotopes as hydrologic tracers is that nature and anthropogenic activities show the path for the tracer experiment. Some of the tracers are the water molecules themselves containing stable or radioactive isotopes characteristic of conditions of recharge, or time or precipitation. The solute category of environmental tracers requires careful consideration of possible sources of isotope itself in the aquifer or sources of stable isotopes of the same element. The aquifer derived stable isotope is important as well. As the reported laboratory measurement is in terms of the ratio of the radioactive isotope with respect to the amount of total element.

The standards of measurement for stable isotopes are at the zero pivot points. Samples containing a greater proportion of the heavy isotopes have positive δ values; Samples with smaller R-value than the reference have negative δ values with respect to the reference. For oxygen isotope $_{18}O$ reference material is SMOW with R value 2005.2 X 10^6 The same for hydrogen 2H isotope is has an R value of 158.4 X 10^6

Water Rock Interaction

The other process that can move waters to the right of meteoric line is oxygen isotope exchange with carbonate or silicate rocks. Water can have a varied history including oxygen fractionation between various types of rocks at significant depths in the earths crust. Waters discharged from volcanoes and hot springs help us to study directly the isotopic composition of deep geothermal waters. Craig (1961) demonstrated through oxygen and hydrogen isotopic determination that the majority of hot springs is dominated by meteoric water. Interaction of deep water with rocks causes the $\delta^{18}O$ values of the rocks to decrease and $\delta^{18}O$ values of the waters to increase. This oxygen isotope shift in the $\delta^{18}O$ is attributed to progressive equilibration of oxygen in water with silicate and carbonate rocks. Interaction with silicate rocks will cause the $\delta^{18}O$ values of the waters shifted to higher $\delta^{18}O$ values but will not significantly affect the δD values of the water due to low content of hydrogen in most of carbonate and silicate rocks. According to Aggarwal and Gibson (2002) models developed through combined use of physical, isotopic and geochemical tracers, which can effectively label water sources, pathways and processes.

4.0 STUDY AREA

About 125 sq. km of area draining westwards into River Godavari, which is bounded by Khondalite hills on the north and Trap on the south is selected as shown in Fig 5. About 1000mm annual rainfall occurs in the region, which is poorly drained and flat plain where Tertiary tirupati sand stones are appearing as out crop and extend to large depths of about 250 to 300 m. The field investigations viz., geo-hydrological studies, RS and GIS techniques, sampling for quality and isotope analysis of pre and post monsoon Groundwater samples, monitoring for depth to groundwater levels are undertaken. The piezometer fitted with AWLR at Gandepalli records the groundwater level data in this formation. Studies and analysis of data of 15 villages illustrates that the ground water table has fallen to depths of about 30 to 50 meters below ground level in the area, which has about 2200 electric motors with an average installed capacity of 10 HP. The water table was falling at a rate of 3 m per year since 90's and existing rainfall recharge is not able to arrest such fall. To visualize the source of supply of water for recharge, information on irrigation canals under proposal and construction are also considered. In the study area, there is a proposal to take up two-canal systems, which divert water from Godavari for irrigation of upland areas. The Chagalnadu project irrigates about 2200 Ha and the Pushkar project, which is part of Polavaram project will irrigate about 8700 Ha through its 17.8 by 3.0 m section having 42.62 cumecs discharge capacity and running for about 10 km in the study area as shown in dotted lines in Fig. 5. By 2005, this project was taken up and main canals are formed. Polavaram LBC will also fall in the study area when taken up and is a lined canal. The Gandepalli piezometer records the groundwater level data in this formation and the Pushkar canal passes with in a kilometer from the piezometer.

Status of the data on population, Well inventory, land use, irrigation particulars in the study area is compiled. The village wise well inventory is shown in Table 1. Village wise number of agricultural electricity connections and load is combined to develop a village level GIS information system. To visualize the source of supply of water for recharge, information on irrigation canals under proposal and construction are also considered. The land use classification of the study area based on the digital analysis of IRS LISS II data is as give in Table 2 and is a typical replica of rain fed upland area. From the Figure 6, shown to depict the classified land use map, water bodies and dark plantation areas fed by groundwater in the discharge area and fallow recharge area of the upstream can be seen.

An attempt is made to undertake such classification in the upland mandals of the east Godavari district where Tertiaries in the form of Tirupathi sand stones are outcropping. The depth of wells was about 30 metres up to 1970’s, where as, now the bore wells are about 75 to 100 metres deep. Godavari River, adjoining the area, surpluses large quantities of water during monsoon season, which can be good source of water for storing in the underground reservoir, when appropriate artificial recharge techniques are adopted. There are two canal systems fully on the study area. The villagewise details with the canal systems are shown in Table 3. The villagewise details are proposed pushkar canal systems are also shown in Table 4.

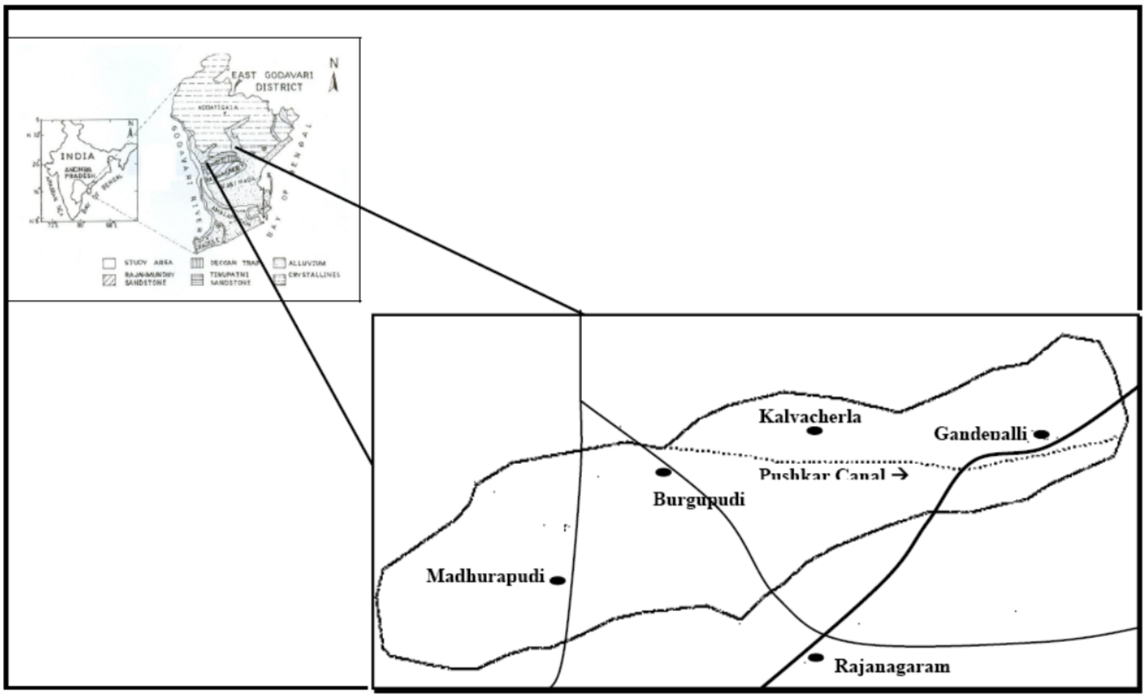


Fig. 5 Study area of Tirupati sandstone aquifer in East Godavari District

Geology

According to CGWB (2003), the East Godavari District is underlain by various geologic formations from olden Archaens through Gondwanas and Tertiaries to recent Alluvium. The Tirupati sandstones are upper Gondwanas and are oldest sedimentary rocks occurring in the dstirict and are represented by sandstones and clay of upper Zurassic age. These sandstones are white to grey clayee and fine to coarse grained. Numerous well sections indicated the occurrence of mottled clayee sandstones, coarse-grained sandstones and mottled clays. The strike of the sandstones varies from east - west to northeast - southwest. The rocks dip towards south to southeast at 6^{o} to 12^{o} but sometimes 20^{o} due south.

Prominent exposures of this formation are seen as detached patches between Mirtipadu and Burgupudi; near Tatiparti; between Simhadripuram and Dharmavaram and near Chebrolu in the district. Of these the former two are the most extensive and the study area falls in the first region. Alluvial deposits at the surface separate them. The upper Gondwana rocks in the main outcrop area between Mirtipadu and Burugupudi lie at elevations of 32 to 75 m above msl.

Table 1 Status of the data on Well inventory in the study

Name of the Mandal	Geographical Area in Acres	Shallow	Deep	Dug	Population
Seetha Nagaram Mandal					
Mirtipadu	1018		64		3149
Hundeswarapuram	826		37		2820
Total	1844		101		5969
Gandepalli Mandal					
Murari	5813		146		6873
Gandepalli	3075		108		4748
NT Rajapuram	1675		87		2672
Total	10563		341		14293
Rajahmundry Mandal					
Torredu	2735	10	56		5160
Total	2735	10	56		5160
Rajanagaram Mandal					
Nandarada	2515		14	98	3303
Kalavacherla	4907		144	56	5355
Narendrapuram	3015		89	9	4530
Velugubanda	4359		49	1	6812
Total	14796		296	164	20000
Korukonda Mandal					
Dosakayalapalle	2127		188		4576
Burugupudi	4262		25	97	5856
Butchampeta	1726	3	24		2631
Madhurapudi	3067		98		2215
Nidigatla	2471		100		2298
Gadala	2152		13		3631
Total	15805	3	448	97	21207
TOTAL	**45743**	**13**	**1242**	**261**	**66629**

Table 2

Landuse classification in the Tirupati Sand stone area from IRS LISS II data for 1996-97

Landuse	Area in ha	Area in %
Horticulture	3010.5	23.78%
Crop-1	547.1	4.32%
Crop-2	187.3	1.48%
Crop-3	388.6	3.07%
Crops/ horticulture/ grass	925.5	7.31%
Grass	1632.8	12.90%
Barren	5257.6	41.53%
Forest(dense)	54.1	0.43%
Forest (Sparse)	10.2	0.08%
Water (pre)	176.3	1.39%
Water (Post)	399.9	3.16%
Waterlogged	70.4	0.56%
Total	**12660**	

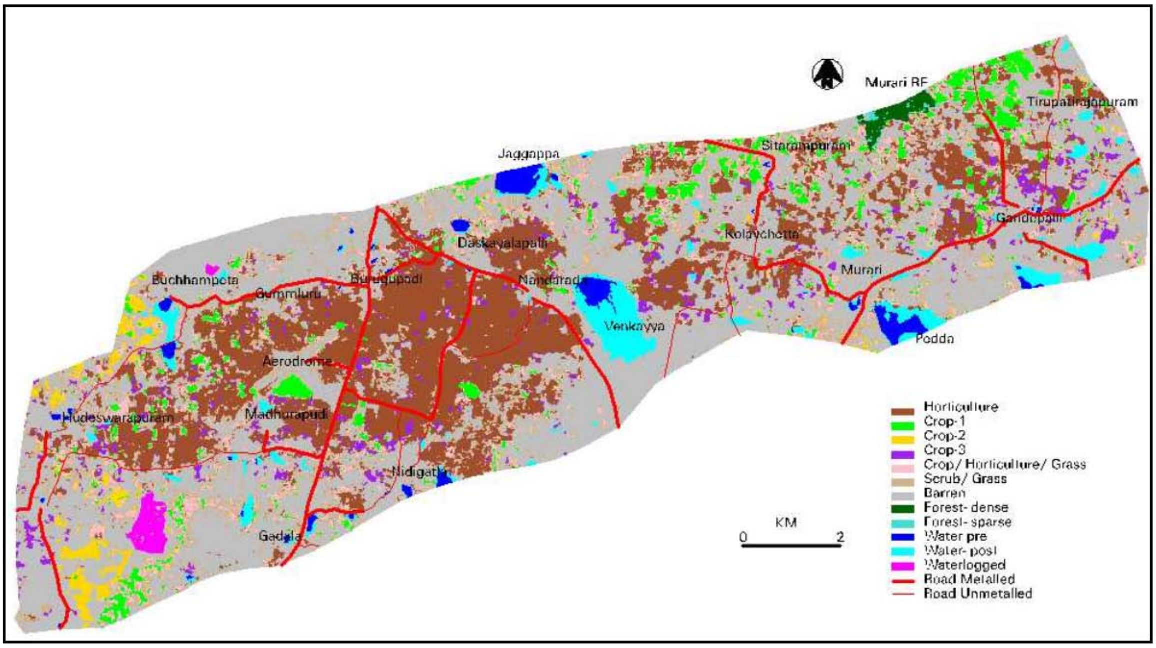


Fig. 6 Land use map of study area

Table 3

Villages in Study Area falling under Chagalnadu Lift Irrigation Scheme

Sl. No.	Villages	Area in Hectares
	Rajanagaram Mandal	
1	Kalvacherla	346.39
2	Narendrapuram	619.45
3	Velugubanda	468.96
4	Nandarada	228.63
	Total	**1663.43**
	Korukonda Mandal	
1	Nidigatla	363.29
2	Gadala	197.47
	Total	**560.76**

Table 4

Villages in the study area falling under Pushkar Lift Irrigation Scheme on river Godavari near Puroshothapatnam village in Sitanagaram mandal in East Godavari district

Sl. No.	Name of Village	Ayacut in Acres
1	Seethanagaram Mandal	
	Undereswrapuram	151
	Mirthipadu	400
	Total	**551**
2	Korukonda Mandal	
	Dosakalyalapalli	1885
	Burugupudi	3730
	Madurapudi	1938
	Gadala	1612
	Butchampeta	955
	Total	**10120**
3	**Rajanagaram Mandal**	
	Kalvacherla	942
	Nandarada	1736
	Total	**2678**
4	**Gandepalli Mandal**	
	Murari	4564
	Gandepalli	2262
	N. Tirupathirajapuram	1535
	Total	**8361**

Subsurface Geology

Red soils occur in the study area. They are medium to coarse in structure and are permeable extending to a depth of 1.8 m. From the number of boreholes drilled by CGWB in the district especially where Tirupaties are exposed the subsurface geology can be well understood. The maximum thickness of the Gondwana rocks are 300 m in the Gadala where the slim hole pierced through Tirupati Sandstone of 316m thickness below which Khondalite was encountered. Mallepalle borehole also indicated 314 m thick Gondwana rocks and according to CGWB it is very likely that further drilling be few meters would have revealed the basement. These two points are to the west and east of the study area. At Burugupudi towards further east the bore hole encountered basement at depth of 228 m. At Peddapuram to the south of the study area the deep bore hole revealed more than 335 m thick Gondwana formation. Here deccan traps with Intertrappeans of Eiocene overlie the Tirupatis. At this point the top of the Gondwana was struck at a depth of 415.6 m and extend beneath upto 750 m below ground level. The lithology for a few locations in the study area is shown in Fig. 7. From the north as we move towards Godavari river, the tirupati sandstones which are outcropping in the north are overlain by trap and rajahmundry sandstones towards Godavari river.

Hydrogeology

Groundwater in Tirupati Sandstones occusr under water table or confined condition depending on their occurrence. In the area where Gondwana rocks are exposed at or near the surface the groundwater is mainly developed by dugwells and dug cum borewells and tube wells. During eighties the water table varied form 2.28 to 15.05 m. Dug well ranging from 4 to 20m . Most of the dugwells for irrigation purpose tap deeper confined aquifer by means of bores in the bottom of the well. Dug cum borewells and tube wells tap confined aquifers between 27 and 100 m. The tubewells tap aquifers from 29 to 150 m. 20,000 to 50000 liters per hour from varying drawdowns from 15.7 to 35.7 m (CGWB,1982). Accordingly the data of the dugwells, dugcumborewells and tube wells suggested the existence of confined aquifer below 27 m. According to CGWB,1982 the Gondwanas and Tertiaries contain potential aquifers to sustain construction of deep tube wells and the tertiaries are far more prolific.

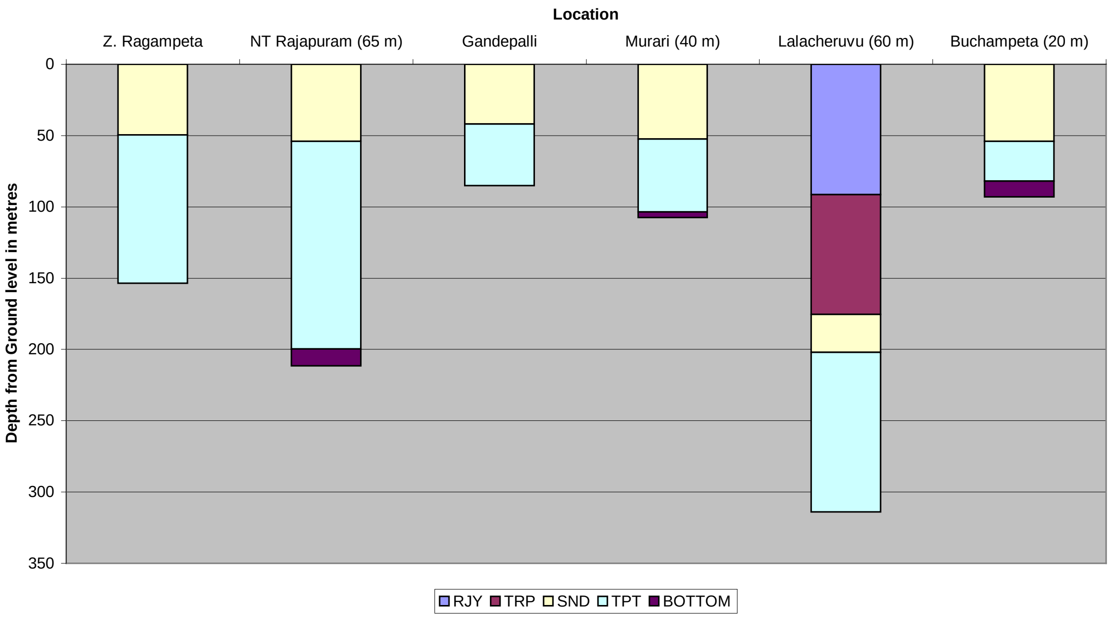
Aquifer Characteristics

The capacity of the aquifer to transmit water depends upon the transmisivity of the aquifer which ranges widely from 17.3 to 2240 sq. m /day. Within the depth range of 300 m for different aquifers. For Gondwana formation transmissivity range from 17.3 to 96.8 with an average of 53 sq. m /day.

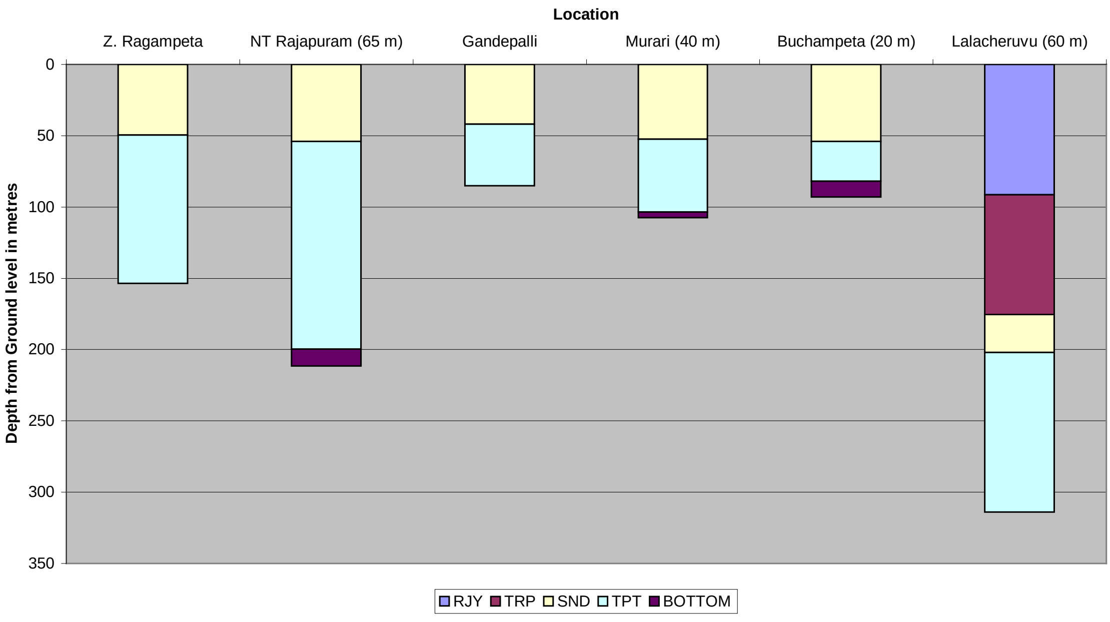
Hydrochemistry

According to CGWB 1982 the water samples from wells in Tirupati sandstones indicate that waters are mild alkaline and have bicarbonate in nature. The total hardness range form 290 to 490 ppm. The TDS values vary from 76 to 790 ppm and that of chlorides from 25 to 225 ppm.

Fig. 7 **Lithology of different location around the study area along decreasing longitude**



Lithology of different location around the study area along decreasing latitude

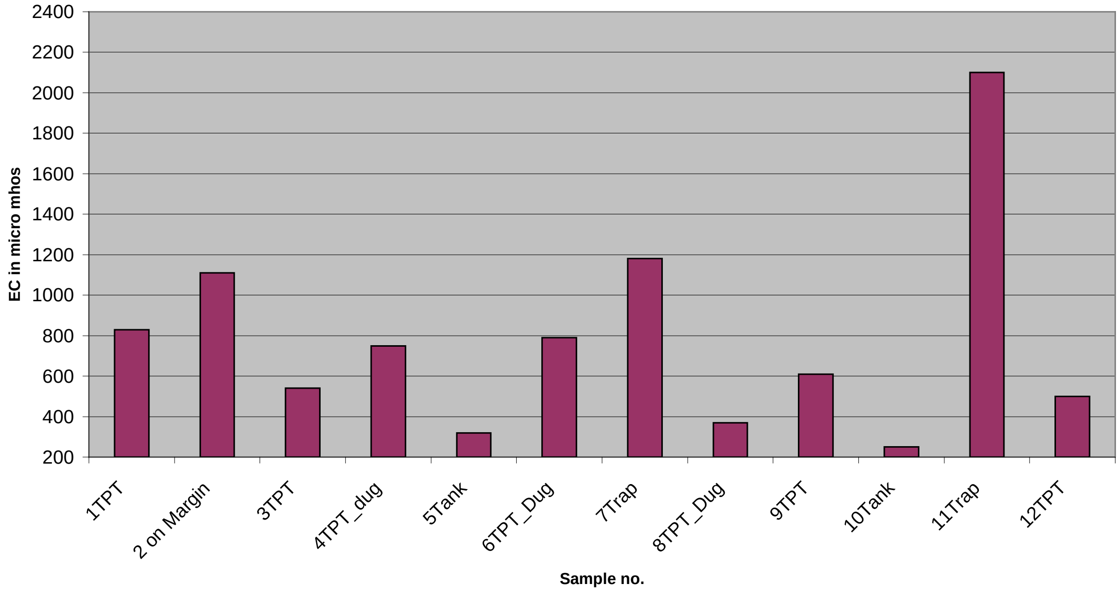


5.0 SAMPLING AND ANALYSIS

Status of the data on population, Well inventory, land use, irrigation particulars in the study area is compiled. Monthly rainfall data from Rajahmundry, Rajanagaram, Gandepalli and Korukonda from 1990 till 2004 are analysed. Litho logs from exploration boreholes of CGWB and APSGWD in the area are collected. Historical groundwater level data from a dug well from 1989-90 and a peizometer from October 2001 at Gandepalli are analyzed. Literature on Artificial recharge of groundwater is compiled. Water samples from 13 locations are collected from OB wells and tanks in September 2004.

In this study a relationship is established to understand the characteristics of groundwater recharge in an upland sandstone aquifer with respect to rainfall. Studies and analysis of data for 15 villages illustrates that the ground water table has fallen to depths of about 30 to 50 meters below ground level in the area, which has about 2200 electric motors with an average installed capacity of 10HP capacity. It indicates that the area is underlain by a huge underground reservoir from which about 120 MCM of groundwater is withdrawn annually and need to be recharged artificially for the survival and development of those who depend on the success of this infrastructure. Such approach adopted for other regions may help in identifying potential

Fig. 8 Variation of EC in the Tirupati sandstone area



underground reservoirs for undertaking artificial recharge of groundwater.

The field measurements of EC and pH indicate that the area is freshly recharged even at large depths indicating favorable recharge conditions (Fig. 8 and 9). EC of groundwater varies from 370 to 780 micro mhos even when DTW is at a depth of 40 to 50 m for which pH is 7.9 and 7.7. The temperature is strikingly regulated at about 29 degree Centigrade in tube wells and about 25 degrees in a dug well and 35 in shallow tank and 32 in a normal tank. Variation of temperature of groundwater in this study area is shown in Fig. 10.

The monthly rainfall at Korukonda, Gandepalli, Rajanagaram and Rajahmundry in and around study area are shown as graph plots in Fig. 11. The average monthly rainfall in this study area from 1992 to 2003 is shown in Fig. 12.

The well hydrograph of a piezometer that automatically records groundwater levels every six hours and located in an upland area are analyzed to visualize the suitability of undertaking appropriate water conservation practice. Well hydrographs are plotted against accumulated rainfall since beginning of rainy season so as to understand how the groundwater level is reacting to the cumulative effect of rainfall. The variation of groundwater at Gandepalli with respect to rainfall from 1992 to 1996 is shown in Fig. 13. The depth to groundwater table in dug well and in deep tube well at Gandepalli is shown in Fig. 14. It was observed that the dug wells that occur in small patches in perched aquifers and upto a depth of 5 m. Where as the general groundwater in the sandstone aquifers is about 35 m below groundlevel during 2001 and has fallen to a depth of 52 m by 2004. The upland tirupathi sandstone formation along NH5 has a good characteristic for recharge, as the topography is flat, soils are sandy and porous, aquifer is under water table condition in general etc., The upland areas are under recharge zones and best suited for water harvesting compared to coastal areas which are close to discharge zones.

Fig. 9

Variation of pH in samples of the Tirupati sandstone area

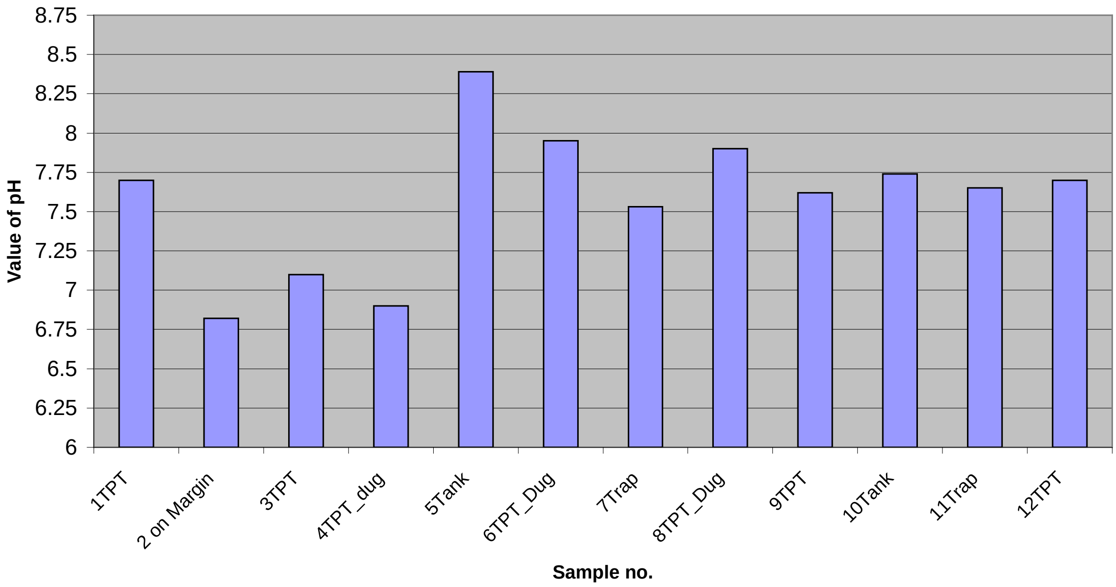


Fig. 10

Variation of Temperature in samples of the Tirupati sandstone area

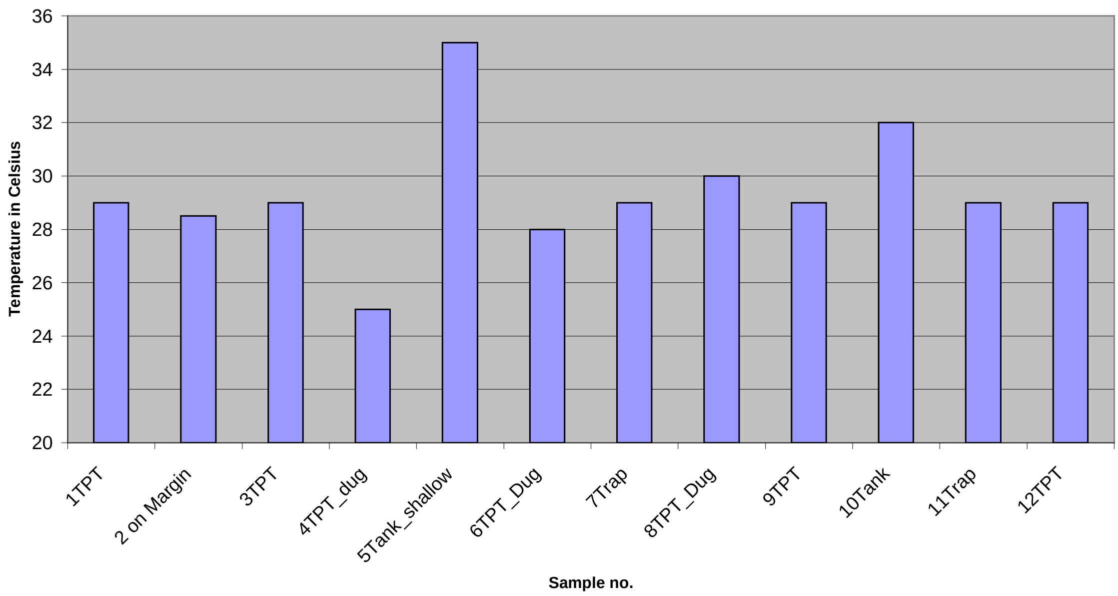


Fig. 11

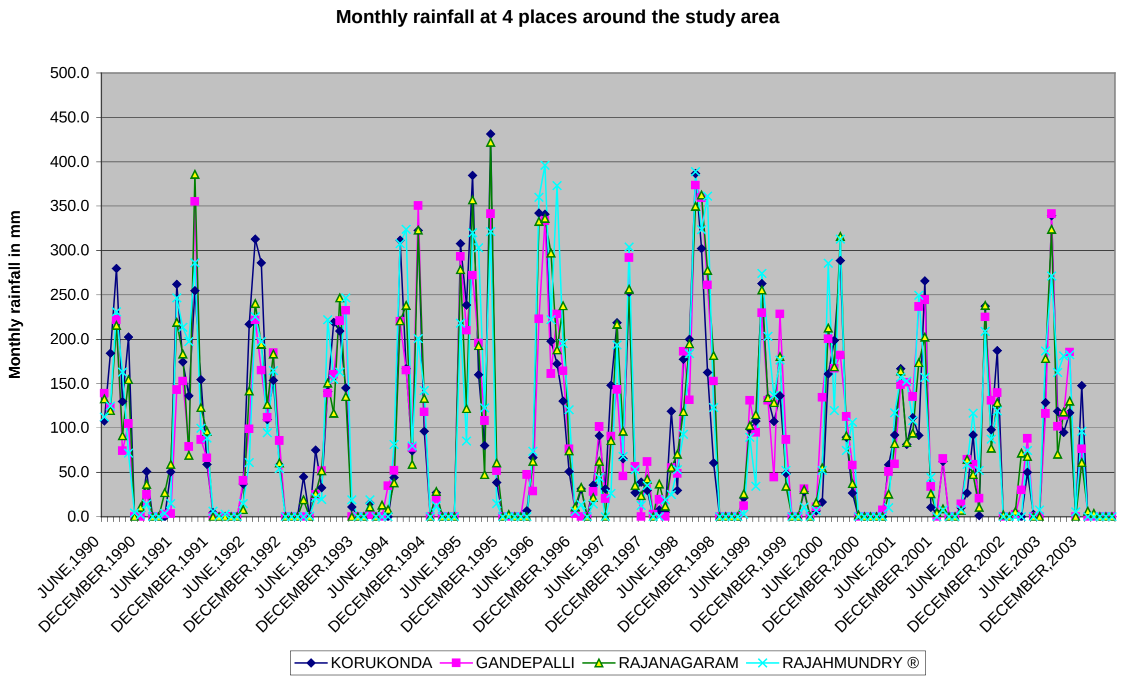


Fig. 12

Average monthly rainfall in the study area from 1990 to 2004

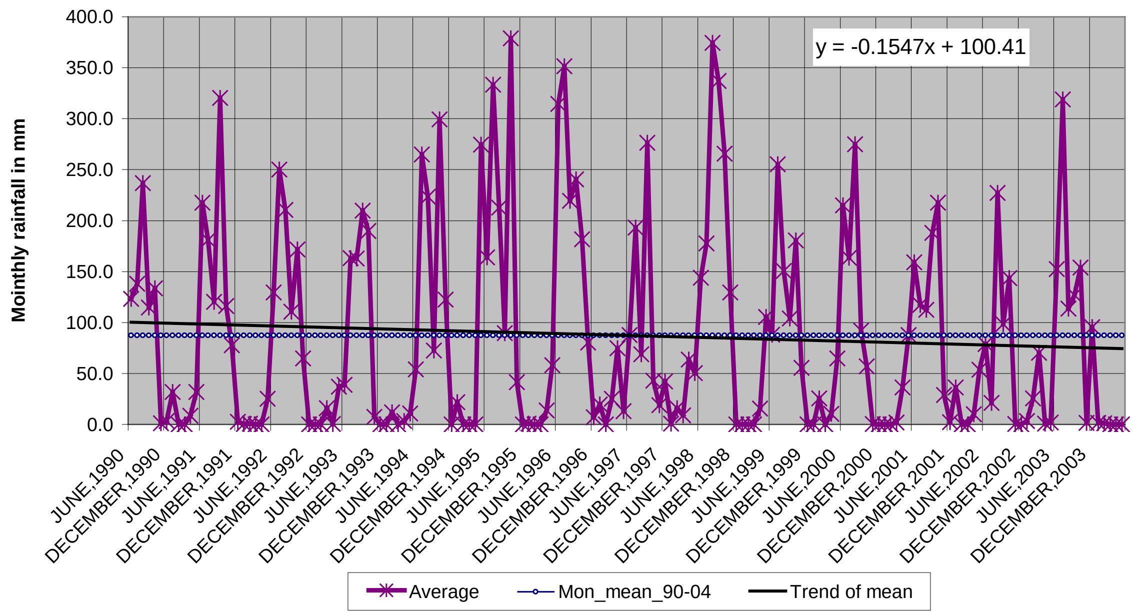


Fig. 13

Gandepalli well hydrograph vs monthly rainfall

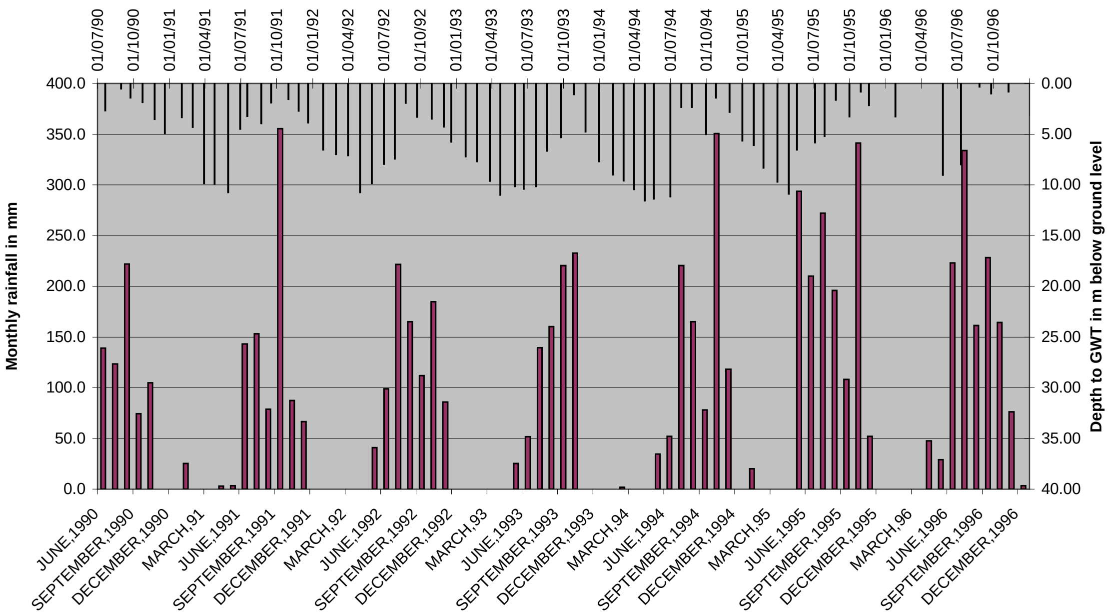
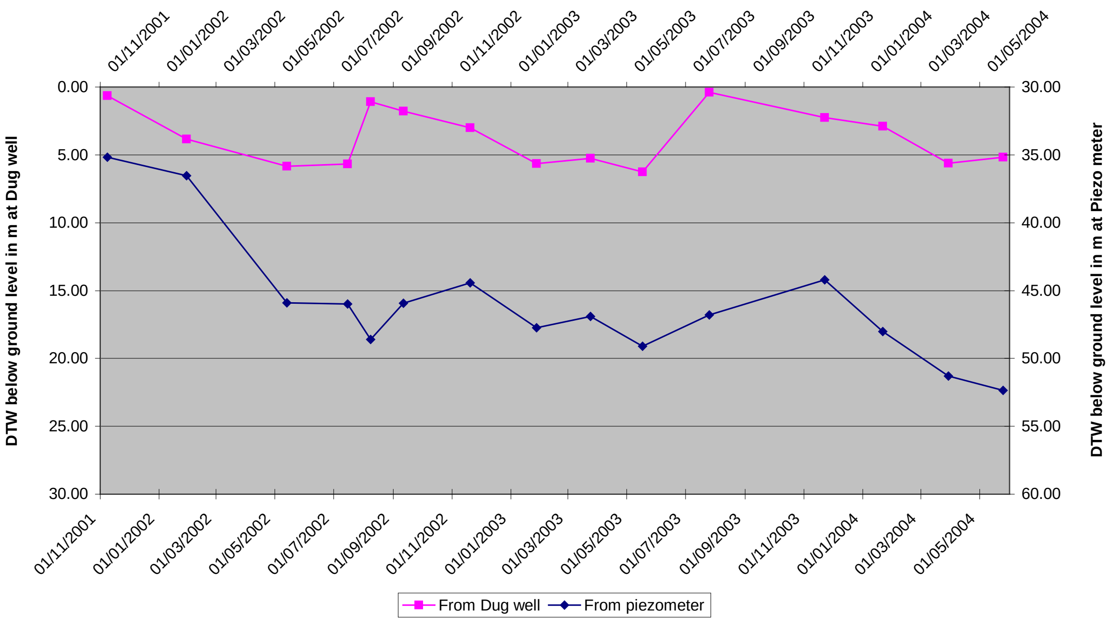


Fig.14

DTW for dug well vs piezometer at Gandepalli from 2001 to 2004



A network of tube wells and deep dug wells is established for collection of water samples. The field investigations like geo-hydrological studies, sampling for quality and isotope analysis of pre and post monsoon Groundwater samples, monitoring for depth to groundwater levels were undertaken during 2004 and 2005. Hydrological investigations were conducted to monitor water levels and collection of water samples from about 13 locations like Gandepalli, NT Rajapuram, Murari, DSK Palli, Madhurapudi, Gummaluru etc. The water samples of precipitation, tank water and groundwater were collected during September 2004, June, August and November 2005 for chemical and isotope analysis. Efforts were made to avoid any contamination, evaporation and effect of exchange with atmosphere. The procedure of sampling water for deuterium and oxygen-18 analyses is very simple. A very small amount of sample is enough. But to be on safer side and for repeated measurements a minimum of 20 ml sample is collected in a HDPE bottle. While collecting samples, groundwater from tube wells and hand pumps water was left for sufficient time so that the sample represents groundwater of the aquifer understudy. The sample bottles were sealed with wax and transported to laboratory for isotopic analysis. The physical properties of water are measured in-situ. The samples were analyzed for δD and $\delta^{18}O$ stable isotopes using Continuous flow isotope ratio mass spectrometer and Dual inlet isotope ratio mass spectrometer available at NIH, Roorkee. The measured error in estimates is $\pm$ 0.1 $\%_0$ in $\delta^{18}O$ and is $\pm$ 1.0 $\%_0$ in δD. The rainfall is collected at Kakinada, which is about 50 Km from the study area. The same is considered as representative of local precipitation of the study area.

The variation of $\delta^{18}O$ and δD values at some locations in the groundwater of sand stone aquifer along that of local rainfall during May and November 2005 is shown in Fig. 20 and 21 respectively. The field measurements of EC and pH indicate that the area is freshly recharged even at large depth indicating favorable recharge conditions. EC of groundwater varies from 370 to 780 micro mhos even when DTW is at a depth of 40 to 50 m for which pH is 7.9 and 7.7. The $\delta^{18}O$ value is –4.00 in August 2004 for precipitation and –0.7 and 0.29 during September 2004 for water samples from a deep tank at Gandepalli and a shallow tank at Nandarada respectively showing the evaporation effect at shallow tank clearly. The $\delta^{18}O$ has a value of –3.61 at Gummaluru; -3.09 at Hudeswarapuram; -3.8 at Madhurapudi; -4.03 at Murari for groundwater during September 2004. The linear equation of local precipitation occurred at Kakinada, LMWL i.e, local meteoric water line during the study period is plotted for $\delta^{18}O$ vs δD. The equation (4) as explained previously is found to be

$$\delta D‰ = 8.2516\ \delta^{18}O + 11.541 \qquad (5)$$

6.0 RESULTS AND DISCUSSION

Following the methodology proposed, analysis is undertaken in the study area. Some of the results are shown here using the MAPINFO for presenting data and results in maps. Spatial interpolation and plotting of contours for different parameters is carried out using surfer. The groundwater exploitation index which is obtained using average installed power in HP and number of wells at village level for agricultural electricity services in study area. The same is shown graph plot overlaid over the land use. At each location the average installed power is shown on the top, the groundwater exploitation is shown in middle and number of electrified tube wells shown in the bottom. From the Fig. 15, it is can be observed that areas to the right are over exploited and is a good underground reservoir for artificial recharge.

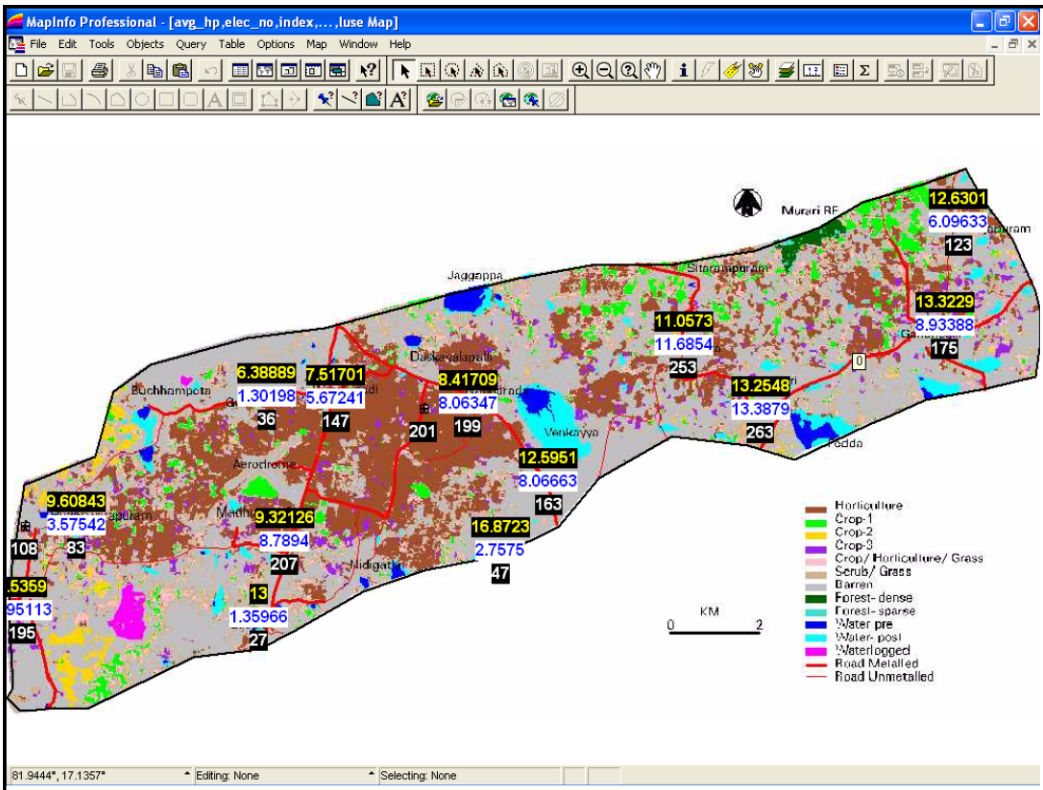
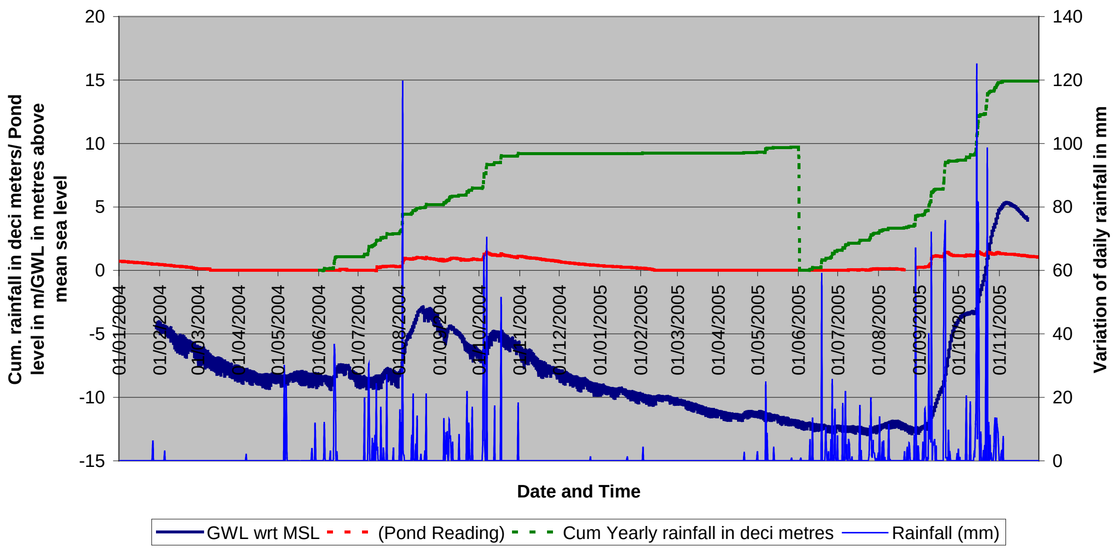


Fig.15 Landuse/land cover map of the study area along with groundwater exploitation index

The fluctuation of groundwater level recorded every six hours during 2004 and 2005 at Gandepalli is plotted along with cumulative rainfall, and pond water level and is shown in Fig. 16. The variation in groundwater level signals the different scenarios of presence and absence of recharge and in combination with pumping. The weekly roaster of the electric supply can also be noticeable form such a plot. Next, when recharge starts, the deviations slowly retard and as recharge rate increases, even for pumping conditions the change will be positive. Thus, from the plot we can monitor effects of pumping and recharge on the groundwater level in the aquifer. This indicates that the groundwater level is gradually rising in the aquifer. A good water conservation practice should be able to sustain such a situation over as long period as possible.

Fig. 16

A plot showing variation of rainfall, Yearly cumumative rainfall, pond water level and groundwater level in a piezo meter along with time



Nitrate Variation

Nitrate occurs in groundwater due to various reasons of which anthropogenic causes are predominant. As sand stones are reasonably porous, low concentration of nitrate ion indicates that there is good recharge and quality is acceptable. Spatial variation of Nitrate ion concentration in the groundwater in the study area during August 2005 is presented in Fig. 17. It can be observed that the nitrate values are varying from 12 to 28 mg/l i.e., within permissible limits and indicate low anthropogenic effects on the recharge water. The slope line indicates the general groundwater flow direction. The high values at Kalvacherla are because of the large anthropogenic effects as the well is a dug cum bore well and has lot of vegetation all around.

Stable O^{18} isotope

Dansgaard (1964) conducted one of the earliest studies of the $\delta^{18}O$ in precipitation. It is observed that $\delta^{18}O$ in precipitation collected at high latitude coastal weather stations showed that a linear relationship with mean annual air temperature and the temperature coefficient was about 0.7 δ / ^{o}C. Here δ value is the most common way to express the difference in isotopic composition between a sample and a reference with a ratio of R-value, which is a reference standard for the substance. This difference is most commonly expressed in terms of parts per thousand or permil (%$_o$) and is symbolized by δ.

Relationship between O18 and D isotopes

The per mil values for del O18 del D for different waters have a strong relationship and are generally plotted along local meteoric water line. Del O18 and del D values during May and November 2005 are shown in Fig. 18 and 19. The variation of change in del O18 values between September 2004 and May 2005: May 2005 and November 2005: between August 2005 and November 2005: between shown in Fig. 20 to 22. Spatial variation of difference of $\delta^{18}O$ values of stable O^{18} isotope in the groundwater in the study area during 2004 and 2005 are presented in Fig. 20 to 22. The plot indicates the freshening of groundwater during monsoon season indicating the presence of rainfall recharge in the study area.

Fig.17

Variation of NO3 in the groundwater of the study area during August 2005

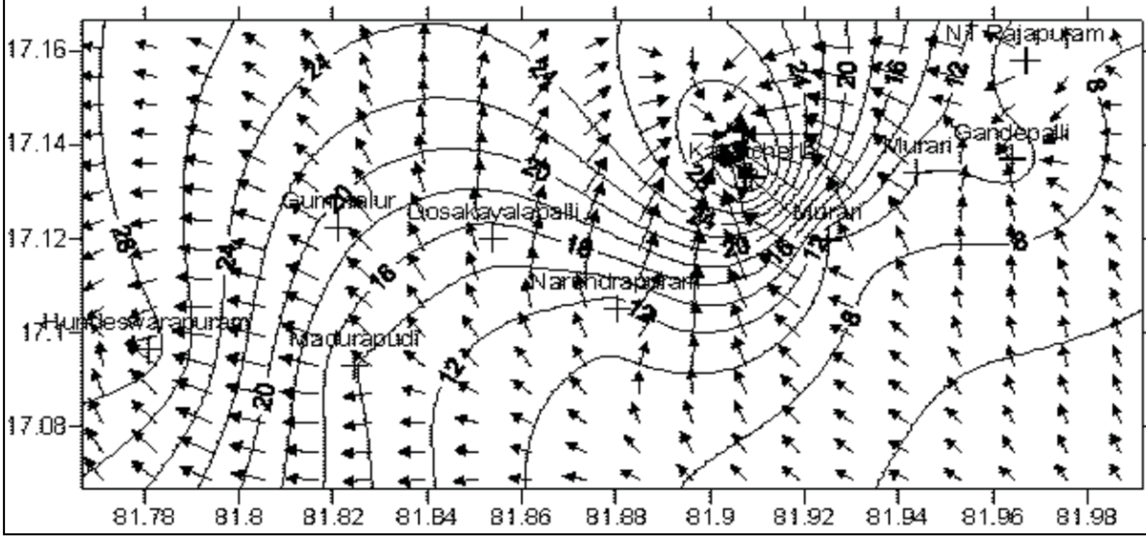
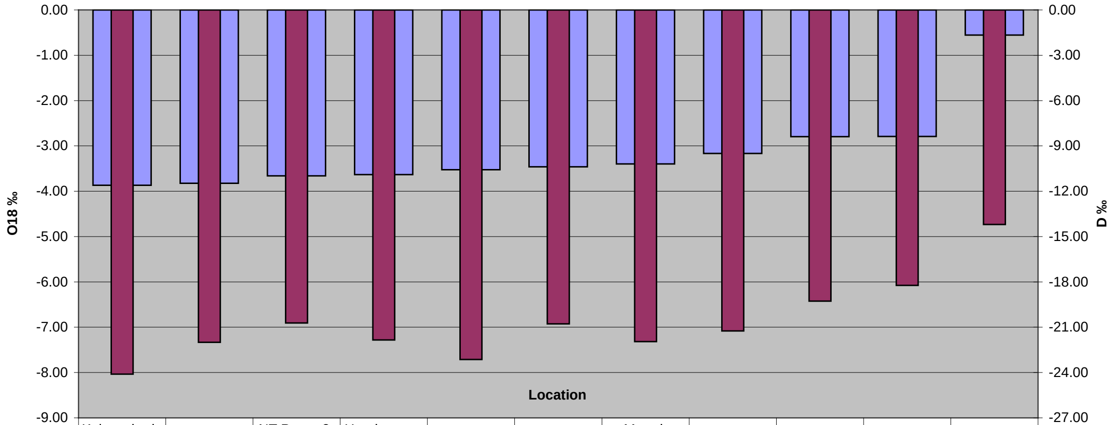
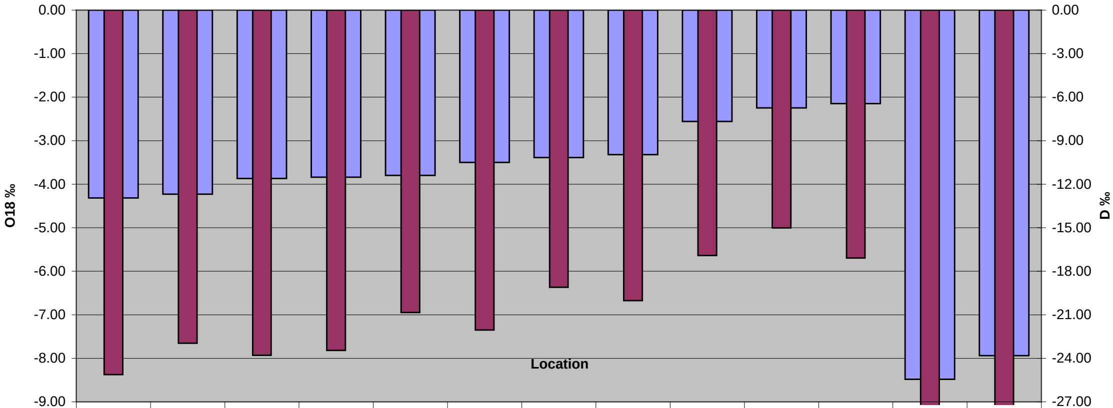


Fig. 18 O_{18} ‰ and D ‰ at different locations in May 2005 in the study area



	Kalavacharla 2	Gummalur	NT Puram2-Panchayat	Hundeswara puram	Kalvacherla1	Gummalur2	Murari-Panchayat	DSK Palli	Murari-Fish	NT Puram	Madhurapudi
O18‰	-3.87	-3.82	-3.66	-3.63	-3.53	-3.46	-3.40	-3.16	-2.80	-2.79	-0.56
D‰	-24.10	-22.00	-20.72	-21.84	-23.13	-20.78	-21.95	-21.24	-19.28	-18.23	-14.20

Fig. 19 O_{18} ‰ and D ‰ at different locations in November 2005 in the study area



	Kalvacherla	Murari	Murari	Dosakayalapalli, School	Madhurapudi-Rjy (Chandana	Gummalur	Gandepalli	NTR Puram	Murari Near Fish T ank	Hundeswarapuram	Nanadarada	Rainfall Oct 05	Rainfall Nov 05
O18‰	-4.32	-4.23	-3.87	-3.84	-3.80	-3.50	-3.39	-3.32	-2.56	-2.25	-2.15	-8.48	-7.94
D‰	-25.12	-22.96	-23.79	-23.46	-20.84	-22.05	-19.11	-20.02	-16.91	-15.01	-17.08	-55.62	-49.37

The spatial variation of change in $\delta^{18}O$ values over seasons of 2004 and 2005 plots are presented in Fig. 20 to 22. Fig. 20 indicates the spatial variation of change in $\delta^{18}O$ values between September 2004 and May 2005. The plot clearly indicates the effect of evaporation in groundwater that reveals groundwater has been generated due to summer precipitation. It also indicates the effect of monsoon as seen in Fig. 21 which shows the spatial variation of changes in $\delta^{18}O$ values between May 2005 and November 2005. The areas where groundwater is getting enriched due to recharge can be distinguished. Most of the area, especially the central portion of the study area is showing significant variation in $\delta^{18}O$ values in both the plots and indicates the seasonal response of aquifer due to recharge and pumping or evapotranspiration. The plots indicate clearly the effect of evaporation during non-monsoon season of 2004-05 and freshening of groundwater during monsoon season of 2005 indicating the presence of rainfall recharge in the study area.

Fig. 20

Variation of del O18 values from Sep 2004 to May 2005 (O18 Sep 2004 value – O18 May 2005 values

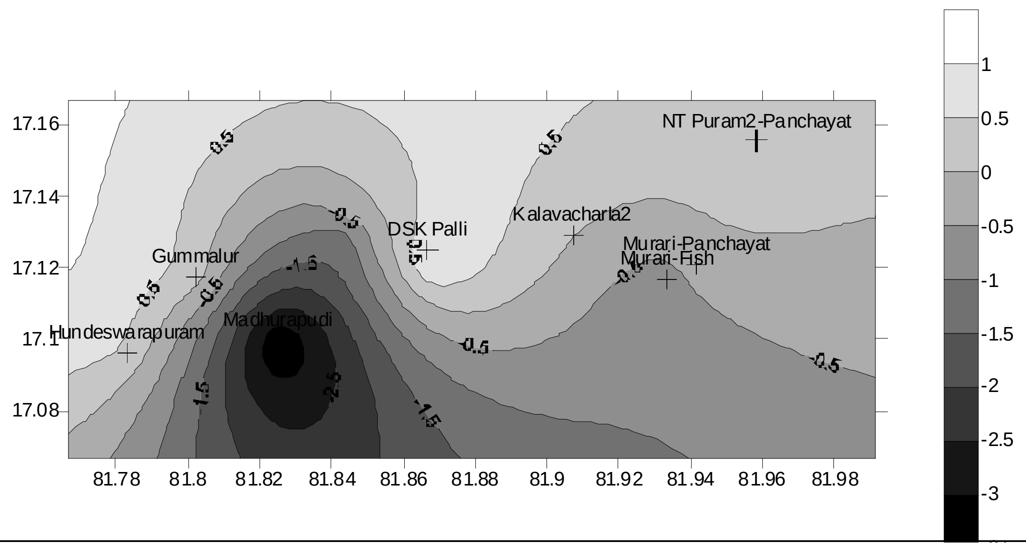


Fig. 21

Variation of Del O18 from May 2005 to November 2005 (O18 May values – O18 November values)

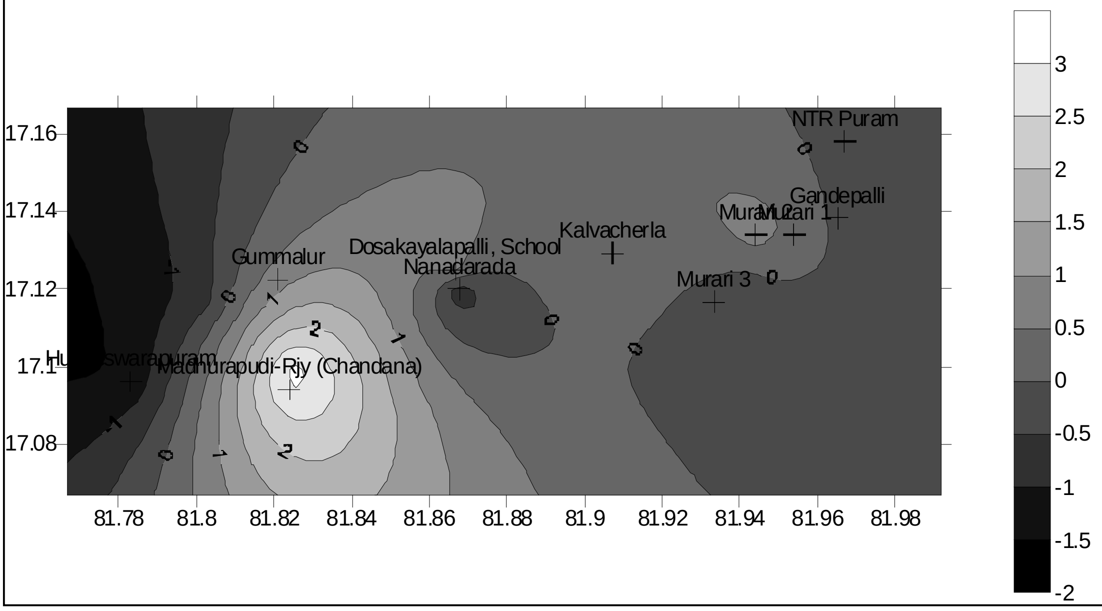
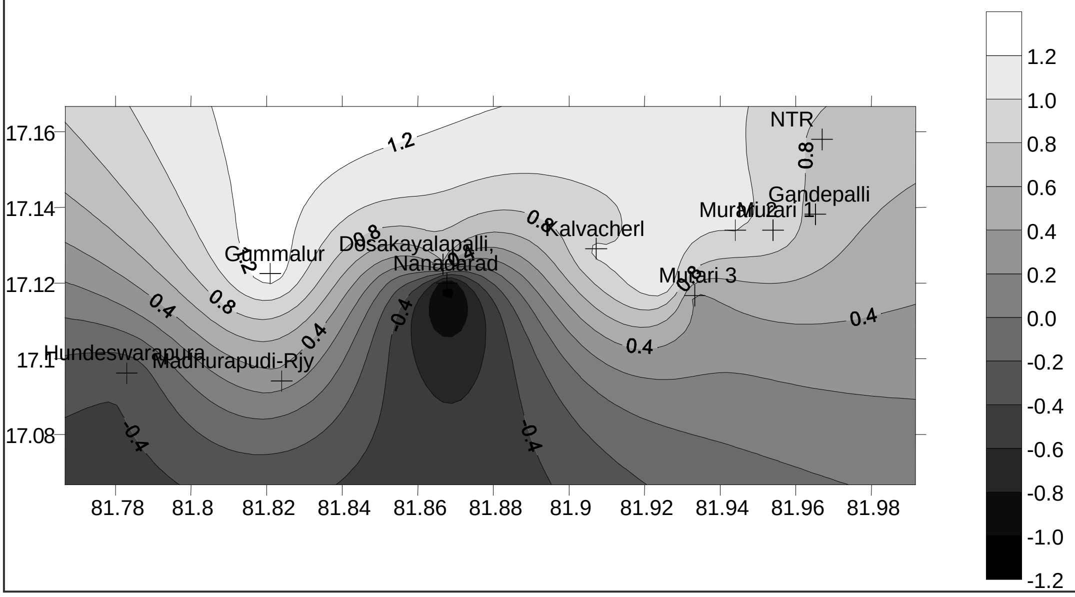


Fig. 22

Variation of Del O18 fromAugust 2005 to November 2005 (O18 August values – O18 November values)



Relationship del O18 and del D relationship along with the local meteoric water line for June 2005, August 2005 and November 2005 for the groundwater in the study area is analysed. The δD vs δ^{18}O plot for LMWL and ground water line, GWL of the study area are shown in Fig. 23 to 25 for June 2005, August 2005 and November 2005 respectively. The results indicate that the slope of GWL for September 2004 (5.01), June 2005 (2.81), August 2005 (4.75) and November 2005 (4.03) is less than that of LMWL (8.25). This shows that residual liquid water that has undergone evaporation and plots to the right of the meteoric water line. GWL shows the evaporation effects. The GWL of June 2005 has less slope compared to the slope of GWL of September 2004 as the contribution from rainfall ceases and isotopic composition of groundwater changes and shows that residual liquid water that has undergone evaporation. As the monsoon of 2005 advanced, the GWL of August 2005 is steeper than that of June 2005 indicating the enrichment of groundwater of aquifer due to recharge from precipitation. Towards the end of monsoon i.e., by November 2005 the slope of GWL increases and also approaches the LMWL indicating the recharge. The intercept of GWL in the month of September 2004 (-4.25), June 2005 (-11.74), August 2005 (-6.245) and November 2005(-6.84) is less than the intercept of LMWL (11.54). This indicates the enrichment of Deuterium in Groundwater during monsoon of 2004 and evaporation during the following non-monsoon and again enrichment during next monsoon season and indicated active response of the deep aquifer to precipitation.

Fig. 23

Relationship of Oxygen 18 vs Deterium for Groundwater in June 2005

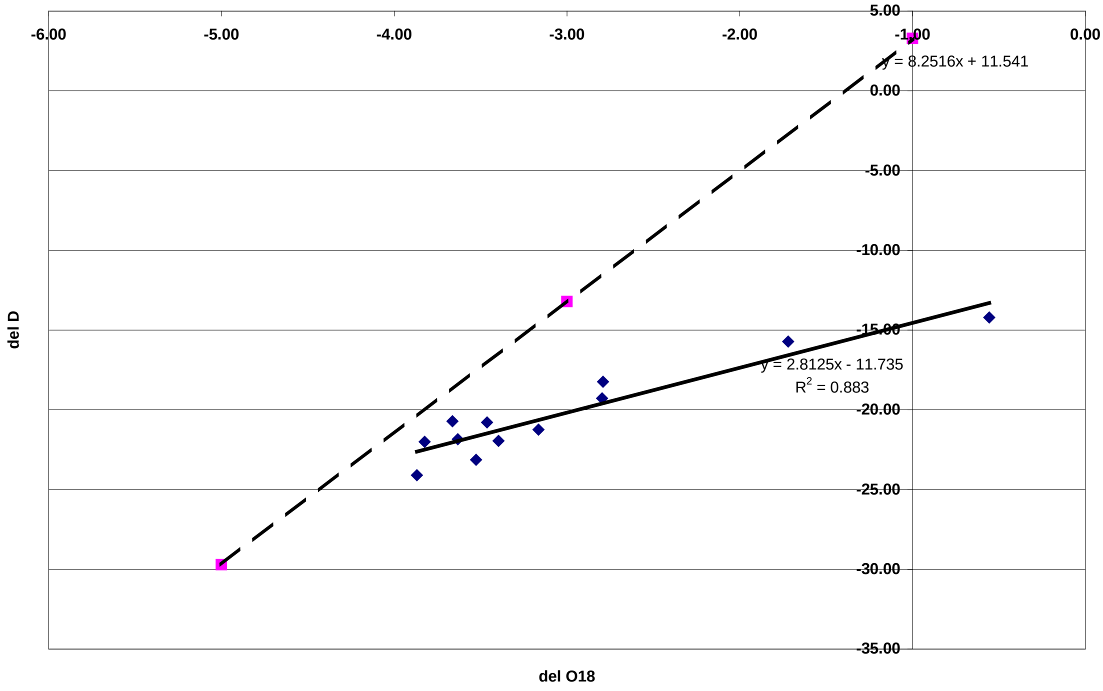


Fig. 24

Relationship of Oxygen 18 vs Deterium for Groundwater in August 2005

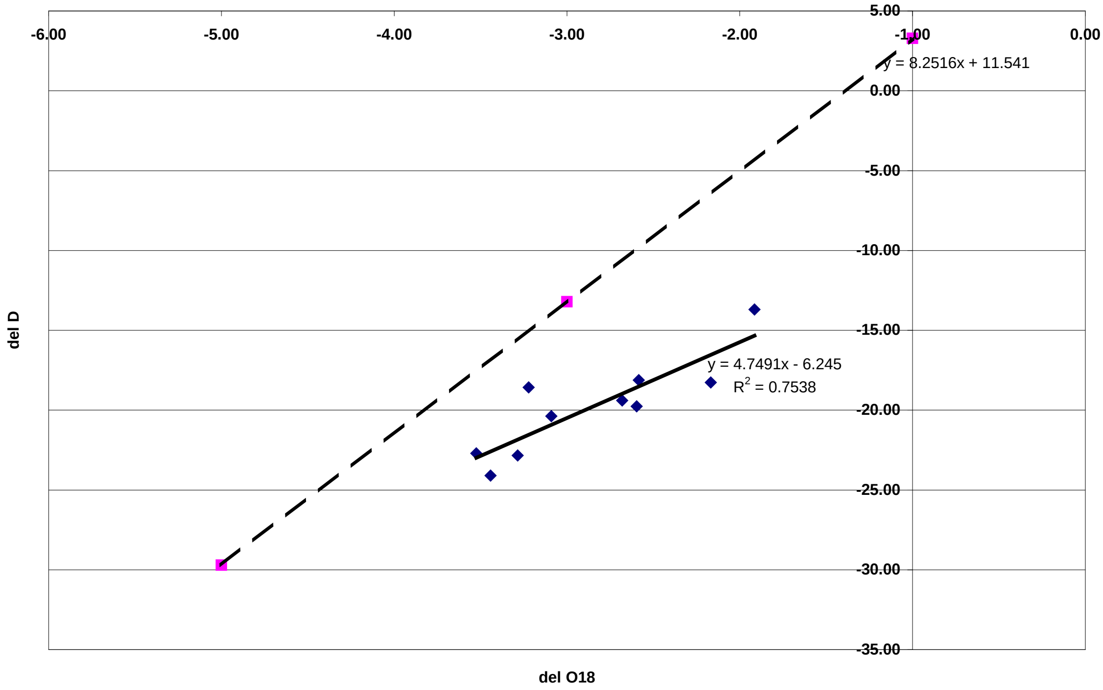
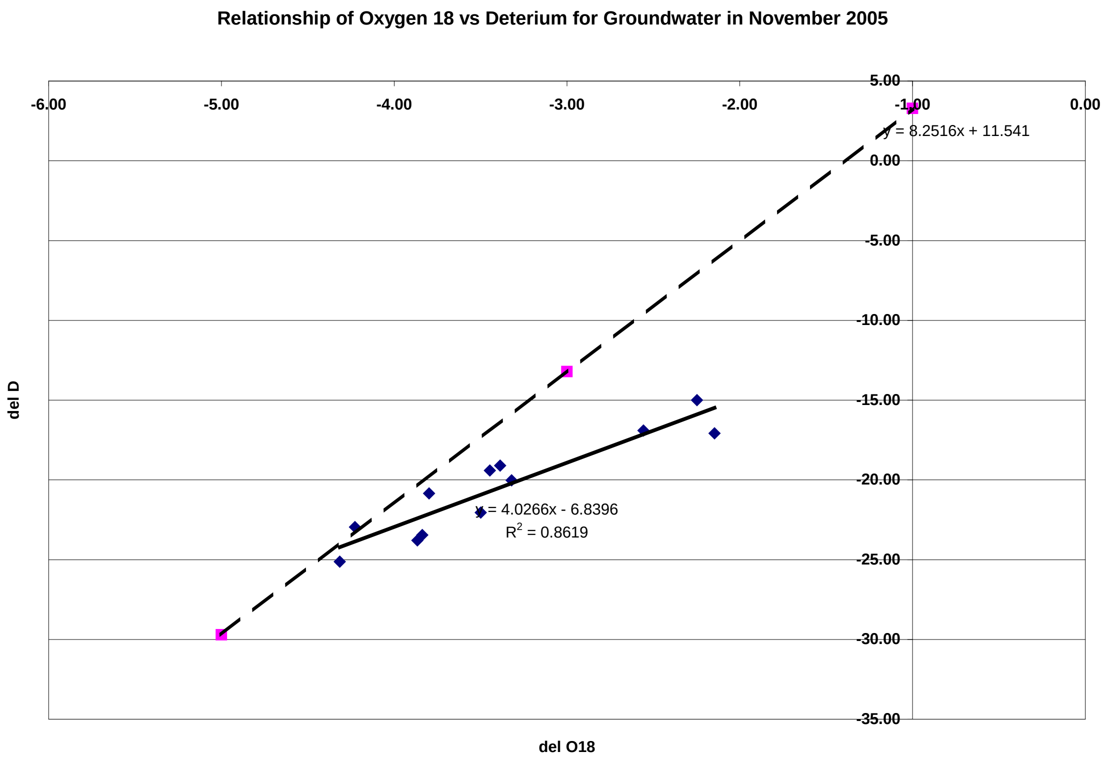


Fig. 25



The del O18 and del D values along with Electric conductivity of groundwater in the study area during May and November 2005 is shown in Fig. 26. The chemical classification using the CGWB method for anions and cations is plotted and shown in Fig. 27 and indicates that most of the waters are in recharge zone. The tritium isotope activity of groundwater in the study area is shown as graph plot in Fig. 28 and horizontal transmissivity are estimated using this plot. The horizontal flow rate of groundwater is about 1 km per year or 2.74 m / day.

Fig.26 Stable isotope and EC of groundwater in the Titupati Sandstone aquifer and local precipitation during pre and post monsoon in 2005

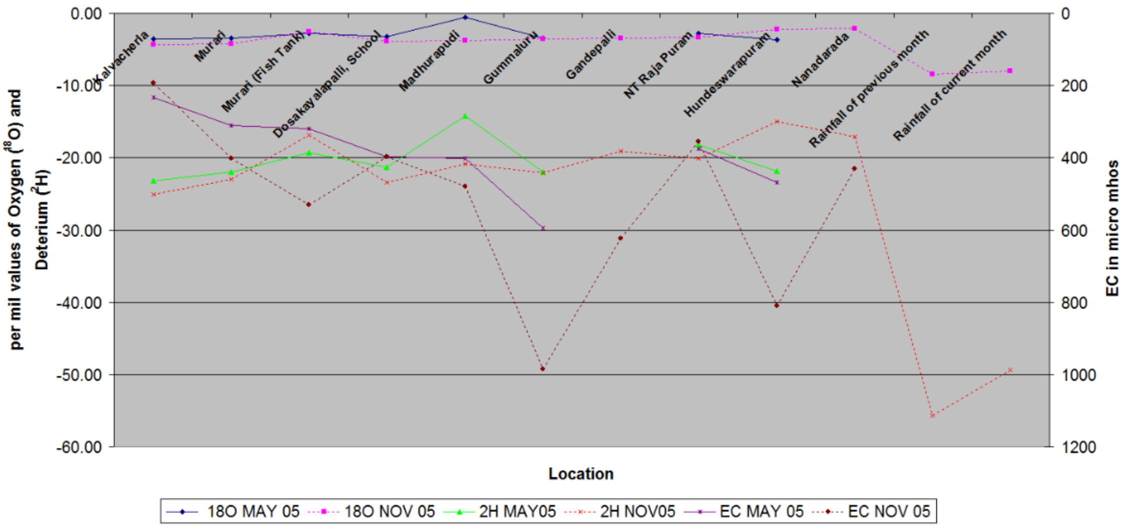


Fig. 27 Artificial Recharge Study: OB well water and CGWB chemical classification

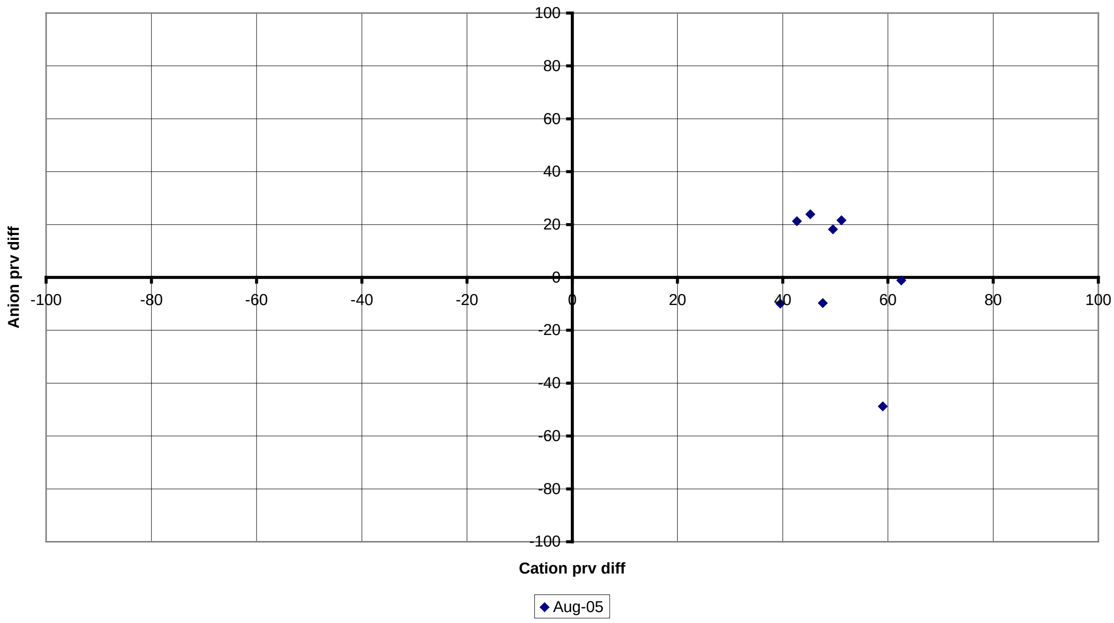
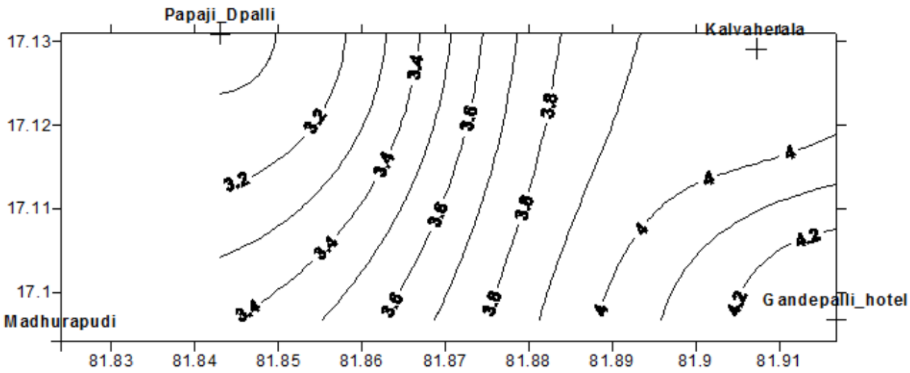


Fig. 28

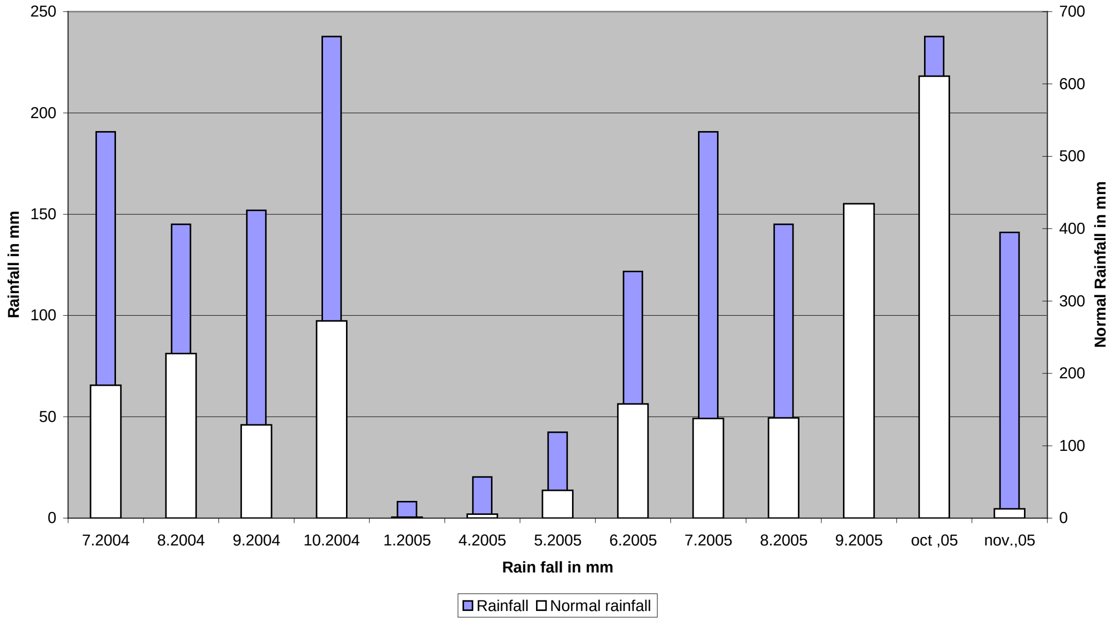
Tritium isotope concentration in the deep groundwater in the sandstone aquifer during Sep 2004



Recharge or Recovery of Groundwater

The rainfall is the major recharge component in the study area. Rainfall during 2004 and 2005 along with normal rainfall is shown in Fig. 29. From the piezometer data recorded at Gandepalli, variation in `natural recharge/recovery of the aquifer is evaluated from the daily observations at 03 00 hours, in the early hours, during which the influence of pumping is minimum as the free electricity is supplied during day shifts in this region. The plot indicates that the recovery/recharge is showing high values when the groundwater level is between –4 and –9 m below MSL.

Fig. 29 **Rain fall Vs Normal Rainfall in 2004 and 2005 in the study area**

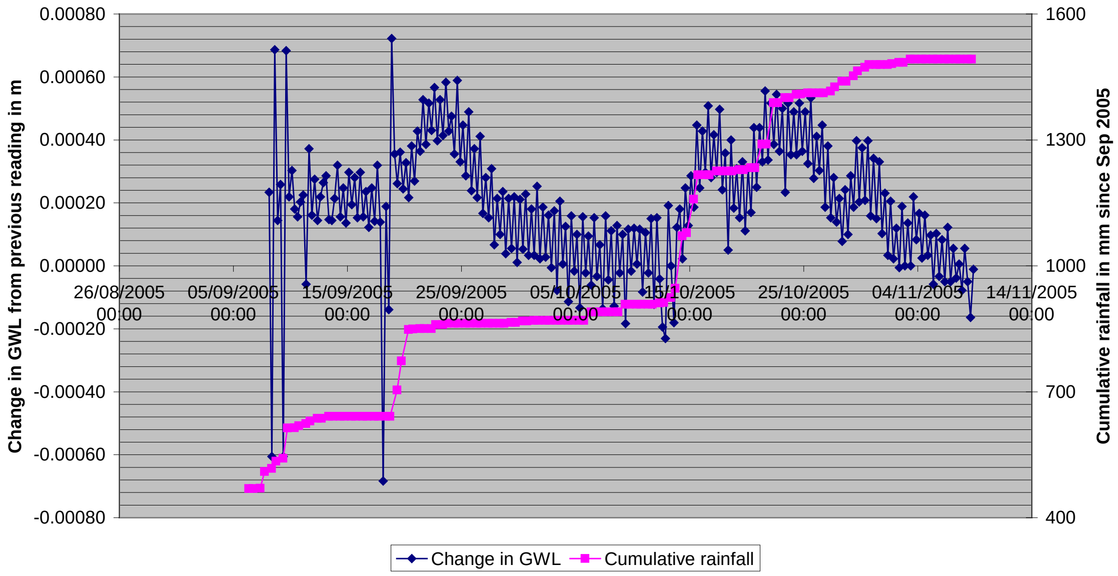


The well hydrograph of a piezometer that automatically records groundwater levels every six hours and located in an upland area are analyzed to visualize the suitability of undertaking appropriate water conservation practice. Well hydrographs are plotted against accumulated rainfall since beginning of rainy season so as to understand how the groundwater level is reacting to the cumulative effect of rainfall. The upland tirupathi sandstone formation along NH5 has a good characteristic for recharge, as the topography is flat, soils are sandy and porous, aquifer is under water table condition in general etc., The upland areas are under recharge zones and best suited for water harvesting compared to coastal areas which are close to discharge zones. The analysis of well hydrographs will be able to reflect the scenarios of recharge process when analyzed during any monsoon season for a short duration piezometric level and daily rainfall data.

The Gandepalli piezometer records the groundwater level data in this formation and the Pushkar canal passes with in a kilometer from the piezometer. The fluctuation of groundwater level recorded every six hours during September to November 2005 at Gandepalli is plotted along with cumulative rainfall and is shown in Fig. 30. The variation in groundwater level signals the different scenarios of presence and absence of recharge and in combination with pumping. The same are explained here.

When there is no recharge to the aquifer, the negative change in groundwater level indicates pumping of groundwater, which is only during the supply of electricity and is about 6 to 8 hours for agricultural services. After pumping stops, the groundwater level recoups at a high positive rate to fill the cone of depression. After which, the recharge is from natural yield of the aquifer. These two trends can be distinguished during the remaining 16 to 18 hours after which the cycle repeats. Thus, the weekly roaster of the electric supply can also be noticeable form such a plot. Next, when recharge starts, the deviations slowly retard and as recharge rate increases, even for pumping conditions the change will be positive. Thus, from the plot we can monitor effects of pumping and recharge on the groundwater level in the aquifer. This indicates that the groundwater level is gradually rising in the aquifer. A good water conservation practice should be able to sustain such a situation over as long period as possible.

Fig. 30 Scatter plot of change in Groundwater level at 6 hours at Gandepalli in Sep-Nov 2005



The groundwater level data is plotted against cumulative rainfall as shown in Fig. 31 to understand the rate of recharge with respect to rainfall during September to October 2005 during which more than normal rainfall occurred. The rainfall occurred in 4 different spells of which that of 3rd week of September and October with an amount of 250 and 350 mm are of interest as there is a rise of about 6 m and about 7 m in groundwater levels respectively without any noticeable fall in water table. Best line fits for both rainfall and groundwater level indicate that for a rainfall of 17 mm daily on an average, the groundwater table can rise by about 29 cm even while pumping continues. This is equal to an average 'Storativity' or storage coefficient, 'S_Y' of about 5.8%. The formations have a maximum 'S_Y' of about 10%. The recovery is increasing up to a high rate of about 0.0007m/mimute. The average rate of rise is about 0.0004 m/minute in this zone. From such plot one can decide on the typical depth of recharge shaft while designing a artificial recharge scheme. A plot of spot fluctuations along with the respective groundwater elevation is shown as scatter plot in Fig 32. This is a good indication for potential recharge characteristic of the aquifer system. So, by designing a suitable artificial recharge system, using flood flows of the Godavari River and using the ongoing Pushkar and other canal system the aquifer can be used as an underground aquifer.

Fig. 31 Impact of rainfall on groundwaterlevel in an upland sandstone aquifer at Gandepalli during Sep-Nov 2005

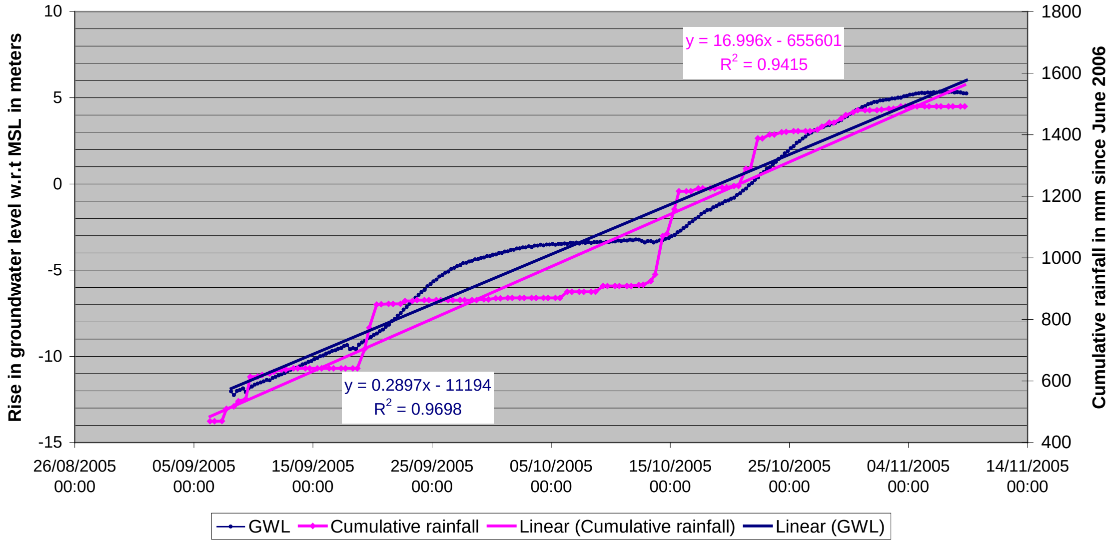
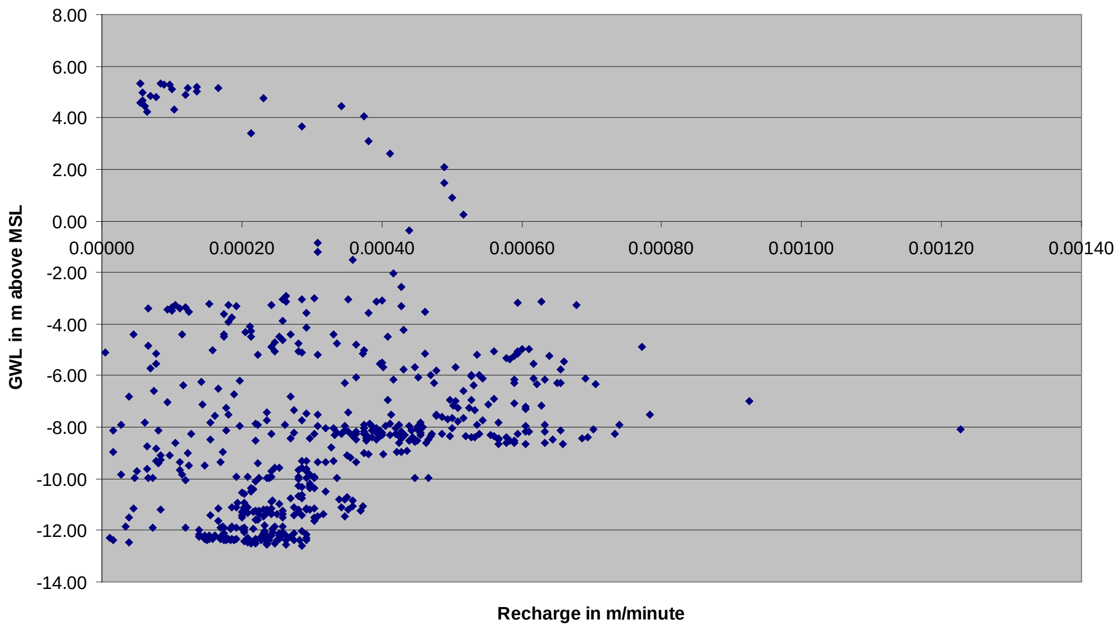


Fig. 32 **Recharge in m/minute at 0300 hours with GWL at Gandepalli piezometer**



7.0 CONCLUSIONS

Water conservation practices to be taken up in upland areas are illustrated in the study. Results of detailed hydrological investigations taken up in upland areas with particular reference to stable isotope composition in the groundwater of the Tirupati sandstone aquifer are presented. The analysis presented the variation of local meteoric precipitation line with respect to groundwater line as dD vs. d18O plots for 2004 and 2005. The analysis indicated that the d18O values of the groundwater of the aquifer are changing from pre monsoon to post monsoon even at large depth indicating the porous nature of the aquifer and the presence of rainfall recharge in the aquifer. The results on spatial variation of the d18O values in the study are useful in identifying suitable locations for undertaking artificial recharge measures in the aquifer to supplement the natural recharge to groundwater aquifer.

In the study groundwater exploitation index in the study area is arrived at and the volume of the aquifer possible for artificial recharge is quantified. An index for the groundwater exploitation in the study area is developed combining the % number of tube wells and the % of average electricity load at each village. In a given location, the larger the index, the deeper and most exploited the aquifer is. Thus, the index helps in identifying the extent of the underground reservoir. It also help in demarcating the recharge and discharge areas in the aquifer system. The areas up to Murari and Kalavacherla, which lie in the middle of the system under study, are underlain by a huge underground reservoir that is empty. Taking up Artificial recharge measures is top priority here to rejuvenate the system, as the present natural recharge is not able to arrest the about 2 to 3 metres yearly fall of water table.

The suitability of upland aquifers for undertaking groundwater recharge is discussed for a sand stone aquifer from observed piezometer data. The analysis indicates from the September October 2005 rainfall recharge process that a daily rainfall of 17mm on an average can yield in a rise of about 29 cm of groundwater level in the aquifer. This is a positive signature of the aquifer to take up appropriate natural or artificial water conservation measures. Such application undertaken at other upland areas may help in evolving suitable relationship of rainfall and recharge. The tritium isotope activity of groundwater in the study area has shown that horizontal transmissivity are of groundwater is about 1 km per year or 2.74 m / day.

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ACKNOWLEDGEMENTS

Director, A P State Groundwater Department, Hyderabad, for their support.

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