NIH/CS/12-13

Groundwater flow modeling in D1 and D2 disributaries of left main canal under Talluru lift scheme of Pushkar canal system

National Institute of Hydrology

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Kakinada

2013

Preface

Groundwater resources need to be assessed properly for better management of aquifers. This approach should be more scientific, realistic and directly measurable unlike other approaches where assumptions are made for most of the time. According to GEC, 1997 to account for spatial variations distributed parameter modelling has to be undertaken by the use of FD & FE methods.

There are number of ongoing projects in East Godavari District, Andhra Pradesh for irrigation purpose. After introduction of canal water, there was sustained rise in groundwater table, which has lead to adopt conjunctive use of surface and groundwater. Therefore, water management practices are to be planned scientifically in ongoing projects. In this direction pre project studies were undertaken on hydro-geological conditions and on canal design and flow for Pushkar canal area. The objective of the IWRM study in the Pushkar canal system is to study groundwater budget and modelling of groundwater flow to simulate the interaction of canal water and groundwater and long term effects of irrigation in the command area of D1 and D2 distributory of Left main canal under Talluru lift scheme.

The study was conducted under the supervision of Dr J. V. Tyagi, Scientist F and Co-rdinator, as a part of work programme of the Deltaic Regional Centre, Kakinada by Shri. S. V. Vijayakumar, Scientist F, as Principal Investigator with Dr. Y.R.Satyaji Rao, Scientist 'F', Shri V.S. Jeyakanthan, Scientist 'D', Dr. P.C. Nayak, Scientist 'D', Shri B.Krishna, Scientist 'C' as co-investigators with Sri T. Vijaya, SRA, Sri U. V. N. Rao, SRA and Sri P. R. Rao RA as support staff.

Abstract

Pilot command area of 7393 acres with a geographical area of about 40 sq. km under distributaries D1 and D2 of its Left main canal under Talluru lift Scheme of Pushkar canal system, located in the uplands of the Gandepalli and Jaggampeta mandals in Andhra Pradesh, is studied for its hydrologic budgeting under changed land use conditions. Seasonal groundwater balance has been carried out for study area. Groundwater flow model is conceptualized based on land use, command area and lithology. Modelling is undertaken using MODFLOW to simulate the impact of surfacewater irrigation on the groundwater recharge in the command area. Simulated groundwater level scenarios over different scenarios are analysed.

In this study on Pushkar Canal system the interaction of canal water and groundwater is established using stable isotope characterization. The groundwater balance is carried out to estimate the seasonal change in groundwater storages due to rainfall, tube wells and impact of canal network in the study area. Also, a pilot area of D1 and D2 command area and its canal system was setup over an area of 10 by 8 km using MODFLOW. Steady state simulations are done for scenarios of 1980s, 1990s, with canal and with canal and increased pumping (conjunctive use). Results indicate that the aquifer can be used as potential underground reservoir to store surplus flows and to rejuvenate existing wells and to increase their yields. IWRM plans in this direction may be useful in conservation and management of surface water, canal water and groundwater in this upland command area.

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1.0 INTRODUCTION

Groundwater resources need to be assessed properly for better management of aquifers. This approach should be more scientific, realistic and directly measurable unlike other approaches where assumptions are made for most of the time. This, however, requires adequately spaced setting up of observational wells and water level records for a sufficiently long period. Richard et. al (1980) prepared a manual for preparation of water balance which describe in detail the selection of parameters, boundaries, time period, and level of detail for different applications. The change in groundwater storage is an indicator of the long-term availability of groundwater. The change in groundwater storage between beginning and end of the non monsoon season indicates that the total quantity of water withdrawn from groundwater storage and similarly, the change between the beginning and end of the monsoon season indicates the amount of water gone into the reservoir. Since the accumulated storage of monsoon season is utilized subsequently during non-monsoon season one should be very cautious while assessing the storage. This storage plays a very important role while formulating the conjunctive practice in the study area.

In 1984, the groundwater estimation committee of union ministry of water resources after making a review of various aspects has made certain recommendations for evaluating the groundwater potential of any region. Those were modified incorporating new observations in 1997. The report of Groundwater Estimation Committee of Ministry of Water Resources, Govt. of India, in 1997 has observed that the methodology proposed is an idea to get the status of groundwater development in a administrative unit and to estimate utilizable or dependable groundwater resource for further use. It opined that there is considerable scope for refinement and improvement. In states or regions which are predominantly of alluvial terrain, a geographic unit on the basis of 'Land between two streams' (Doab) may be a proper one as delineating watersheds is difficult in such areas. Remote-sensing techniques can be profitably employed for quantifying different components referred in earlier sections. To demarcate cropped area under only groundwater and to delineation of good and poor water quality zones RS & GIS may be advantageous both from space and time aspects. To account for spatial variations distributed parameter modelling has to be undertaken by the use of FD & FE methods.

There are number of ongoing projects in East Godavari District, Andhra Pradesh for irrigation purpose. After introduction of canal water there was sustained rise in groundwater table, which has lead to adopt conjunctive use of surface and groundwater. Therefore, water management practices are to be planned scientifically in ongoing projects. In this direction pre project studies were undertaken on hydro-geological conditions and on canal design and flow for Pushkar canal area and documented. Using the said information there is need to undertake a study to understand the future scenarios of surface water and groundwater interaction in irrigated command area at typical locations of the Pushkar canal system

The objective of the IWRM study in the Pushkar canal system is to study groundwater budget and modelling of groundwater flow to simulate the interaction of canal water and groundwater and long term effects of irrigation in the command area of D1 and D2 distributory of Left main canal under Talluru lift scheme. The following analysis and methodology is attempted in this study. Data and information on canal and its water distribution system up to tail end is collected. Necessary data and information of identified pilot command area is obtained from different sources and compiled. A seasonal groundwater balance in the selected command area is carried out. From rainfall, canal water and groundwater flow the MODFLOW is applied in the study area. For some expected scenarios surface water and groundwater interaction is studied using model parameters developed.

2.0 STUDY AREA

Pushkara lift irrigation scheme at Purushotham patnam contemplates pumping 42.82 cumecs of water over a static head of +28.2 mts from River Godavari in Andhra Pradesh and is operational since 2007 and is in various stages. It is proposed to supply water from River Godavari by lift to irrigate a command area of 1,85,900 acres in about 14 Mandals, most of them in Upland areas in the East Godavari district (Fig. 1). It is also expected to provide drinking water to a population of about half a million in 139 villages. About 1000mm annual rainfall occurs in the region. This irrigation canal of about 95 km long is under construction and partially operational in upper and middle parts of its reach.

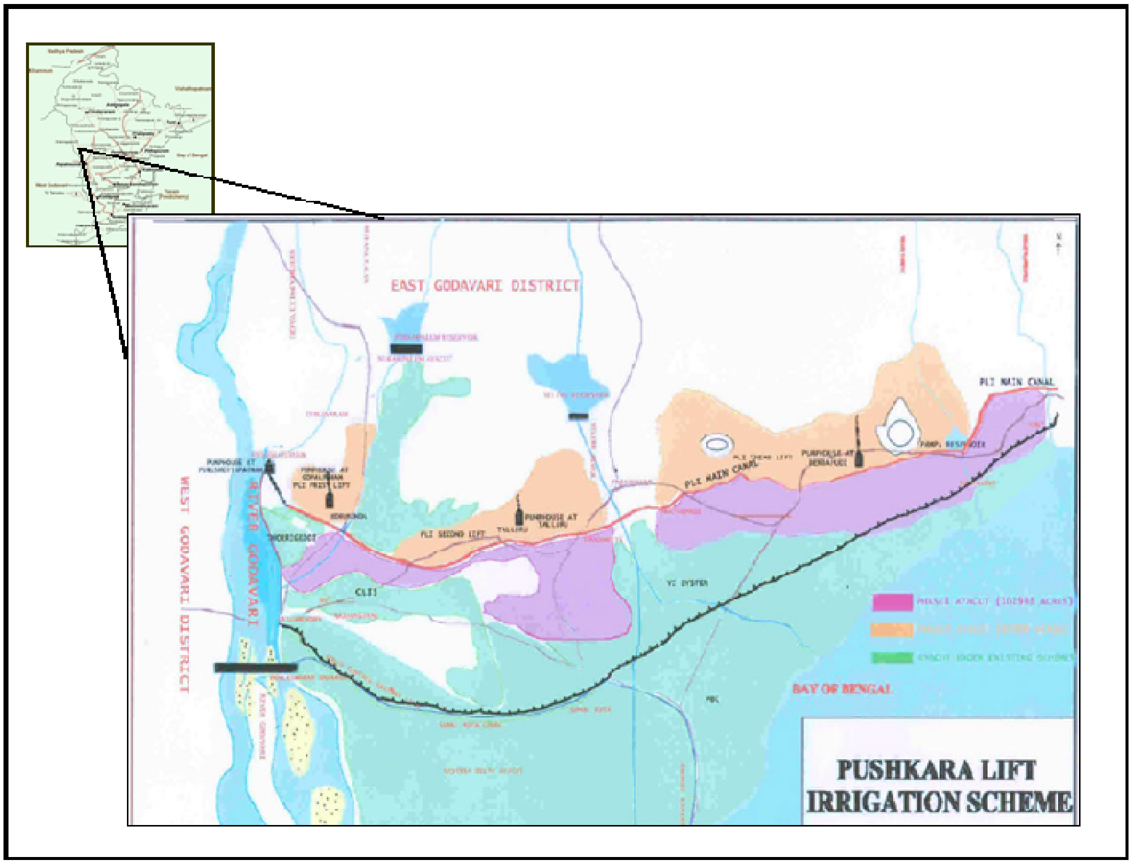


Fig.1. Location and plan of Pushkar Lift Orrigation Scheme

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 district 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

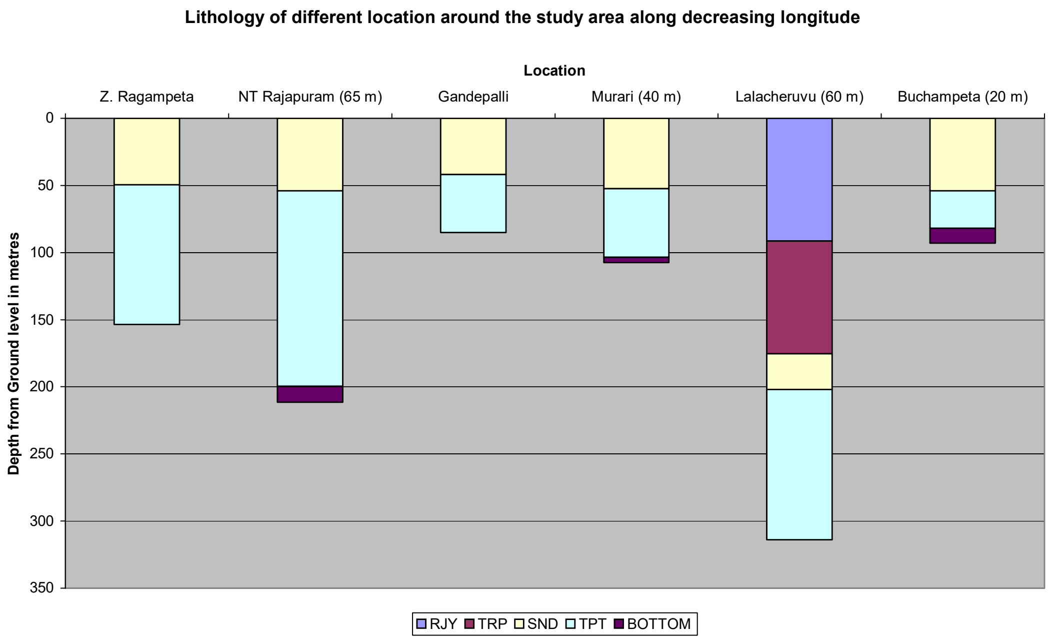
Pushkar canal mostly traverses in cutting at around +40 m contour from its origin near to Godavari river at Sithanagaram to its tail near Thondangi close to sea coast. The groundwater occurrence varies from unconfined to confined conditions in different parts of the command area of the system based on the groundwater conditions and nature of formation. The ground water levels are shallow in perched systems in local scale and deep in general from regional scale aspect.

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 Burugupudi and is most extensive 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.

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, located south west, and where the slim hole pierced through Tirupati Sandstone of 316m thickness below which Khondalite was encountered. To the east, bore hole at Mallepalle also indicated 314 m thick Gondwana rocks and according to CGWB it is very likely that further drilling by few meters would have revealed the basement. At Burugupudi towards further east the bore hole encountered basement at depth of 228 m. At Peddapuram to the south east 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 up to 750 m below ground level. The lithology for a few locations with decreasing longitude and latitude is shown in Fig. 2.



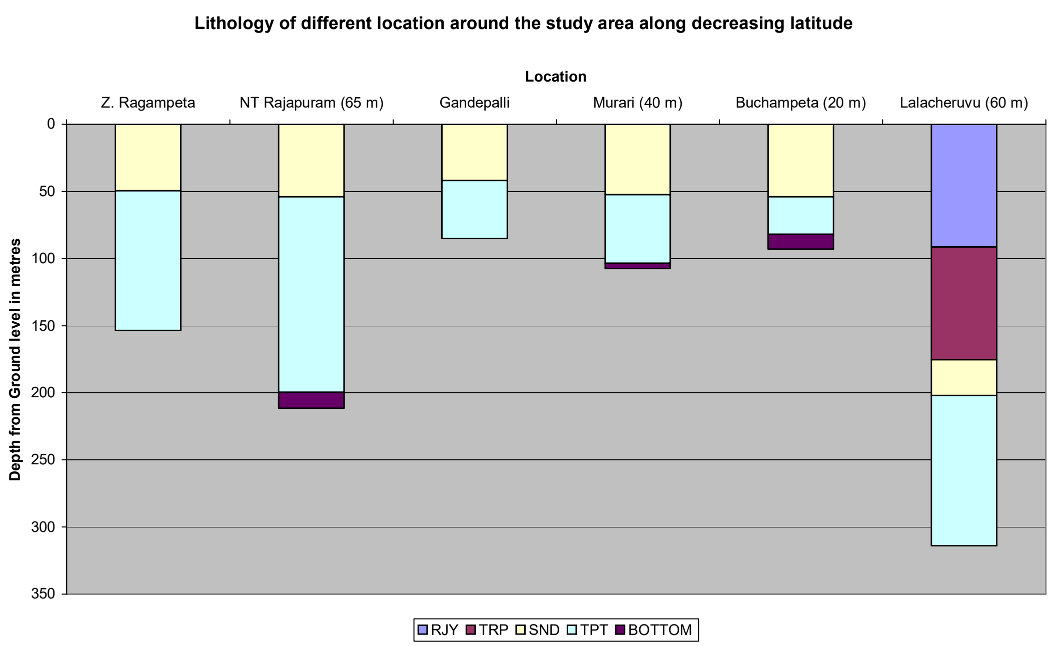


Fig. 2. Lithology at some Locations in the study area

Hydrogeology

Groundwater in Tirupati Sandstones occurs 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 dug wells and dug cum bore wells and tube wells. During eighties the water table varied form 2.28 to 15.05 m. Dug well ranging from 4 to 20 m . Most of the dug wells for irrigation purpose tap deeper confined aquifer by means of bores in the bottom of the well. Dug cum bore wells and tube wells tap confined aquifers between 27 and 100 m. The tube wells tap aquifers from 29 to 150 m. 20,000 to 50000 liters per hour from varying drawdown from 15.7 to 35.7 m (CGWB,1982). Accordingly the data of the dug wells, dug cum bore wells and tube wells suggested the existence of confined aquifer below 27 m at some locations. 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. In the Gondwana formation, transmissivity ranges from 17.3 to 96.8 with an average of 53 sq. m /day. 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.

Pilot Area & Data

A pilot study area covering command area of 7393 acres with a geographical area of about 40 sq. km under distributaries D1 and D2 of its Left main canal under Talluru lift Scheme of Pushkar canal system, located in the uplands of the Gandepalli and Jaggampeta mandals in Andhra Pradesh, is studied for its hydrologic budgeting under changed land use conditions (Fig. 3). Seasonal groundwater balance has been carried out for study area. Groundwater flow model is conceptualized based on land use, command area and lithology. Modelling is undertaken using MODFLOW to simulate the impact of surface water irrigation on the groundwater recharge in the command area. Simulated groundwater level scenarios over different scenarios are analysed.

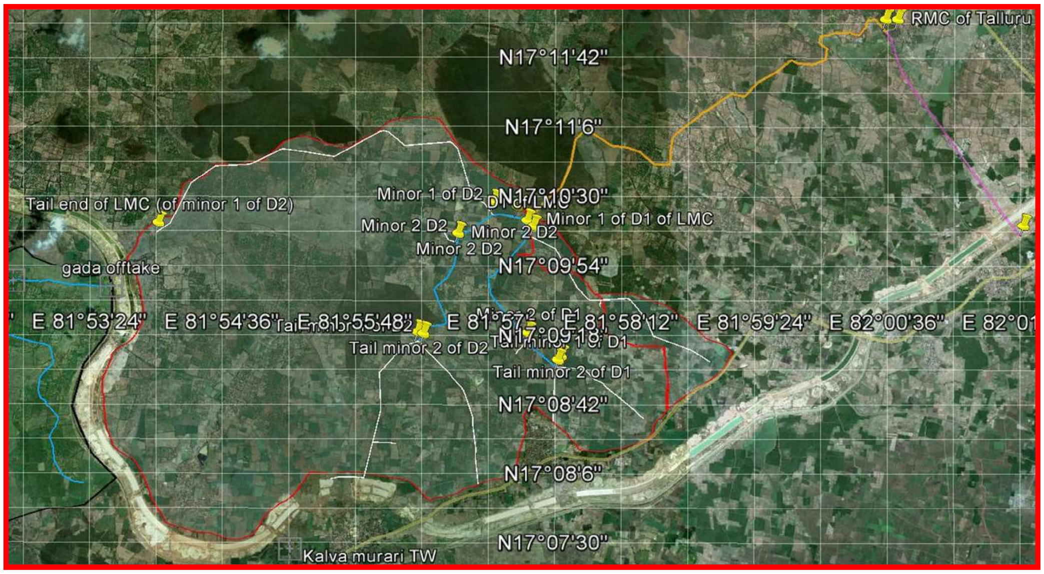


Fig. 3. D1, D2 Pilot Study area under Pushkar canal system

Local irrigation authorities are interacted to collect Pushkar system's tail-end command area information and recent canal releases is necessary. Also, collaborate with groundwater authorities on groundwater inventory and level data respectively while undertaking detailed groundwater flow modelling study is taken care of. The village wise information at some location is shown in Table 1. In this direction pre project studies were undertaken on hydro-geological conditions and on canal design and flow for Pushkar canal area and documented. During pre-project the ground water table in the study area was very deep and at Gandepalli piezo meter it was about 40 m below ground level.

Table 1. Village level socio-agri data study area

Sl. No.	Villages	No. of Families	Total Population	Cultivators	Cultivation Labour	Electrical Service Connections(Agriculture)	Average Pumping Capacity in HP
Gandepalli							
1	Singarampalem	268	1093	90	326	53	
2	Murari	1813	7175	580	1791	263	13.3
3	Gandepalli	1357	5306	311	1531	281	13.3
4	NT Rajapuram	760	2986	254	887	123	12.6
5	Mallepalli	1986	7814	430	2379	67	
Rajanagaram							
1	Kalvacherla	1487	6091	425	1852	253	11.1

The project area 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, 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 illustrates that the ground water table has fallen to depths of about 30 to 50 meters below ground level in the area, which is dotted with large number wells fitted with electric motor of 10 to 16 HP capacity. 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, a project is under progress which diverts water from Godavari for irrigation of upland areas.

Pushkar project, which is part of Polavaram project will irrigate large extent of upland from 80 to 20 m contour through its 17.8 by 3.0 m section having 42.62 cumecs discharge capacity and running for about 5 km in the study area. The lift scheme located at Talluru and part of the Pushkar canal project has a distributary system to irrigate 7393 acres with a geographical area of about 40 sq. km under distributaries D1 and D2. In N T Rajapuram village about 1675 acres lies in the study area and has about 90 deep tube wells. In case of Gandepalli village that has 3075 acres under Pushkar command area there are about 110 deep tube wells. At Murari village there are 150 deep tube wells and part of the 5813 acres of the system falls under the study area.

Polavaram LBC is under construction and flows the eastern boundary of the study area and is a lined canal. The piezometer at Gandepalli is the nearest monitoring station and records the groundwater level data in this formation. Pushkar canal releases 2006 to 2009 are obtained from the discharge capacity and working hours of pumps installed. The pumping hours for 2006 to 2009 are at wn as graph plots in 4 to 7.

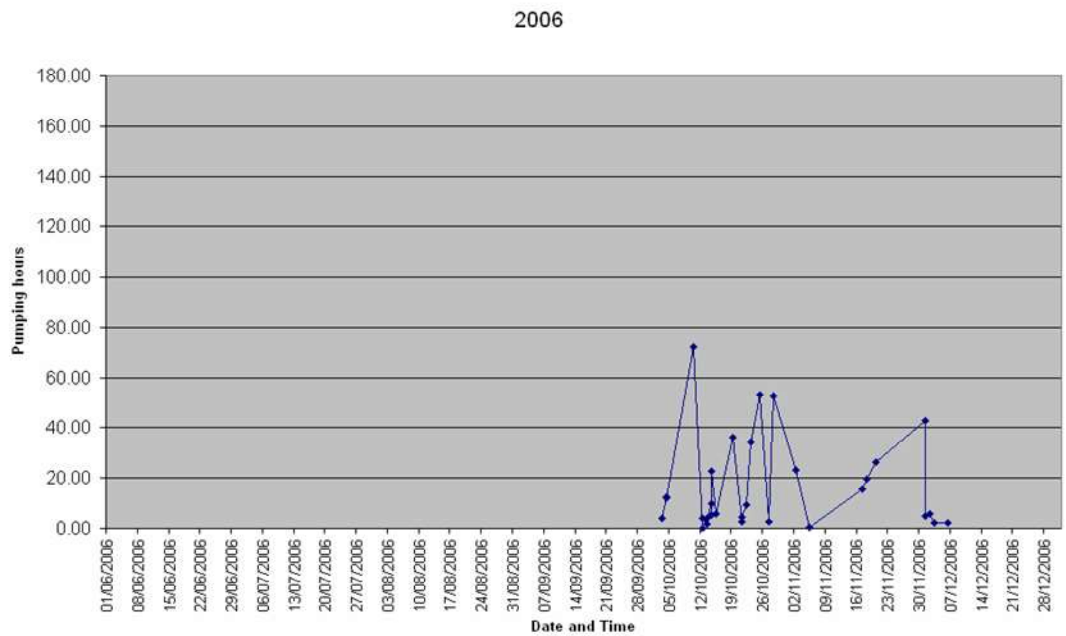


Fig. 4. Plot of Pumping hours in 2006 of Pushkar Lift Irrigation scheme

During pre-project the ground water table in the study area was very deep and at Gandepalli piezo meter it was about 40 to 60 m below ground level. The installed capacity, number of tube wells and area under irrigation in some villages in the study area is shown in the graph plot in Fig. 8. The lithology at some locations in the study area data from exploratory bore hole data is also shown as graph plot in Fig. 9.

Towards undertaking groundwater modeling, studied seasonal groundwater balance in the study area, preliminarily. The variation in monthly rainfall, canal flows and depth to groundwater level is shown in Fig. 10.

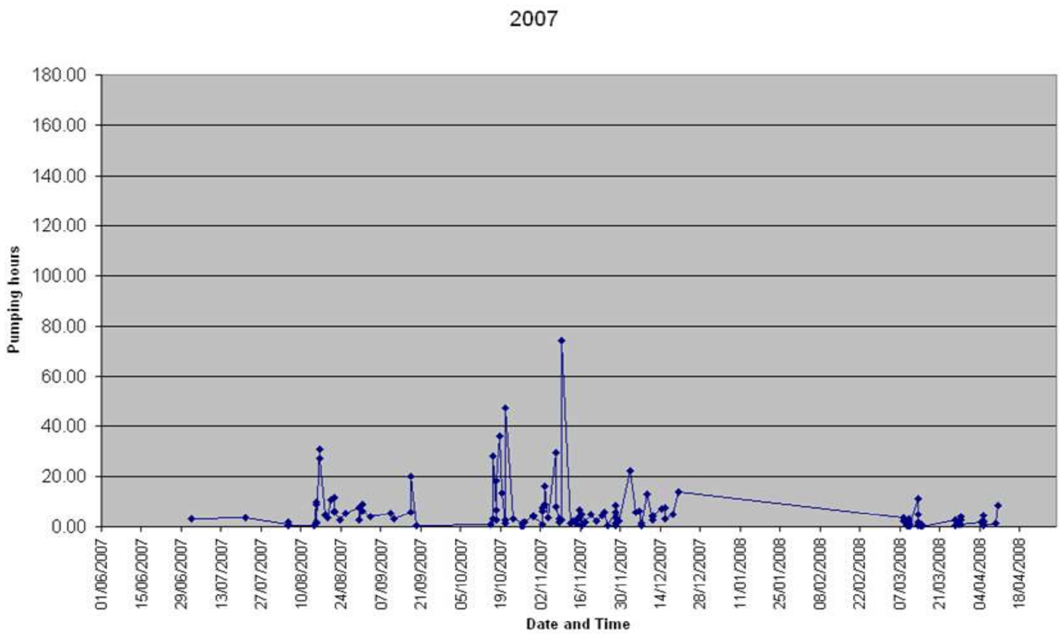


Fig. 5. Plot of Pumping hours in 2007 of Pushkar Lift Irrigation scheme

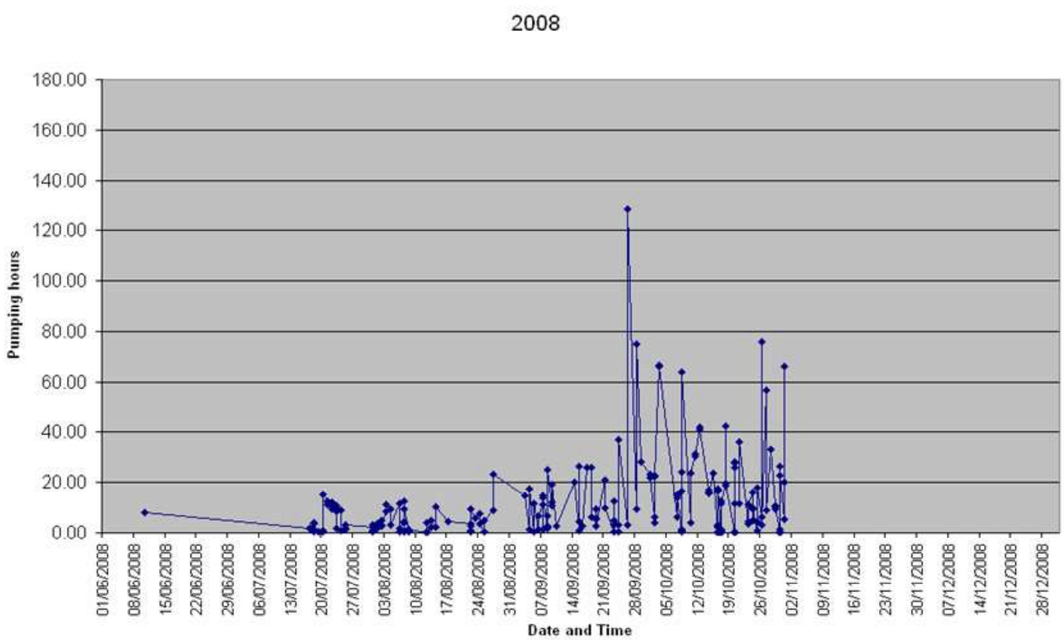


Fig. 6. Plot of Pumping hours in 2008 of Pushkar Lift Irrigation scheme

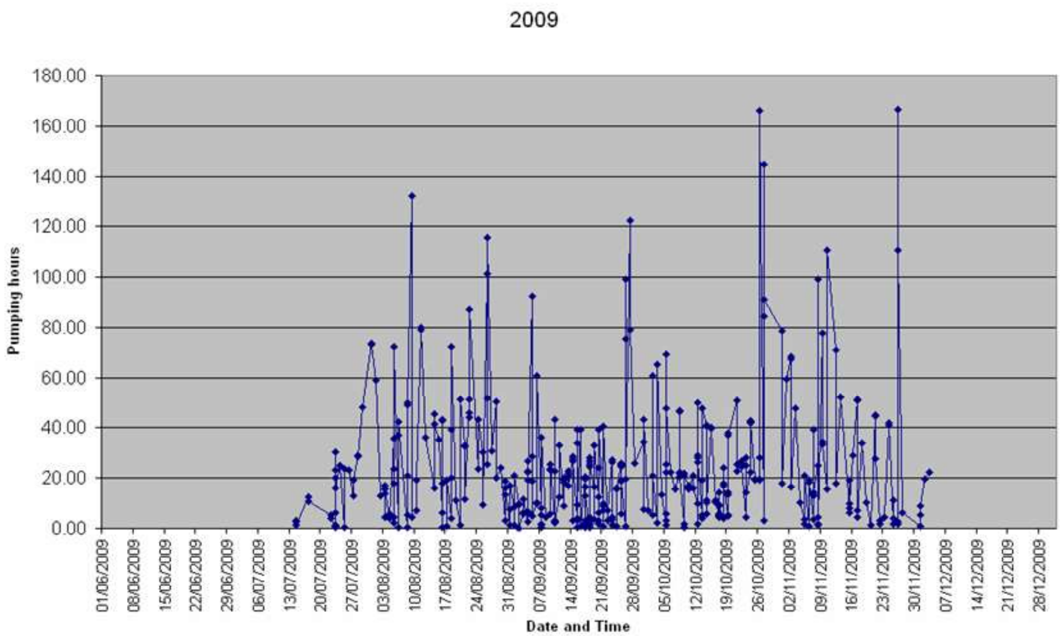


Fig. 7. Plot of Pumping hours in 2009 of Pushkar Lift Irrigation scheme

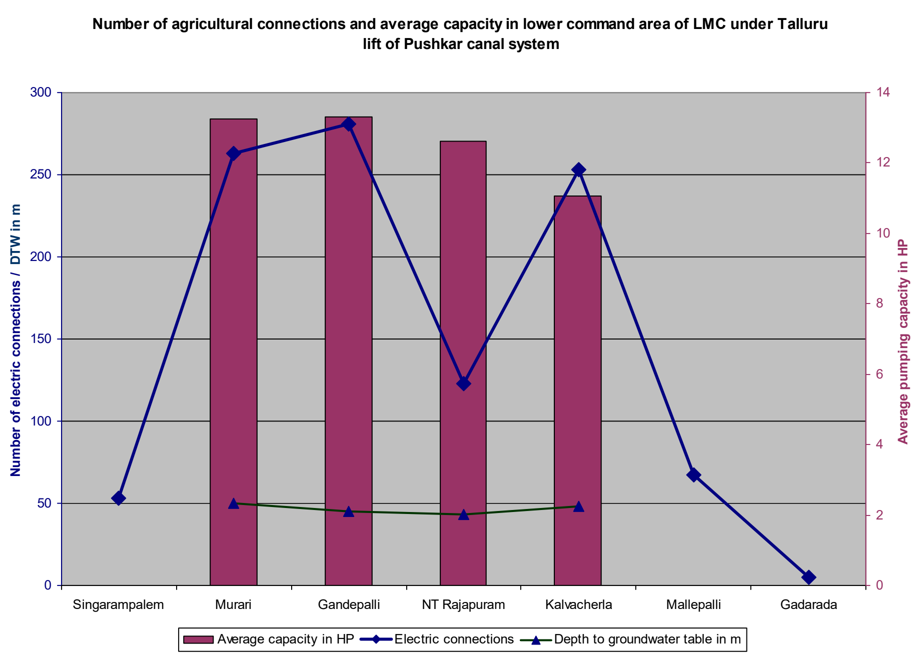


Fig. 8. Villagewise number of tube wells, installed capacity in the study area

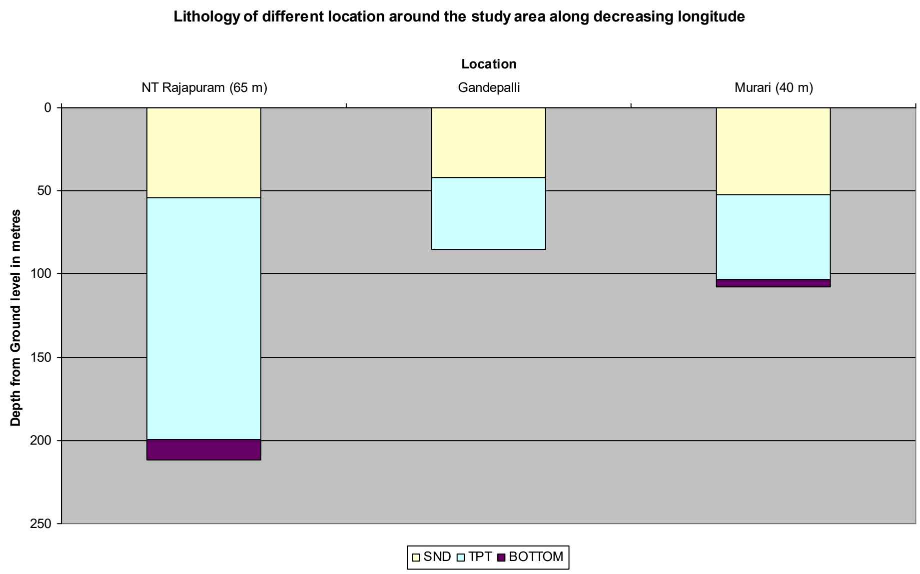


Fig. 9. Lithology at some locations in the study area

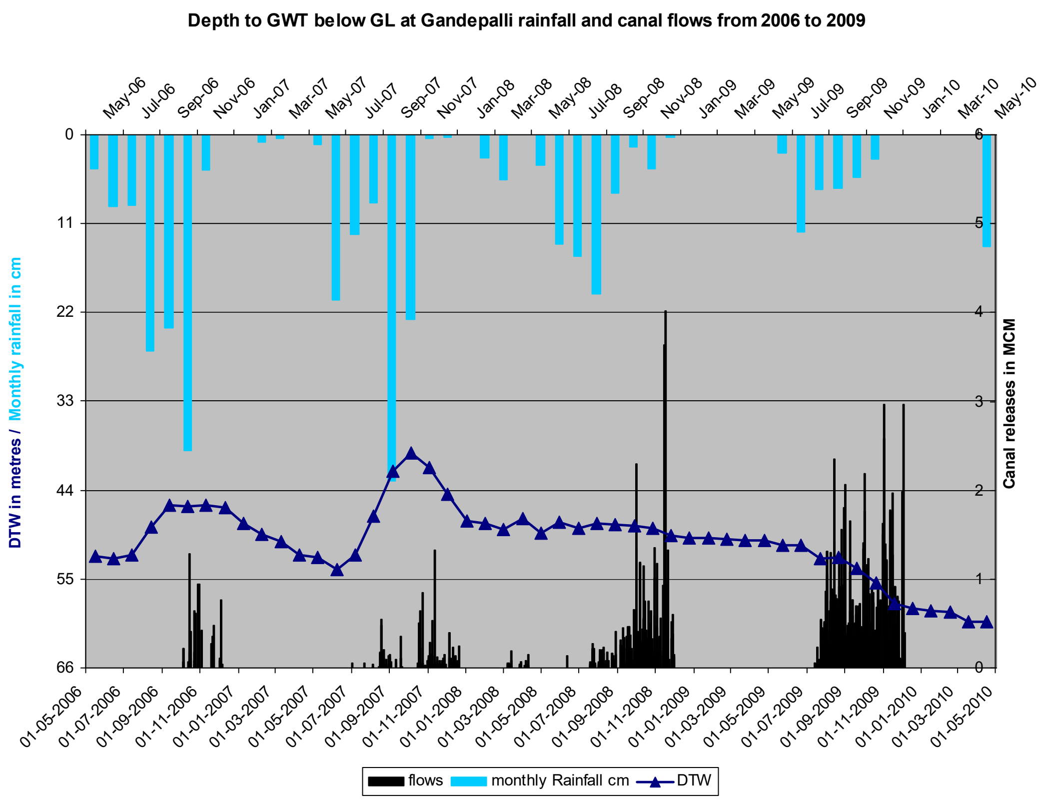


Fig. 10. Variation in monthly rainfall, canal flows and depth to groundwater level in study area

3.0 DATA AND ANALYSIS

Groundwater in general originates as precipitation as rainfall recharge. This means that the amount of recharge to a groundwater system related to its storage capacity determines the maximum available resources for exploitation. By undertaking water balance approach of an aquifer system groundwater recharge can be estimated. Nevertheless, in many cases recharge and water flow are rather complex and more information of the actual process is desirable. Knowledge of the recharge process is also important for preventing deterioration of water quality by salinization and pollution. In regions where temperature and precipitation are distinctly seasonal and groundwater flow occurs in crystalline or Karstick rocks, the stable isotope content of groundwater may indicate the seasonal dependency of recharge. The stable isotope content can also be used to determine the ratio of seasonal recharge.

3.1 Isotope In vestigations

Isotopes are elements that contain atoms with required number of protons but different numbers of neutrons. 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 at sublimation and at melting of compact ice.

The environmental isotopic methods provide a valuable approach to understand these complex phenomena as well as to test the validity of the alternative hypothesis. The application of the environmental isotope methods to understand the origin of groundwater with respect to its recharge is based on the spatial and temporal variability of the isotopic contents of water. The stable isotopes oxygen-18 ($^{18}O_{16}$) and deuterium (D or $^{2}H_{1}$) in precipitation have long been known as potential tracers for natural waters yet they have been little exploited for measuring percolation. The flux of HDO and $H_2{}^{18}O$ from an open water body to the atmosphere is reduced relative to the flux of the lighter $H_2{}^{16}O$ because of the lower vapour pressure of the former species, which causes fractionation in evaporation and condensation processes.

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 isotope with respect to the amount of total element. Vijaya Kumar et. al (2009) presented on the stable isotope characterization of groundwater in a sandstone aquifer in Andhra Pradesh. Kumar et. al (2010) discussed about variation of stable isotopic characteristics of Indian precipitation by analyzing precipitation collected from across India.

Sampling and analysis

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 2008 and 2009. Hydrological investigations were conducted to monitor water levels and collection of water samples from about 40 locations from head to tail in the command area. In the study area the depth to groundwater level is 10 to 30 m in deep wells and 2 to 3 m in shallow wells during post monsoon. The water samples of precipitation, river water, canal water, tank water and groundwater were collected during June, August and November in 2008; April and December 2009. 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 ‰ in $\delta^{18}O$ and is $\pm$ 1.0 ‰ in δD. 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. 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.

Meteoric Water Lines

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. One can notice measurable differences in isotopic character and reasonable explanations are at hand for such observation of variations in the nature. Dansgaard (1964) conducted one of the earliest studies of the $\delta^{18}O$ in precipitation. 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 (‰) and is symbolized by δ. 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)

$$\delta D‰ = 8\,\delta^{18}O + 10 \qquad (3.1)$$

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

$$\delta D‰ = A\,\delta^{18}O + d \qquad (3.2)$$

Where A is the 'slope' and d is the 'intercept' or 'D excess' 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.

3.2 Deviation in Meteoric Water 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 in 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. Indian Meteoric Water Line is

$$\delta D = 8.2\ \delta^{18}O + 9.8\ ‰ \qquad (3.3)$$

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 Gibson et al (2003) models developed through combined use of physical, isotopic and geochemical tracers, which can effectively label water sources, pathways and processes.

3.3 Stable isotope characterization of groundwater

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.

Stable isotope characteristics

The δD vs $\delta^{18}O$ plot for LMWL and best-fit lines for river water, canal water, ground water, in the study period, precipitation at Kakinada and Gandepalli of the study area are shown in Fig. 11. The 'slope' and 'D excess' or 'Intercept' of best-fit lines of different types of water are plotted and shown in tabular form in Fig. 12. On regional scale, the results indicate that the slope of GWL for June 2008 (5.51), August 2008 (5.52), November 2008 (4.91), April

2009 (4.75) and December 2009 (5.29) is less than that of best fit lines of Precipitation at Kakinada and Gandepalli (7.15 and 7.38), river water (11.01) and canal water (24.18). 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.

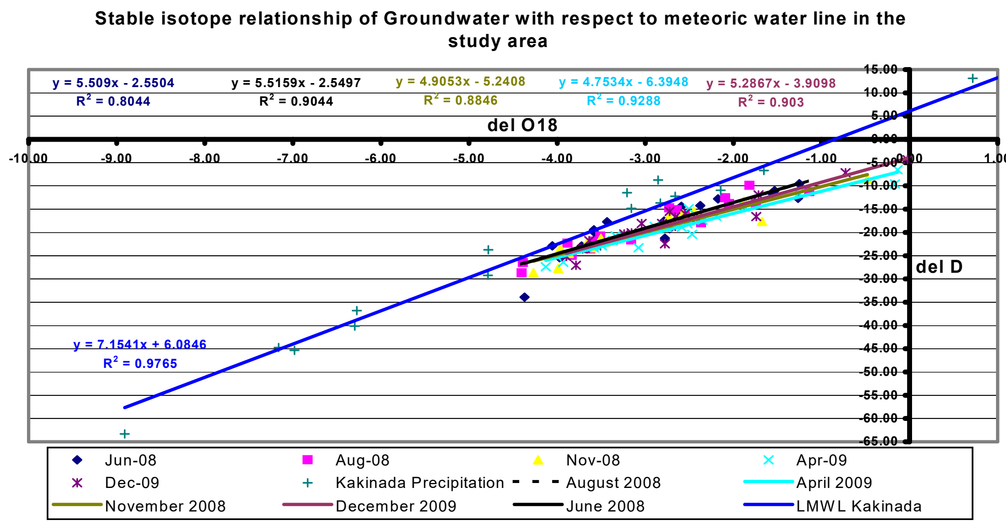


Fig. 11. The δD vs δ^{18}O plot for LMWL and best-fit lines for river water, canal water, ground water

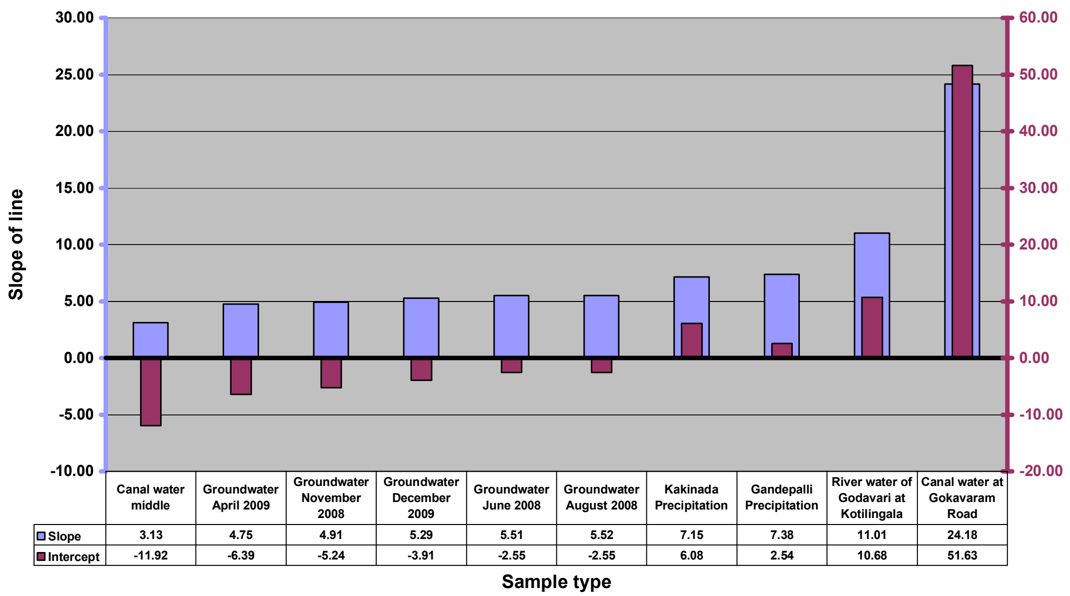


Fig.12. The 'slope' and 'D excess' or 'Intercept' of best-fit lines of different types of water

The GWL during different months has slopes from 4.75 to 5.51 indicating the recharge conditions to groundwater are almost uniform during study period and shows that it is from residual liquid water that has undergone evaporative fractionation and not show any fresh recharge or dilution effects of monsoon. It is to be noted that 2008 and 2009 are low rainfall years with most surface water bodies were under drought and hence groundwater recharge is absent. The D excess of GWL in the month of June 2008 (-2.55), August 2008 (-2.55), November 2008 (-5.24), April 2009 (-6.39) and December 2009 (-3.91) is less than that of best-fit lines of precipitation at Kakinada and Gandepalli (6.08 and 2.54), river water (10.68) and canal water (51.63). This also indicates that the recharge conditions to groundwater are almost constant during study period the fresh recharge is negligible due to drought conditions during 2008 and 2009.

4.0 RESULTS AND DISCUSSIONS

The surface water and groundwater interaction may be studied by groundwater modeling, channel water balance, isotope mass balance method and/or by statistical method using the river and groundwater water level fluctuation data. The statistical method based on Darcy's law involves analyses of the river water levels and groundwater levels adjacent to the river. Here, procedure isotope mass balance method is dealt briefly.

The approach is based on the fact that if the rivers originates at higher altitudes and has a different stable isotopic composition than that of groundwater that is recharged by infiltration of local precipitation then stable isotopes can be used to understand river and groundwater interaction. In most of the cases, the stable isotope ^{18}O is utilized for determining the contribution of groundwater to the river flow. For example, the isotopic balance and mass balance equations of an admixture of rainwater and groundwater in a stream can be written as

$$mg.Rg + mr.Rr = Ram \qquad (4.1)$$

and

$$mg + mr = 1 \qquad (4.2)$$

where, Rg and Rr are the isotopic composition of the groundwater and the river water respectively and mg and mr are the fractions of ground water and river water respectively in the admixture, Ram is the isotopic composition of the admixture.

From the above two equations, we have

$$mr = (Ram – Rg) / (Rr – Rg) \qquad (4.3)$$

$$mg = (Ram – Rr) / (Rg – Rr) \qquad (4.4)$$

Therefore, by knowing the value of Rg, Rr, and Ram, the fraction of river water mixed with ground water can be evaluated. The ^{18}O values of different types of waters are shown as graph plot and in tabular form are shown in Fig. 13. It is to be noted that water was released in Pushkar canal upto Jaggampeta only till 2008. Ellamilli is in the upstream side and Kodavali on the down stream side from Jaggampeta on the Pushkar canal.

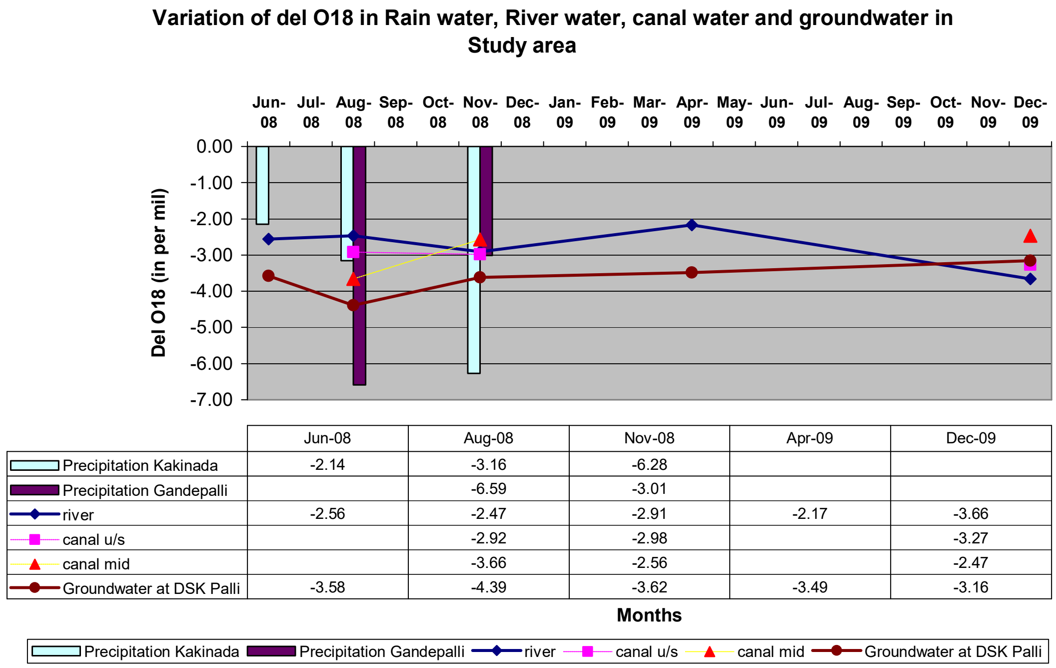


Fig. 13. The ^{18}O values of different types of waters in the study area

The contribution of recharge from rainfall and canal water are estimated using ^{18}O values during the month of November 2008 at two well locations near Ellamilli and Kodavali in the middle of Pushkar canal command area using the mass balance approach and shown in Table 2. It indicates that during the month of November 2008, the contribution of canal water is about 41% and indicates the effect of canal recharge on groundwater there. At Kodavali the situation is different due to different geology there with only 13% of canal water mixing with local groundwater.

Table 2. Contribution of canal water and precipitation in the groundwater in November 2008

Location	Contribution of Canal Water	Contribution of precipitation
Ellamilli	41 %	59 %
Kodavali	13 %	87 %

4.1 Groundwater balance

The principle of water balance or water budget states that, with in any system difference of all the supply components and use components should balance the change in storage of the system. Depending on the water resources development of the system, water balance should be conducted area wise for canal water, groundwater and rainwater. In deltas and coastal areas, where rainfed and public lift irrigation schemes are hardly found, components of rainwater balance and groundwater balance are of less importance compared to water balance components of canal water. Once conjunctive use practice of surface water and ground water commences the components of groundwater balance becomes important in areas where exclusive extraction of groundwater is expected to occur. Canal water balance should be taken up when canal water is the main source of supply supplemented by groundwater from private wells. The hydrologic water balancing for an area is undertaken by estimating or calculating individual supply components and abstraction or use components properly and understanding the change in storage as at Fig 14.

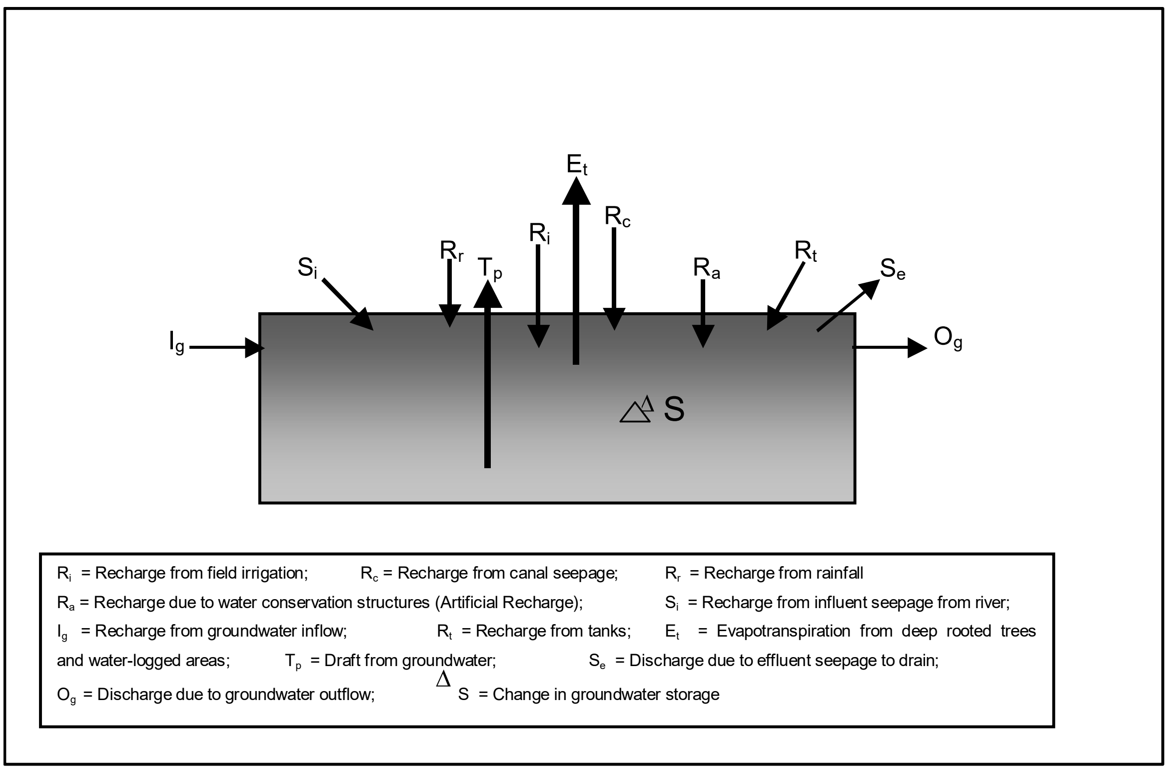


Fig. 14. Water balance components of groundwater system

Precipitation or rainfall; stream flows; storage in tanks and reservoirs; groundwater pumpages; changes in groundwater storage; groundwater inflows; imported water; return flows are some of the supply components. Agricultural water for irrigation; municipal and commercial uses for drinking and industry; compensation releases; water rights and legal entitlements for drawing water; natural depletions through evaporation, evapotranspiration, groundwater outflows and seepage are some of the use components. Standard techniques and methods of estimating most of the components are discussed in brief here. Some of the supply components and use components are being continuously monitored by various State and Central Government organizations, whereas difficulties are being faced in estimating those components which require detailed experiments. Because of this when each experimental information is not available, a suitable empirical relation should be sought in estimating such parameters.

The basic concept of water balance, as mentioned earlier, is

$$\sum I - \sum O = \Delta S \qquad \text{---------} \; 4.5$$

where I is input or supply components of the system, O is output or use components of the system and ΔS is change in storage of the system. The detailed input and output components for groundwater balancing are listed below and the methodologies for assessment are described.

I. Supply components:

A) Natural recharge:

1) Rainfall recharge

2) Recharge from river

3) Recharge from other basins

B. Artificial recharge:

1) Induced recharge from rivers

2) Recharge from Canals and fields

3) Recharge by injection and spreading

II. Use components:

A. Natural

1) Evapotranspiration

2) Regeneration in rivers

3) Outflow to other basins

B. Artificial

1) Groundwater draft through public and private openwells, filter points and tubewells. Some times legal aspects need to be considered.

Considering various inflow and outflow components, the ground water balance can be formulated as

$$(R_i + R_c + R_r + R_a + S_i + I_g + R_t) - (E_t + T_p + S_e + O_g) = \Delta S \qquad \text{----- 4.6}$$

where,

R_i = Recharge from field irrigation

R_c = Recharge from canal seepage

R_r = Recharge from rainfall

R_a = Recharge due to water conservation structures (Artificial Recharge)

S_i = Recharge from influent seepage from river

I_g = Recharge from groundwater inflow

R_t = Recharge from tanks

E_t = Evapotranspiration from deep rooted trees and water-logged areas

T_p = Draft from groundwater

S_e = Discharge due to effluent seepage to drain

O_g = Discharge due to groundwater outflow

ΔS = Change in groundwater storage

From the importance of the components that have considerable impact on the water balance and neglecting the components that are not dominant, the water balance is studied from 2006 to 2010 in the study area for inflow and outflow components and change in groundwater storage over monsoon and non-monsoon seasons. The estimated components from water balance for monsoon and non-monsoon seasons in the study area is shown in Tables 3 and 4.

Table 3. Groundwater balance for monsoon season

Groundwater Balance of monsoon season in the study area (in MCM)				
	2006-07	2007-08	2008-09	2009-10
Recharge from canals	0.000	0.000	0.300	0.300
Recharge from SW	0.000	0.000	0.990	0.990
Draft	2.700	2.700	2.700	2.700
Recharge from GW	0.675	0.675	0.675	0.675
Rainfall recharge	5.096	4.906	2.798	1.639
Net groundwater flow	0.765	0.765	0.436	0.256
Change in Storage	3.836	3.646	2.499	1.159

Table 4. Groundwater balance for non-monsoon season

Groundwater Balance of non monsoon season in the study area (in MCM)				
	2006-07	2007-08	2008-09	2009-10
Recharge from canals	0	0	0	0
Recharge from SW	0	0	0.990	0.990
Draft	5.400	5.400	5.400	5.400
Recharge from GW	1.350	1.350	1.350	1.350
Rainfall recharge	0	0	0	0
Net groundwater flow	0.250	0.250	0.250	0.250
Change in Storage	-3.800	-3.800	-2.810	-2.810

To understand the variation in different components over different years the estimated quantities for monsoon and non-monsoon seasons from the budget are shown as plots in Fig. 15 and 16 respectively. The seasonal variation of change in groundwater storage is shown as graph plot in Fig. 17 as bar chart and in Fig. 18 as line chart. The variation in storage is closely comparable with variation in observed depth to water table as shown in Fig. 10.

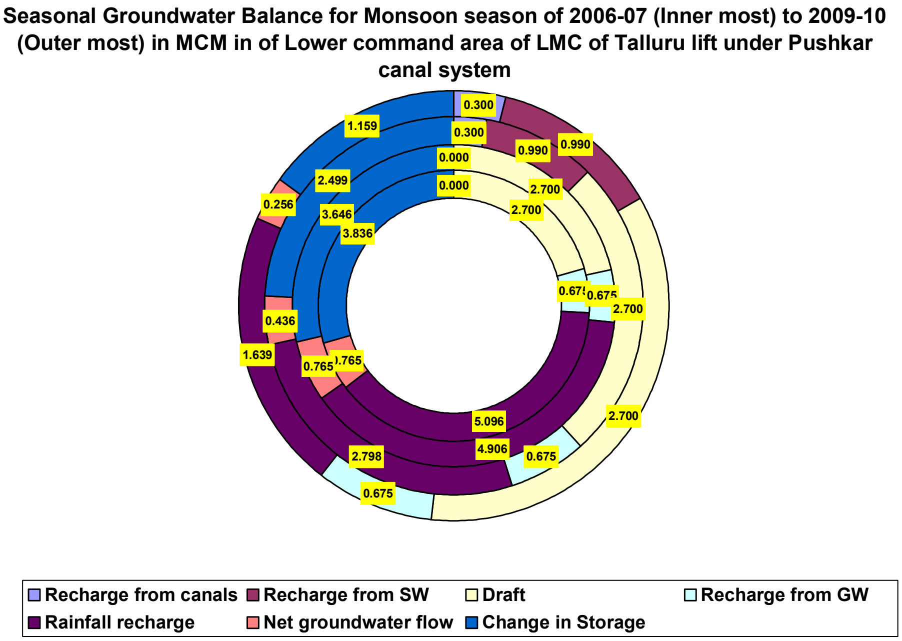


Fig. 15. Groundwater Balance for Monsoon season 2006-07 to 2009-10

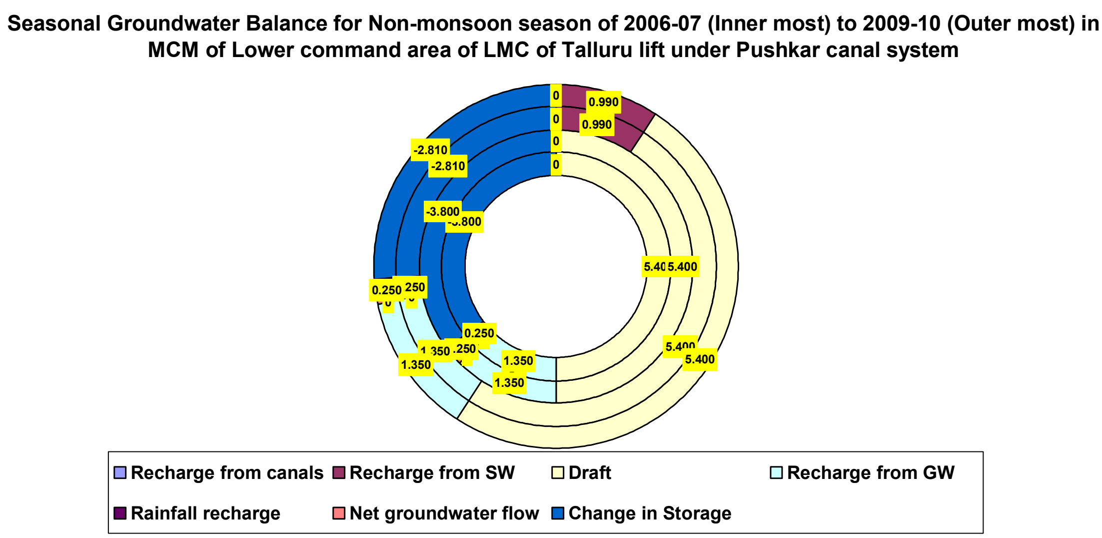


Fig. 16. Groundwater Balance for Non-Monsoon season 2006-07 to 2009-10

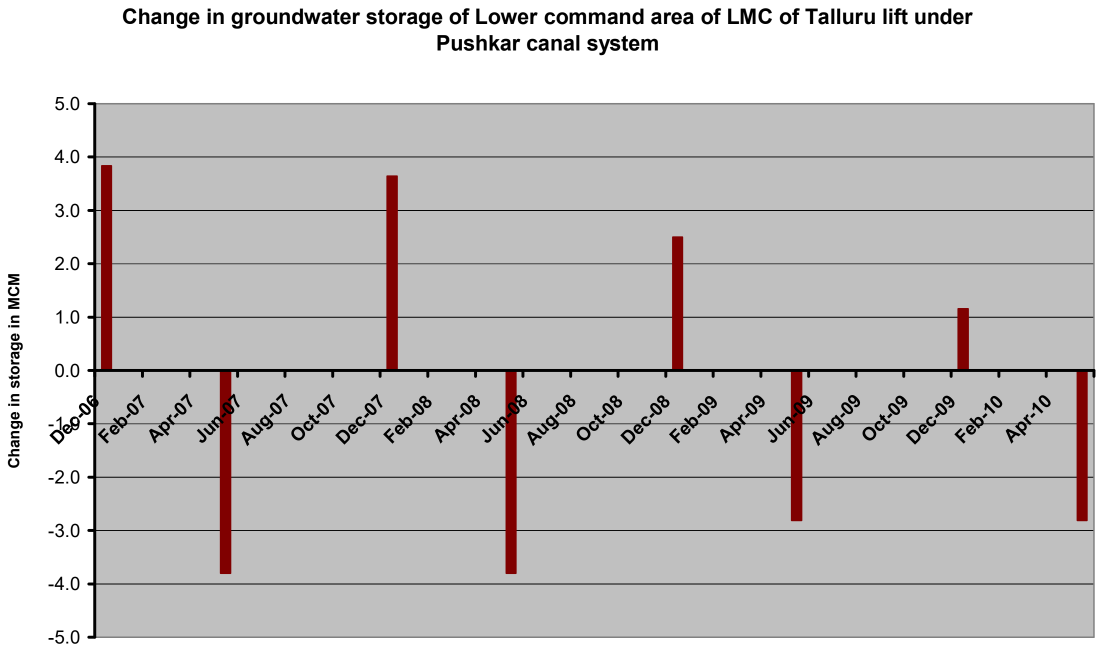
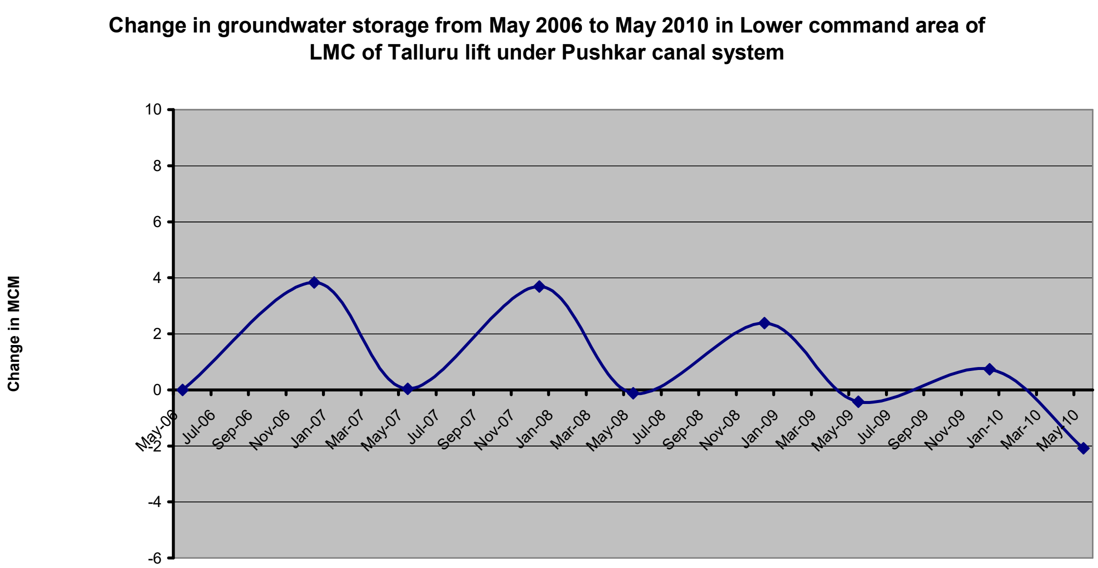


Fig. 17. Bar Chart showing the seasonal variation of change in groundwater storage



	May-06	Dec-06	May-07	Dec-07	May-08	Dec-08	May-09	Dec-09	May-10
Series1	0	3.836	0.036	3.682	-0.118	2.381	-0.429	0.730	-2.080

Series1

Fig. 18. Plot showing the seasonal variation of change in groundwater storage

4.2 MODFLOW Simulation

Subsequently, groundwater flow modelling is carried out using MODFLOW for different scenarios to understand the impact of canal flow in the pilot command area. MODFLOW is a three-dimensional finite-difference groundwater flow model (Mc Donald and Harbaugh, 1988). It has a modular structure that allows it to be easily modified to adapt the code for a particular application. Many new capabilities have been added to the original model. Latest version includes all the major capabilities. MODFLOW simulates steady and non-steady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined (Harbaugh, 1992). Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic (restricted to having the principal direction aligned with the grid axes and the anisotropy ratio between horizontal coordinate directions is fixed in any one layer), and the storage coefficient may be heterogeneous. The model requires input of the ratio of vertical hydraulic conductivity to distance between vertically adjacent block centers. Specified head and specified flux boundaries can be simulated as can a head dependent flux across the model's outer boundary that allows water to be supplied to a boundary block in the modeled area at a rate proportional to the current head difference between a "source" of water outside the modeled area and the boundary block. MODFLOW is currently the most used numerical model in the U.S. Geological Survey for ground-water flow problems. An efficient contouring program is available to visualize head and draw-down output by the model.

The ground-water flow equation is solved using the finite-difference approximation. The flow region is considered to be subdivided into blocks in which the medium properties are assumed to be uniform. The plan view rectangular discretization results from a grid of mutually perpendicular lines that may be variably spaced. The vertical direction zones of varying thickness are transformed into a set of parallel "layers". Several solvers are provided for solving the associated matrix problem; the user can choose the best solver for the particular problem. Mass balances are computed for each time step and as a cumulative volume from each source and type of discharge.

The groundwater flow modeling has been performed using Visual MODFLOW 2.1 version. The different input layers i.e. recharge, boundary conditions, well locations and hydraulic conductivity have been input and created a model in Visual MODFLOW Package for the study area. Collected data has been used as an input for MODFLOW model. Boundary conditions, river, drain, wells based on well data in the model have been input to the model. The different boundary conditions used in the groundwater model such as no flow in Northern side, and flow boundary on the other sides. Canals have been marked for the respective areas for groundwater flow modeling. As per the map, flow direction in general is from north east to south west in study area. The model setup and features adopted in the study is shown in Fig. 19. The topography of the study area is gently sloping as sand stones are exposed here. The elevation of the top surface in the study area varies from 100 to 60 m above mean sea level. Adjusting the top and bottom surfaces in the model is a difficult task and accuracy of the results of the model depends upon the accuracy of the layer. Contour information was used in drawing surface contours. The lithology of the study area is described in previous section.

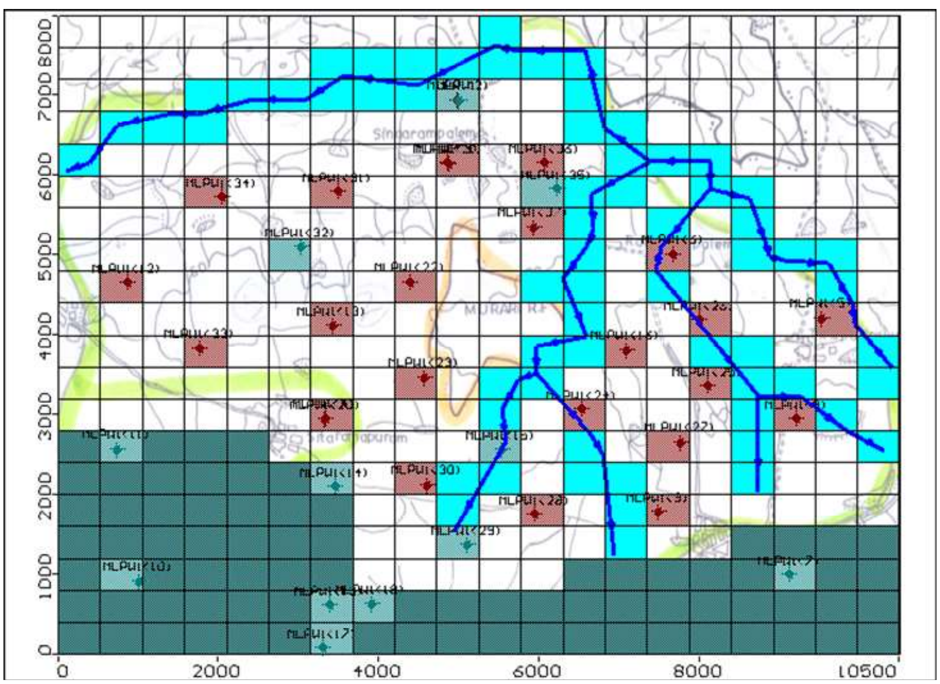


Fig.19. The model setup and features adopted in MODFLOW

The well data and canal data modules adopted are shown in Fig. 20 and 21. The draw down for steady state of that used to be there during 1980s (before the electric pumps came into existence) is shown in Fig. 22 and corresponding ground water levels in Fig. 23.

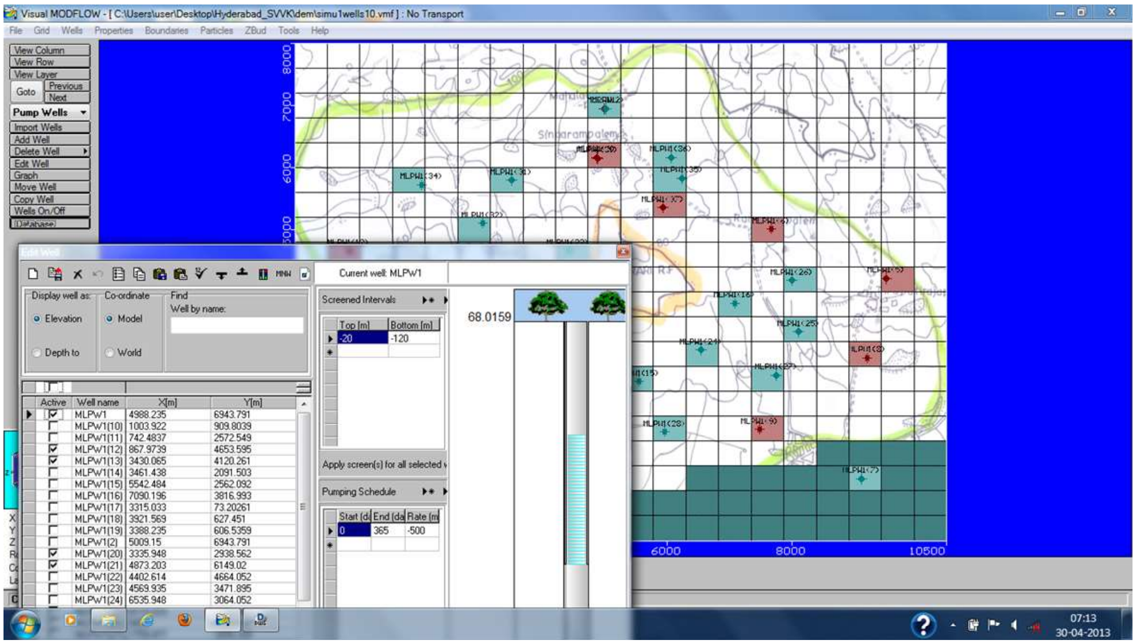


Fig. 20. Well data module adopted in the study area

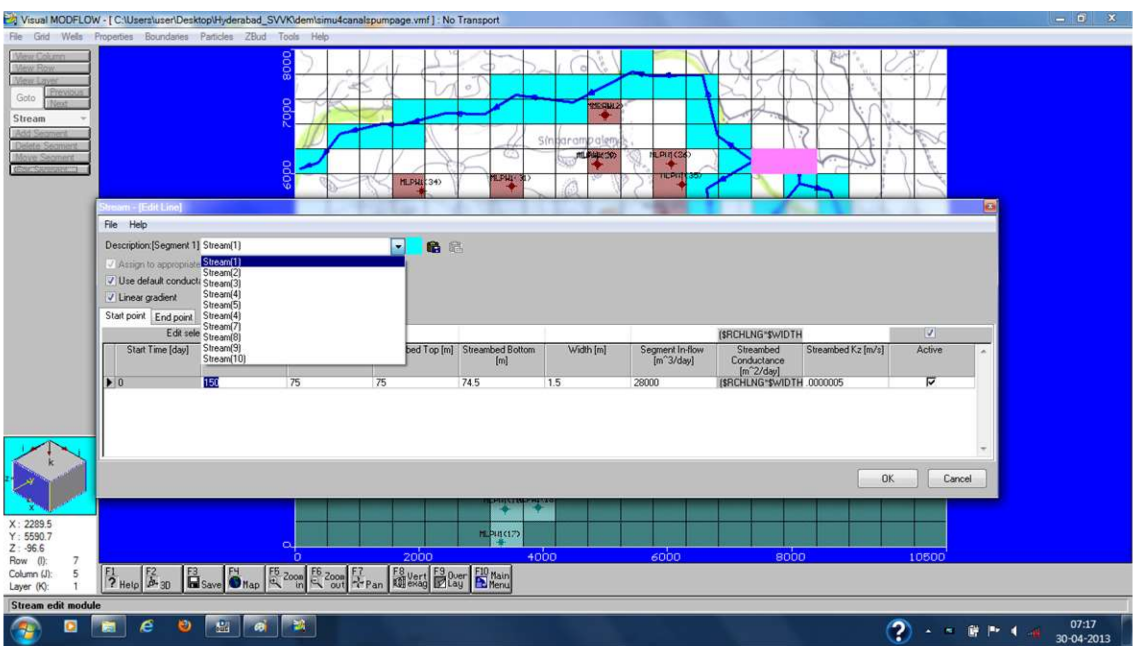


Fig. 21. Canal data module adopted in the study area

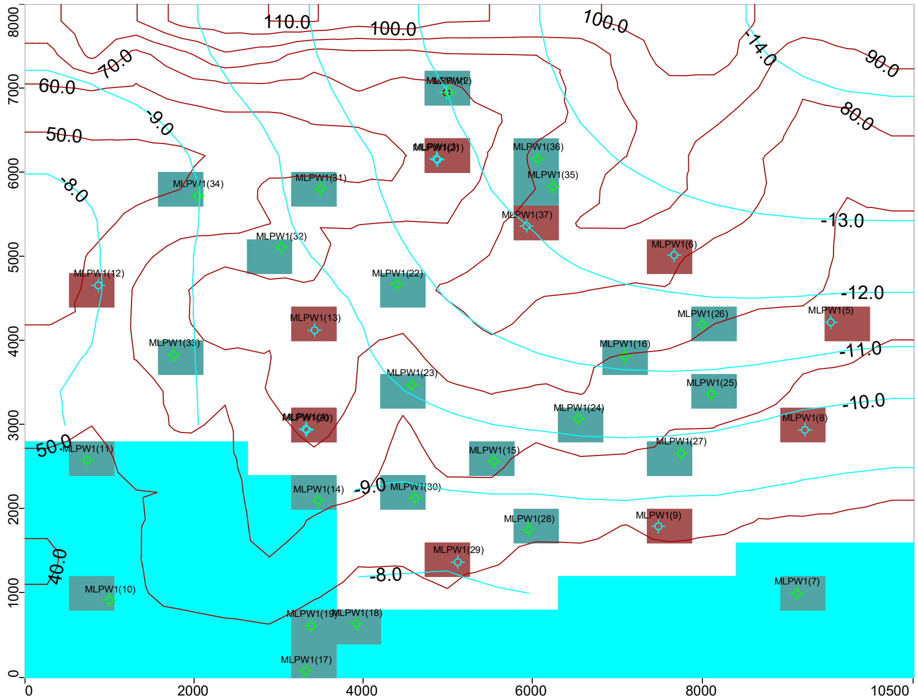


Fig.22. Drawdown scenario for steady state conditions of 1980's

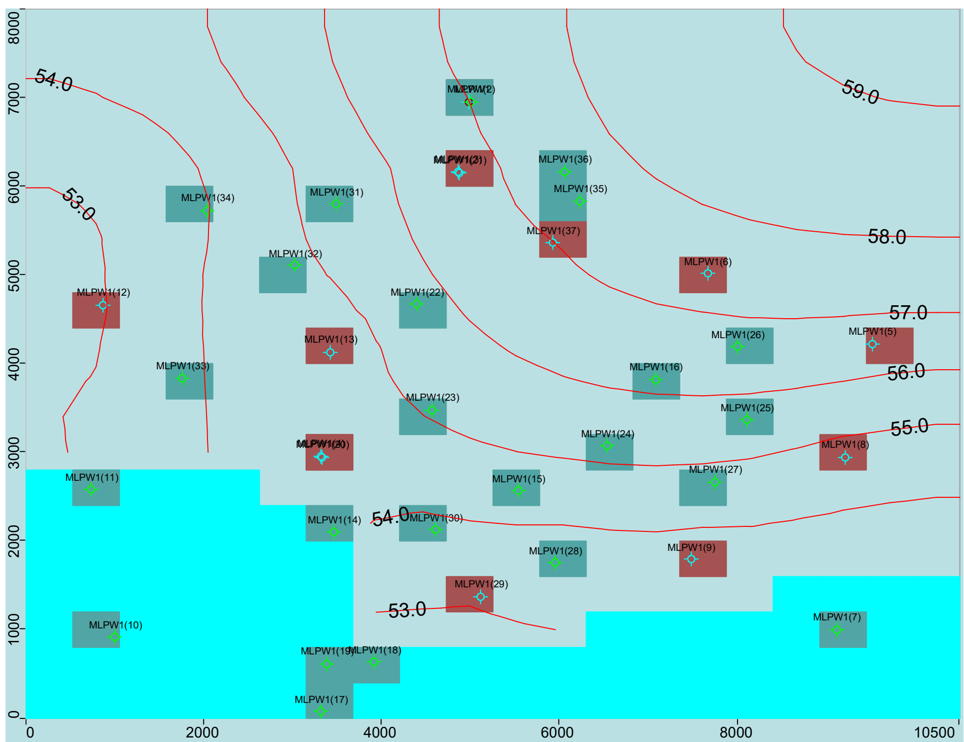


Fig. 23. Ground water levels scenario for steady state conditions of 1980's

The effect of pumping during 1990s can be seen in modeled depth to water table contour plot in Fig. 24 and corresponding level in Fig. 25. The impact of canals is simulated and the corresponding groundwater level map is shown in Fig. 26. The impact under conjunctive use of canal water and groundwater can be seen in the plot shown in Fig. 27 for the groundwater levels for such scenario.

Variation in Groundwater head

The variation in groundwater level in the study area as cross section plot for steady state or during 1980's is shown in Fig. 28. Similar plot for 1990's with increased pumping is shown in Fig. 29. The impact of canal and rise in groundwater head is shown in Fig. 30. From the plot, a rise in groundwater table by about 4 to 5 m can be seen. Similar plot showing the impact under conjunctive use of canal water and groundwater can be seen in the in Fig. 31.

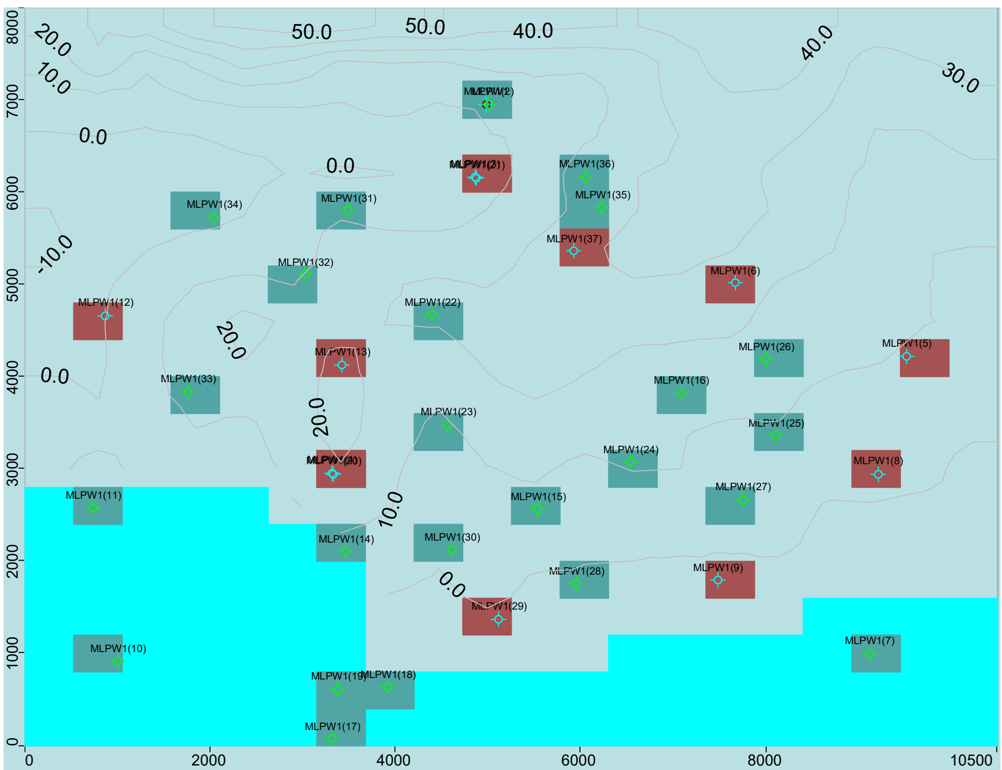


Fig. 24. Plot of depth to water table under the effect of pumping during 1990s

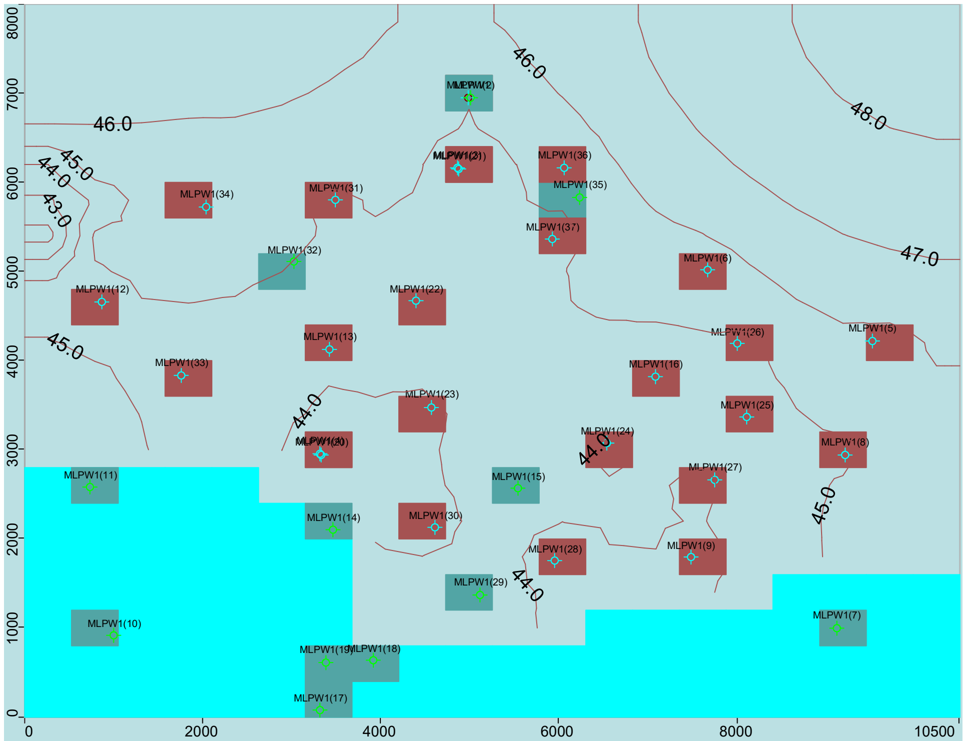


Fig. 25. Plot of Groundwater levels under Effect of pumping during 1990s

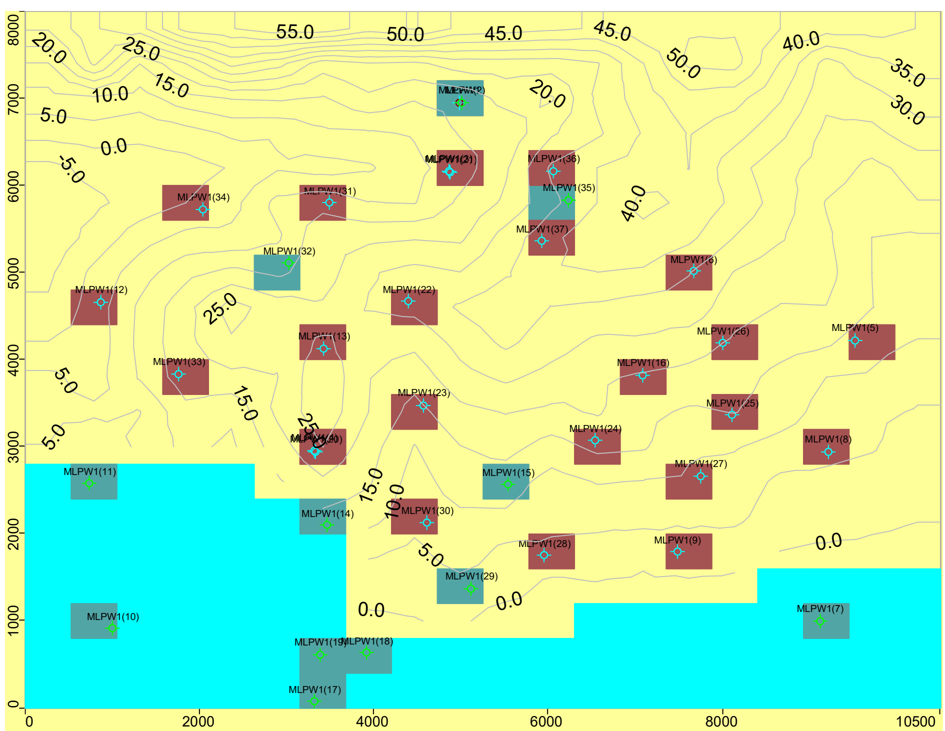


Fig.26. Plot of Groundwater levels under Impact of canals

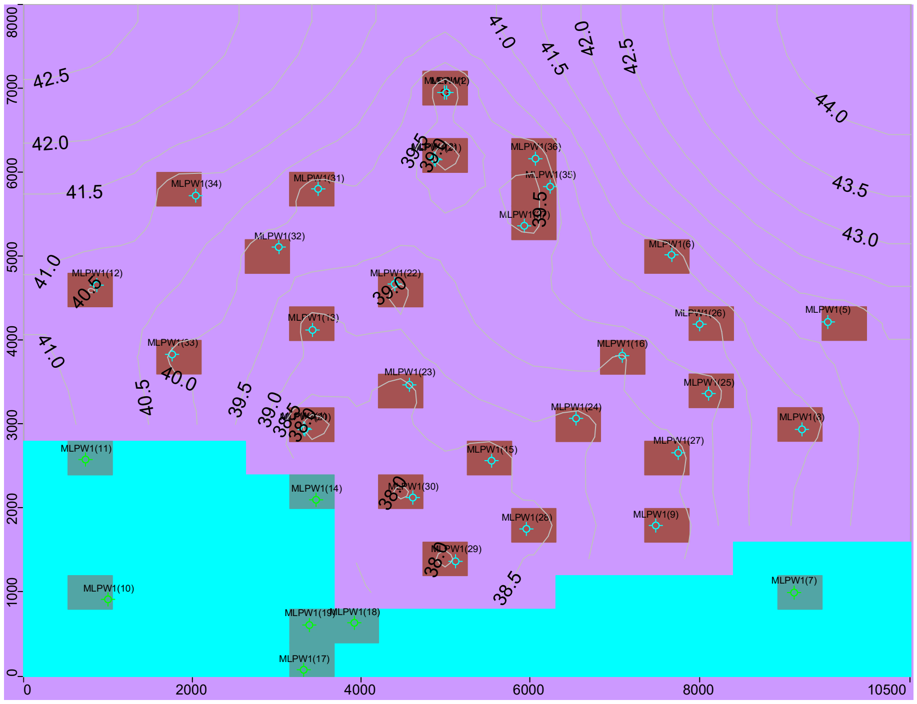


Fig27. Plot of Groundwater levels under conjunctive use practice

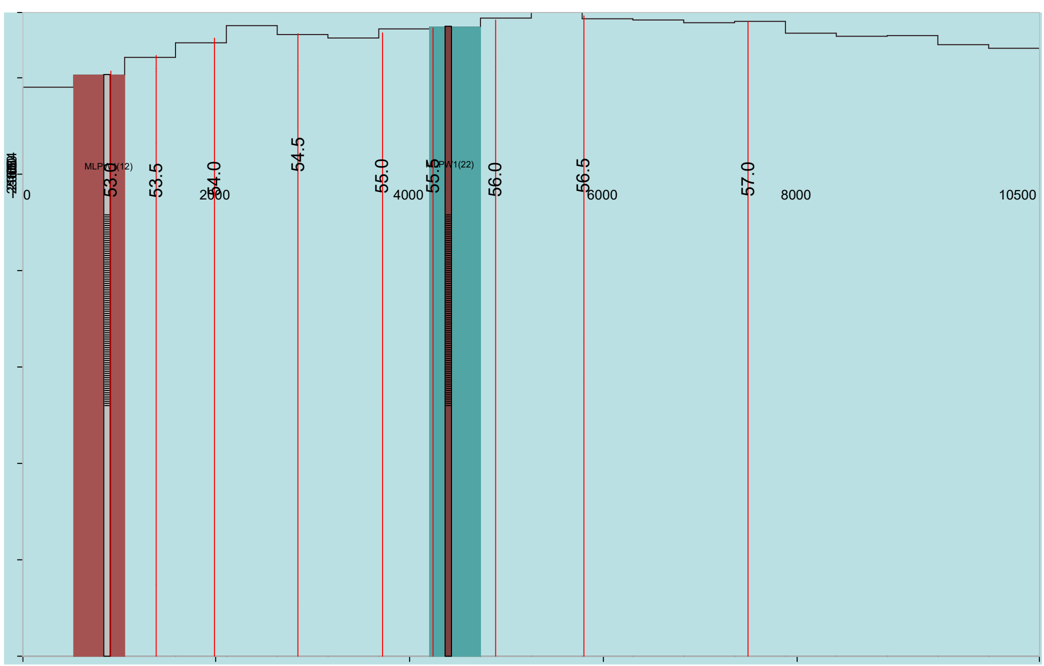


Fig.28. Cross section plot of Groundwater levels for steady state during 1980s

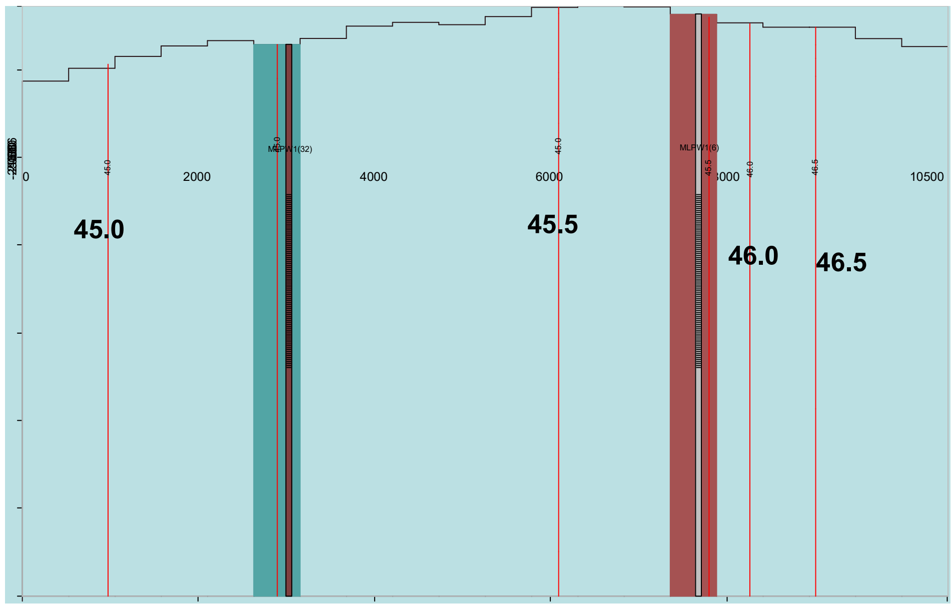


Fig. 29. Cross section plot of Groundwater levels, increased pumping with respect to late 1990s

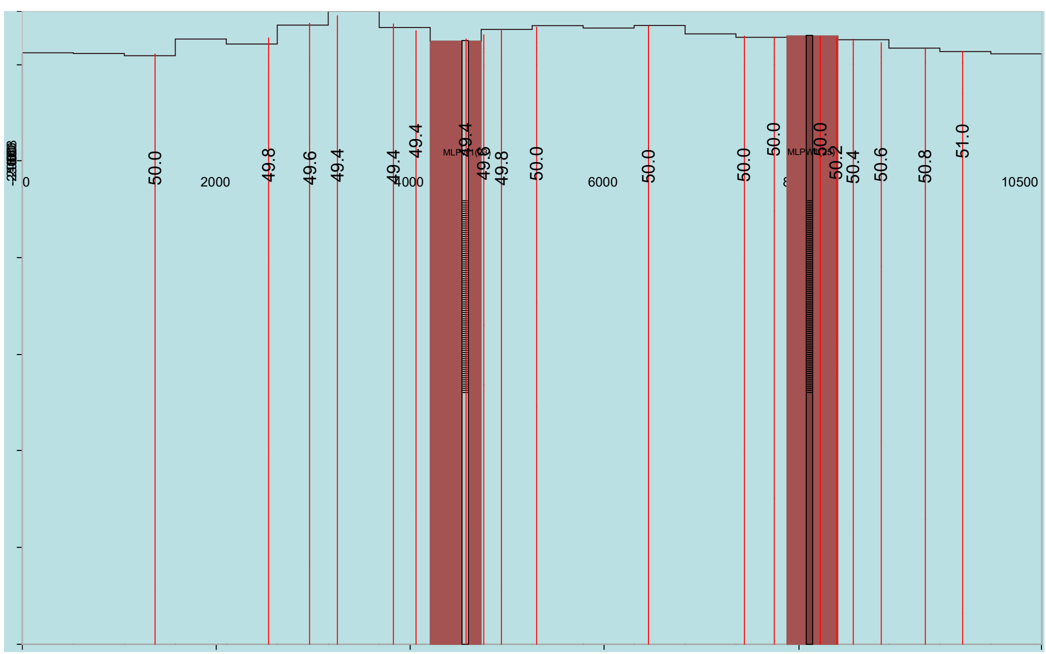


Fig. 30. Cross section plot of groundwater level under the impact of canals

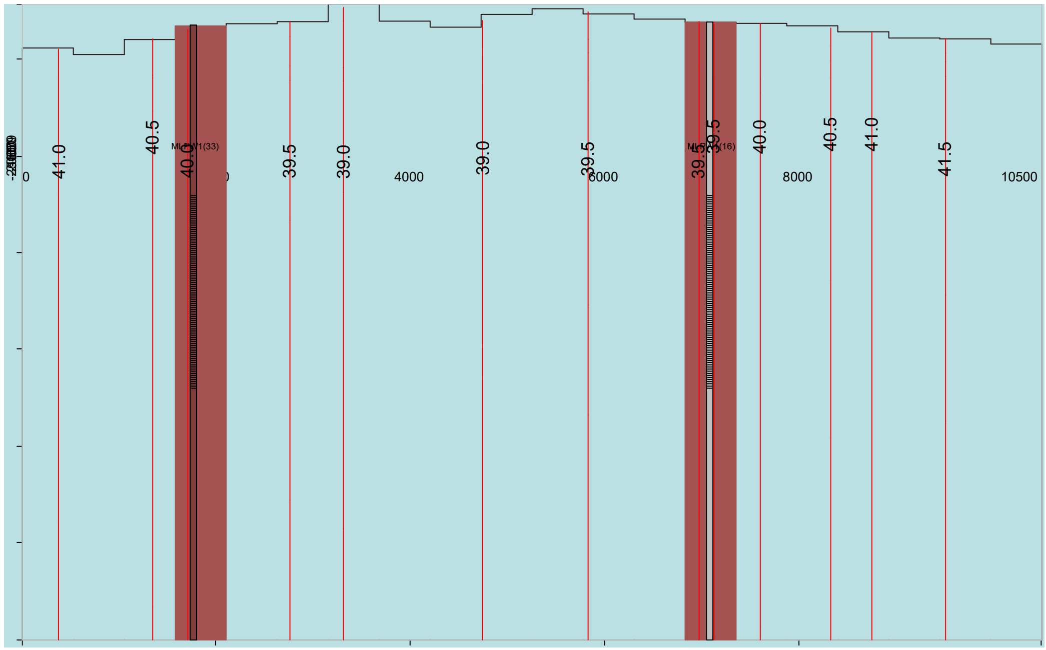


Fig. 31. Cross section plot of Groundwater level under conjunctive use scenario of canal water and groundwater

5.0 CONCLUSIONS

In this study on Pushkar Canal system the interaction of canal water and groundwater is established using stable isotope characterization. The groundwater balance is carried out to estimate the seasonal change in groundwater storages due to rainafall, tube wells and impact of canal network in the study area. Also, a pilot area of D1 and D2 command area and its canal system was setup over an area of 10 by 8 km using MODFLOW. Steady state simulations are done for scenarios of 1980s, 1990s, with canal and with canal and increased pumping (conjunctive use). Results indicate that the aquifer can be used as potential underground reservoir to store surplus flows and to rejuvenate existing wells and to increse their yields. IWRM plans in this direction may be useful in conservation and management of surface water, canal water and groundwater in this upland command area. Similar studies can be replicated for other command areas in this canal system and elsewhere for better management of water resources by stake holders.

Acknowledgements to

1. Director, AP State GWD, Hyderabad and their officers for sharing data

2. Irrigation Dept., Pushkar LIS Engineers for sharing system details

3. Planning dept., Hyderabad for sharing all statistical data

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