Large scale groundwater withdrawal and its consequences on the closing of the upper Musi basin in India

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Abstract: The Musi basin is a sub-basin of the river Krishna in India. Data on ground water levels for 20 years (1985–2004) including the data of Digital Water Level Recorders (DWLR) is analysed to investigate the large scale ground water withdrawal and its affects on reducing the inflows reaching the downstream reservoirs in the basin. The investigations have revealed that the deeper the pre-monsoon ground water levels, the more the recharge to the ground water from the rainfall, consequently reducing the runoff from the basin resulting in the closer of the basin.

Keywords: Musi basin; recharge of rainfall water; inflows to the reservoir; pre-monsoon and post-monsoon ground water levels.

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1 Introduction

The Musi basin is a nearly closed sub-basin of the river Krishna in Andhra Pradesh, India. The present study focuses on the effect of large-scale ground water withdrawal in the upper Musi basin (Figure 1) and its consequences, such as reduction of inflows into the water supplying reservoirs namely Himayatsagar and Osmansagar in the downstream. Further downstream of the reservoirs, the fast developing Hyderabad city is located and whose effects are clearly felt on ground water withdrawals in the upper Musi catchment. Earlier studies, Venkateswara Rao and Srinivasrao (2006) have amply demonstrated that inflows into the reservoirs are fast depleting as shown in Figure 2 though there is more or less normal rainfall existing for the past 46 years. The decrease in inflows is due to increase in agricultural production in the catchment by tapping lot of surface water and ground water. This increased agricultural production is due to the continuously rising demand of Hyderabad city for vegetables, fruits etc. The recent report of the World Bank has also indicated that the increased use of ground water in the Indian agriculture has led to decreased command area under the tanks (World Bank Report, 2005). This is mainly due to the decrease of runoff from the catchment areas of the tanks due to increased surface and ground water tapping through various water and soil conservation works in the catchments (Venkateswara Rao and Srinivasrao, 2006). The objectives of the study are to present investigations of ground water levels in the catchment area and to prove that the deeper the pre-monsoon ground water levels, the more the recharge of rainfall water to the ground.

Figure 1 Location map of the upper Musi catchment

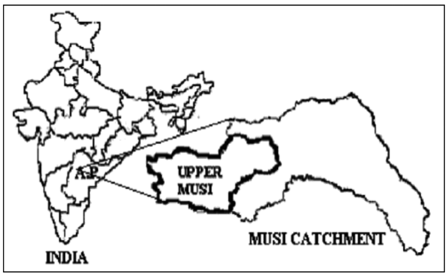
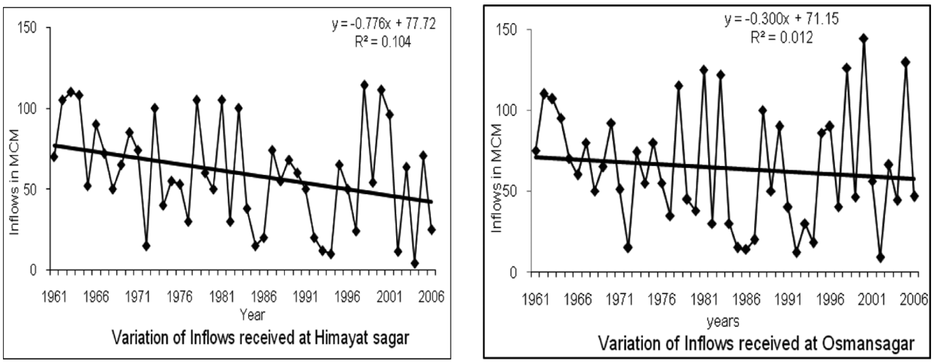


Figure 2 Variation of inflows received at Hymayatsagar and Osmansagar



2 Description of the study area

The study area is upper part of the Musi basin (Figure 1) a tributary of river Krishna in the Southern India. The area falls in the survey of India topographic sheet numbers 56 k/7–56 k/11 and it is bounded by longitudes 77°49′15″–78°56′09″ and latitudes 16°58′12″–17°42′70″. The Study area has an average altitude of 670 m in western part, which gradually decreases towards the east till 450 m.

2.1 Hydrogeology of the study area

The area mainly exposes Peninsular Gneissic Complex that includes a variety of granites, magmatites of various phases and enclaves of older metamorphic rocks belonging to the Archean age (Krishnan, 1956). These are intruded by various acidic (pegmatites, aptite, quartz veins/reefs) and basic intrusive of dolerite and gabbros. Ground water in the area occurs under unconfined conditions in the open wells to semi-confined conditions in the bore wells if they tap deeper fracture zones.

3 Earlier work on ground water level fluctuations

Todd (1980), Karanth (1987), and Fetter (1990) dealt with water level fluctuations in time frames as short as a few minutes to very long periods involving a few decades or even more. They dealt with causes of fluctuations, use of fluctuations in estimation of evapotranspiration losses and recharge to ground water. Healy and Cook (2002) made use of water level fluctuations for estimation of recharge to ground water. Taylor and Alley (2002) dealt with relative merits of frequency of water level monitoring, drought indexing using hydrographs, canal stages and water levels and saline water intrusion. Venkateswara Rao (2003) observed that good well yields are obtained in the areas where there is less fluctuation of water table.

In the present study, water table fluctuations of the upper Musi basin are used to illustrate that areas having deeper ground water levels are inducing more recharge. In addition the study is also going to prove that the influence of pre-monsoon ground water levels is more than the influence of amount of rainfall in recharging the ground water.

4 Material and methods

Ground water levels in the Musi basin were observed during pre-monsoon and the post-monsoon seasons for the year 2005. Similarly 20 years data of the ground water levels of the observation wells and the data recorded by the Digital Water Level Recorders (DWLR) from the Andhra Pradesh State Ground Water Department in the upper Musi catchment have been collected. Changes in ground water levels between pre-monsoon and post-monsoon have been mapped for the past 20 years. It is verified that whether the recharge to the ground water occurs is mostly influenced by rainfall or pre-monsoon ground water levels. Further investigations have been made by analysing the data of the DWLRs installed in the basin. The DWLR records ground water levels for every 6 h and the data set constitutes from the year 1998 to 2005. The rainfall is also recorded near the DWLRs. The combined plot of rainfall and water levels below ground level (bgl) is called Composite Hydrograph, which is used for analysis.

5 Water table contour maps and analysis

Contour maps of water table can be prepared by observing the water levels in open wells or bore wells. These maps are obtained by joining the points, which are having same ground water levels. The movement of the ground water is perpendicular to these lines. The monthly water level data recorded by State Ground Water Department of Andhra Pradesh in 23 monitoring observation wells (for the past 20 years period between 1985–2004) and 24 piezometer wells (in which some wells were established in 1998, some in 1999 and some wells in 2001) in the study area have been considered for the analysis. The location of piezometer wells and observation wells are shown in Figure 3.

The observed water levels give depth in meters below ground level (bgl). This observed depth is reduced to Mean Sea Level (M.S.L.) with the help of topographic contour map in the Survey of India topographic sheets. Water table contour maps for pre-monsoon and post-monsoon for 1985 and 2004 are shown in Figures 4 and 5 respectively. These maps are prepared to identify ground water potential zones by utilising the principle that areas with wider contour spacing may have greater ground water potential (Todd, 1980). From both these maps it can be inferred that, basically ground water levels are following the topography. Ground water flow direction is in the mainstream direction. All along the boundary of the upper part of the basin, the contours are widely spaced and these areas are having more potential for ground water development. Incidentally they are the areas of greater withdrawal of ground water, consequently the ground water levels are deep and influencing more recharge in this region (Figure 6). Figures 3–5 depict only upper part of the Musi basin while Figure 6 refers to the total Musi basin.

Figure 3 Location map of observation wells and peizometer wells in the upper Musi basin

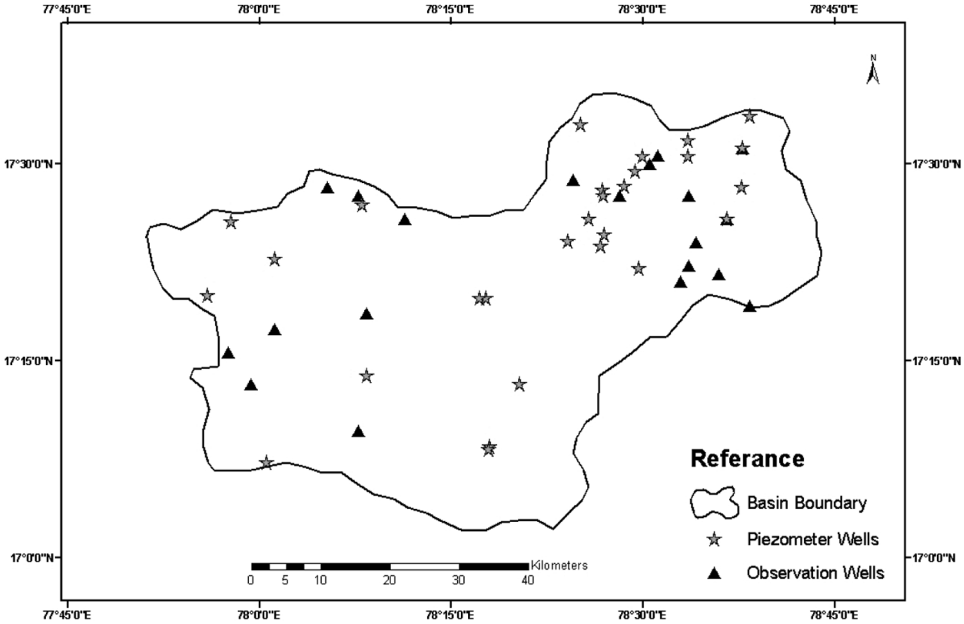


Figure 4 Water table contour map for the year 1985 post-monsoon

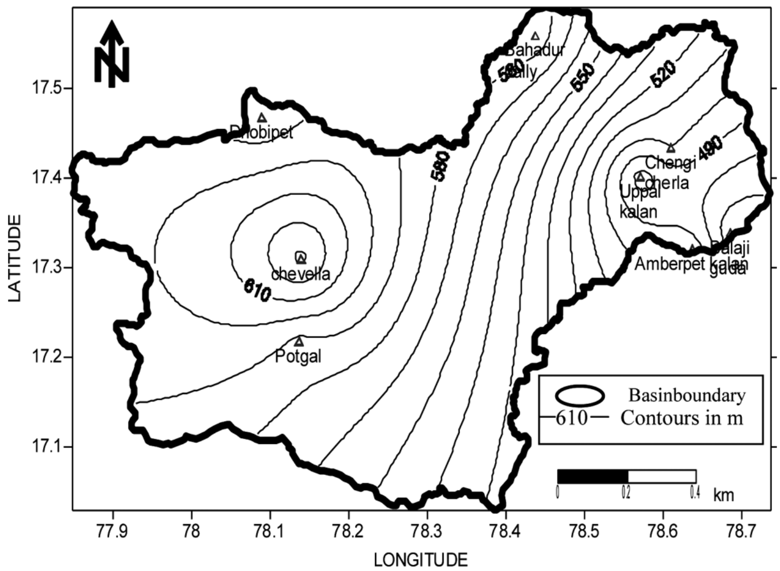


Figure 5 Water table contour map for the year 2004 post-monsoon

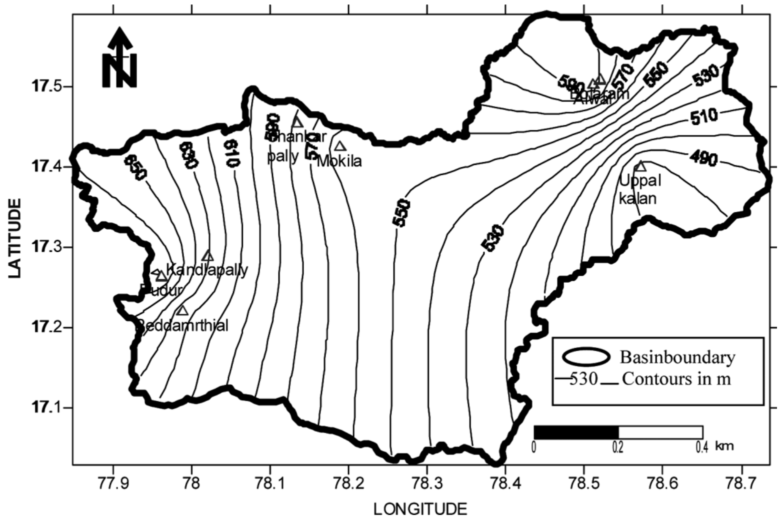
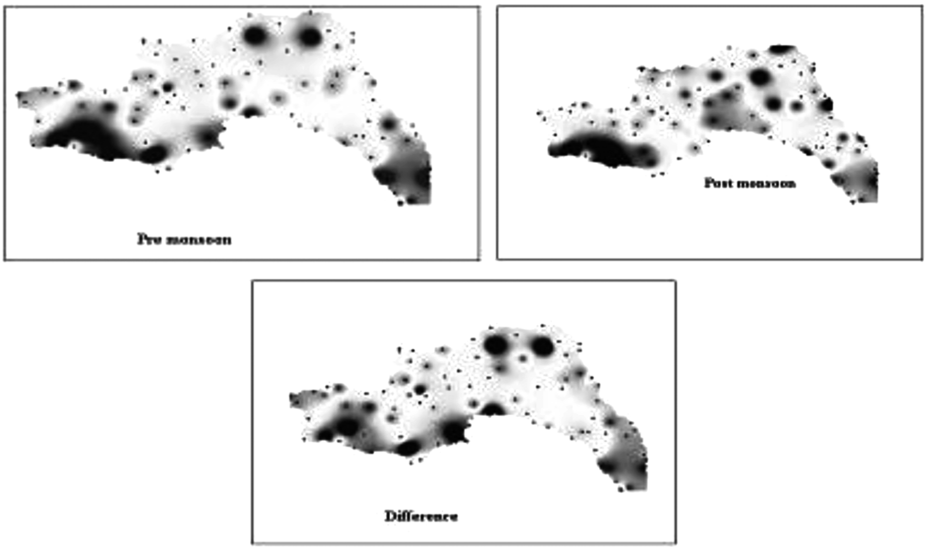


Figure 6 Musi basin depicting pre-monsoon, post-monsoon ground water levels and raise in ground water levels for the year 2005



From the contour maps of 1985 (Figure 4) and 2004 (Figure 5) it can also be observed that there is a progressive increase of area under the successive deeper ground water contours. For example the 620 m contour near Chevella in the contour map of 1985 (Figure 4) is occupied by 590 m contour in the 2004 (Figure 5) contour map indicating depletion of water levels in the upper Musi upto 30 m. There is some good recharge zone near Uppal area where the 490 m contour is being maintained throughout the 20 years period.

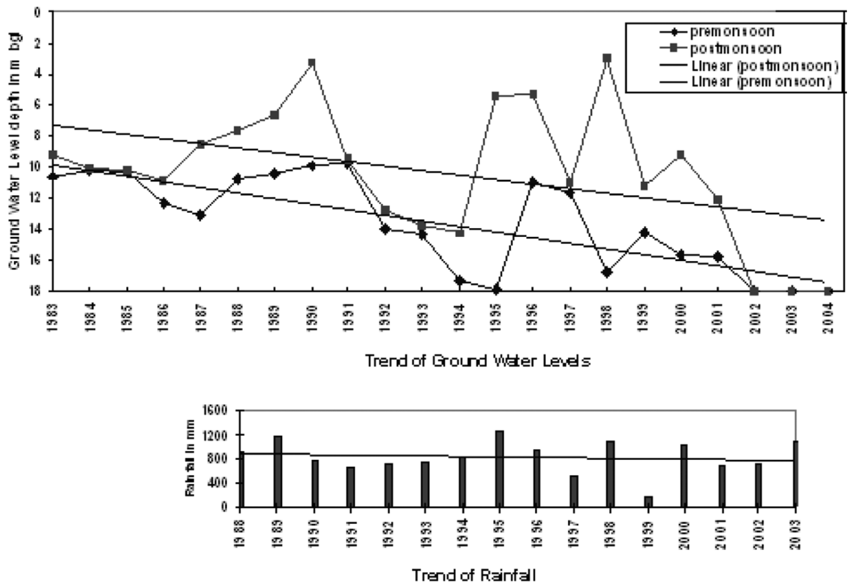
6 Analysis of hydrographs

The raise and fall in water levels due to monsoon as well as artificial recharge structures such as percolation tanks, check dams and other rainwater harvesting structures like desilted tanks, sunken ponds are depicted by hydrographs. The hydrographs of representative observation wells and also composite hydrographs of representative piezometer wells fixed with DWLR are described below.

6.1 Discussion on hydrographs of observation wells

These hydrographs are prepared for eight observation wells for pre-monsoon and post-monsoon periods. Two of these are as shown in Figures 7 and 8. These hydrographs show that water level trends are declining, in spite of normal trend of rainfall for most part of the past 20 years. This is due to (a) high ground water usage (b) greater well density (c) less than normal rainfall received in the periods between 1990–1994 and 2001–2004, and (d) specially very low rainfall received during 1997, 1999, 2001 and 2002 years. Overall the ground water levels in the basin have been declining from the past 20 years. For example in Shankarpally well, the ground water level has declined to as deep as 8 m (Figure 7) making the open well dry by the year 2003 and forcing the farmer to drill deeper bore well.

Figure 7 Ground water levels and rainfall trend in Shankarapally well



6.2 Composite hydrographs of piezometer wells

Composite well hydrographs with rainfall data plotted are shown in Figures 9 and 10. These hydrographs show that water levels are in general declining trend. Out of 19 hydrographs 13 hydrographs are showing declining trend of water levels (Vijaya Sarada, 2005). In general the water levels in most of the cases return to their original position after a good rainfall. From the composite hydrographs (Figures 9 and 10) it can be observed that it took two to three months to raise the ground water level after the rainfall occurrence. This phenomenon may be due to rapid recharge taking place by heavy rainfall and also irrigation returns. If we compare the different years of hydrographs, it is seen that in 1999 the precipitation was less, consequently the raise in ground water level was less or there was no raise at all. In the years 1998 and 2000 the ground water levels react similarly to the monsoon rainfall.

Figure 8 Ground water levels and rainfall trend in Shabad well

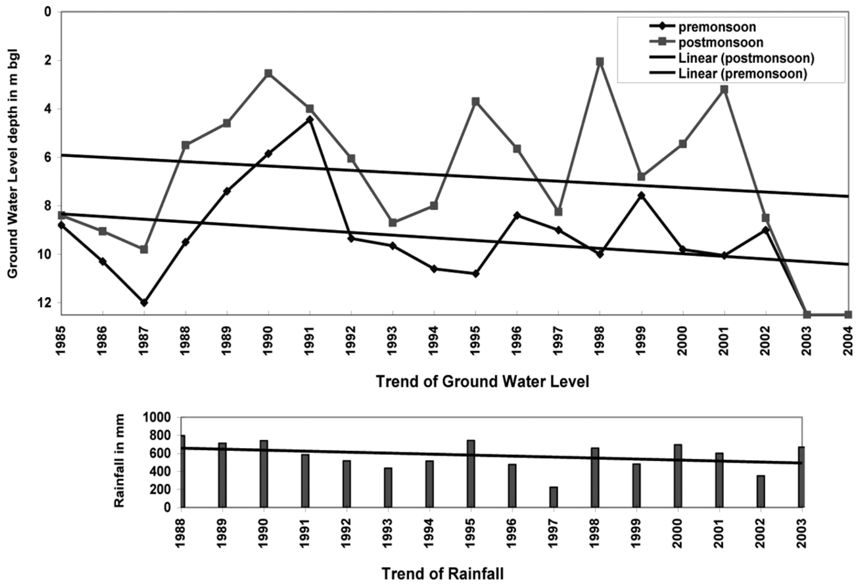


Figure 9 Composite hydrograph of Moinabad well

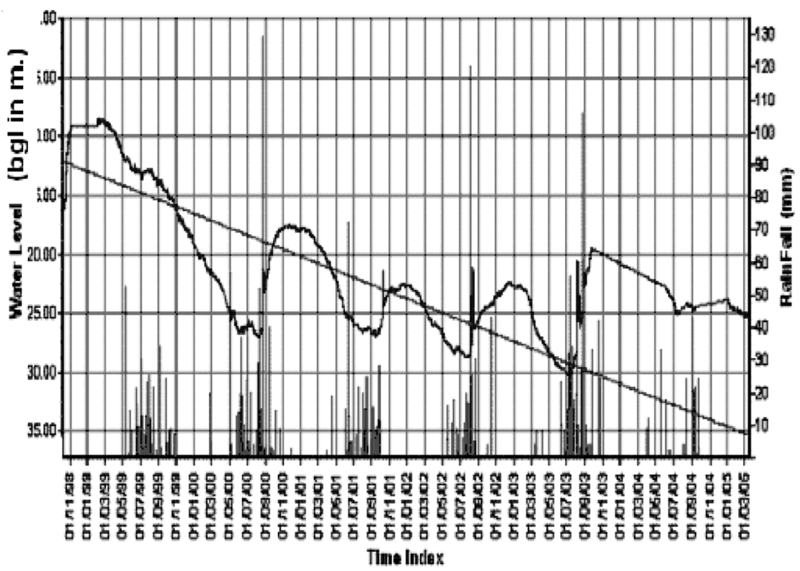
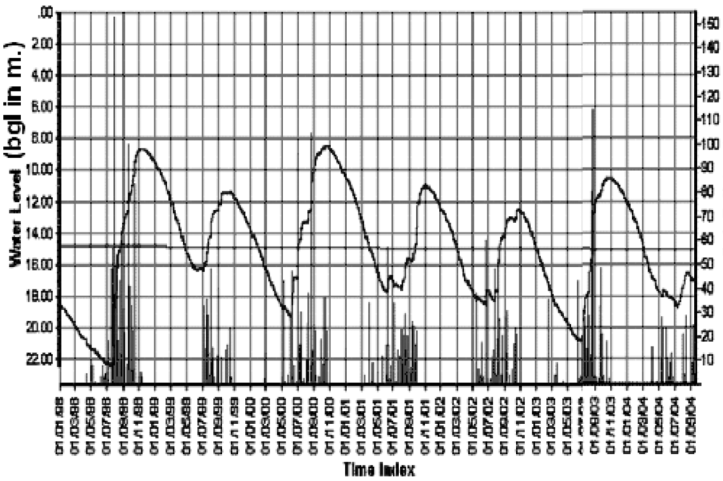


Figure 10 Composite hydrograph of Vikarabad well

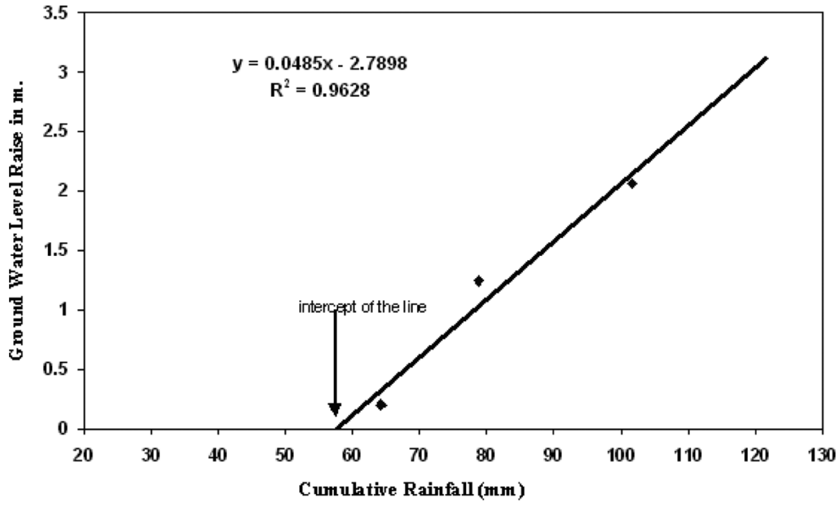


7 Rainfall and water level raise relationships

It is well known that the position of water table is influenced by rainfall, its intensity, duration and total amount received in the area. It is also known that a certain amount of rainfall is needed before percolation can occur. Five composite hydrographs from different wells are used to arrive at the threshold values of rainfall required to induce percolation and thereby to raise the ground water levels of respective places. This exercise was done using the data during July and August months, which receives a good amount of rainfall from southwest monsoon. The relation is obtained by plotting the water level raise as observed in the precision piezometers (fixed with automatic water level recorder) against the rainfall recorded in the nearest rain gauge. In all these cases rain gauge and piezometers are located within few tens of meters of distance between each other.

The best-fit lines are obtained by least square method, which show a linear correlation between rainfall and water level raise in each well, one such relation is shown in Figure 11. The regression line for each well has an intercept on the rainfall axis, suggesting that certain minimum amount of rainfall is required for initiating deep percolation, which in turn recharges the phreatic aquifer. It can be considered as the minimum amount of rainfall required for recouping the soil moisture deficit in the vadose zone. Rainfall and water level raise relation plots shows that the beginning of percolation ranges from 8 mm to 58 mm (Figure 11). It has also been observed that high values of rainfall for inducing percolation are noted at topographic high; where as low values are noticed at topographic lows. R^2 values of these plots suggest that some stations are having higher correlation coefficient and some stations are having lower correlation coefficient, indicating the degree of variability in recharge. This means that sites having higher R^2 value will have greater scope for taking up artificial recharge of ground water.

Figure 11 Rainfall and water level raise relation in Shaikpet well



In this well cumulative rainfall required to affect the raise in water level is 58 mm.

8 Influence of pre-monsoon ground water levels over the recharge of rainfall water to the ground

Pre-monsoon and post-monsoon ground water levels are observed in the year 2005 at 90 locations covering entire Musi basin. A graph (Figure 12) is drawn between pre-monsoon water levels and the difference of pre-monsoon and post – monsoon water levels. The graph has clearly demonstrated that a positive correlation exists (Figure 12) between pre-monsoon ground water levels and the raise in ground water levels (the difference between the pre-monsoon and post-monsoon levels) due to rainfall. That is, the deeper the pre-monsoon ground water levels, the more the recharge to the ground water from the rainfall. In other words pre-monsoon ground water level is determining the rate of recharge during the monsoon, perhaps it is a new concept in hydrology.

This phenomenon is depicted in Figure 6 covering entire Musi basin. In these maps dark to gray shades indicate deep to shallow water levels in pre-monsoon and post-monsoon maps while dark to gray indicates high raise of ground water level to low raise of ground water level in the difference map (Map depicting the difference between pre-monsoon and post-monsoon ground water levels). It is evident from these maps that the deeper water level areas in pre-monsoon have larger water level raise after post-monsoon. There is another data set comprising the amount of rainfall, pre-monsoon water level and the rise in ground water level (Table 1). From this data the graphs have been drawn between pre-monsoon ground water level vs. raise in water level (Figure 13) and rainfall vs. rise in water level (Figure 14). From these graphs it is observed that positive correlation is also found between the rainfall and rise in ground water levels and also between pre-monsoon water level and rise in ground water levels. But it is the pre-monsoon ground water level, which is influencing more recharge than the total amount of rainfall itself, since the slope of this graph is more than that for rainfall graph. It appears that whatever the rainfall that occurs in the upper catchment is simply percolating down to recharge the depleted ground water table, to meet the soil moisture deficiency and to meet the storage of water in smaller or bigger water conservation structures such as tanks, percolation ponds, check dams, etc., and leaving little or no runoff that could reach the downstream. Unless there are extreme rainfall events, it is becoming increasingly difficult to fill the reservoirs. Ultimately there is no water left downstream closing the entire basin.

Figure 12 Relation between pre-monsoon ground water levels and the difference of pre-monsoon and post-monsoon ground water levels (Δh)

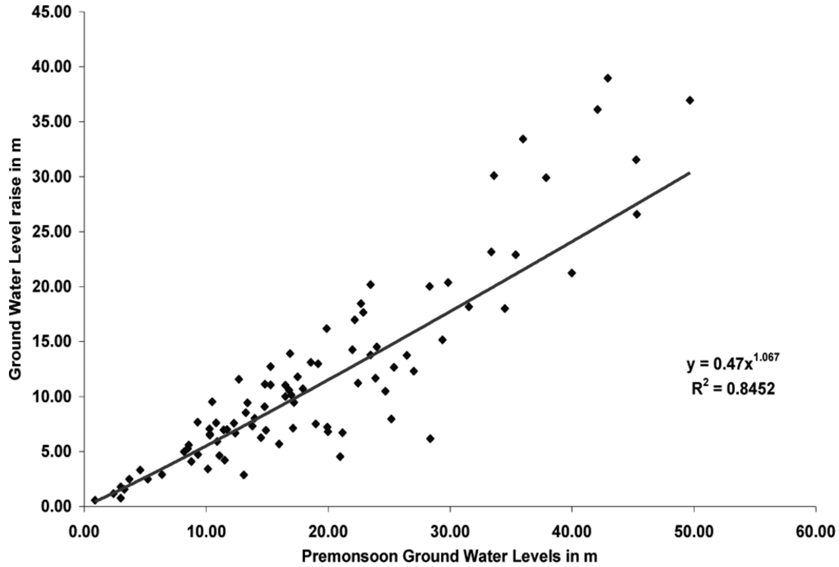


Table 1 Changes of ground water levels in upper Musi basin

Year	*Rainfall* (mm)	*Pre-monsoon ground water levels* (m. bgl)	*Increase in ground water levels* (m)
1998–1999	1128	10.86	2.71
1999–2000	764	9.27	0.6
2000–2001	919	8.69	3.58
2001–2002	877	9.5	2.23
2002–2003	614	10.25	0.25
2003–2004	936	11.13	2.47
2004–2005	611	11.49	1.16
2005–2006*	685	14.45	4.16

*In this year rainfall is upto September only.

Figure 13 Relation between pre-monsoon ground water level and increase in ground water level

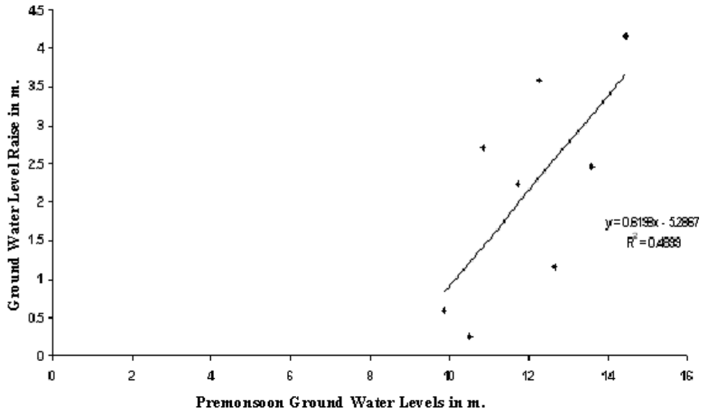
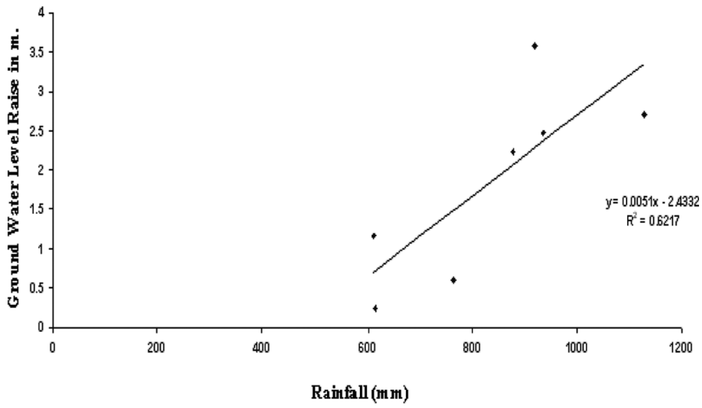


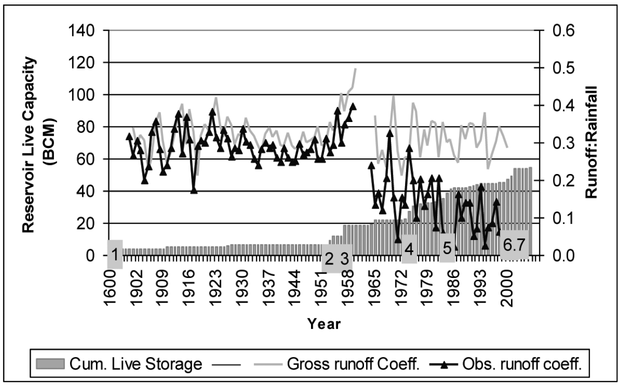
Figure 14 Relation between rainfall and increase in ground water level



9 Implications of the study and conclusions

The above situation holds good not only for smaller reservoir catchments but also for the bigger river basins like Krishna (Figure 15) in which flows have considerably declined after upstream storages have increased. The problem is that we cannot stop the ground water withdrawals and water conservation works in the upstream as the local community simply depends on this agricultural activity. This means that the well established down stream deltaic irrigation systems of Godavari, Krishna and Cauvery in Southern India will be receiving lesser and lesser surface water. Ultimately the erstwhile command areas that were enjoying copious amount of water have to conjunctively use surface water, ground water and rainfall. Since agriculture consumes nearly 80% of fresh water, we have to save lot of water in this sector and provide fresh water for drinking and industrial sectors. Therefore water conserving irrigation practices are to be adopted such as “System of Rice Intensification” (SRI) method. This method requires less than half of the water required for traditional irrigation for rice cultivation and enhance the yield to two to three times. This fact already proved in many parts of south-east Asia or we may have to produce rice under sprinkler irrigation system. Irrigated dry crops are the possible alternatives to the paddy cultivation under the bore wells. Another way to reduce the water consumption in the agriculture is to divert the people from agriculture employment to the manufacturing and service sector employment, which is already happening in the well-developed agricultural areas of the country. This kind of understanding leads us to believe that even in normal rainfall years we have to learn to live with whatever the water that falls on our head. This does not mean that we have to stop constructing the irrigation systems, simply because, due to climate change there is an increasing threat of droughts and floods in the future. Already floods have occurred at many places during the year 2005 and 2006. There was continuous drought from 2001 to 2004 in many places in India. During the heavy floods we have to store as much water as possible and that has to be distributed during the drought periods. In this storage process deeper water table in the upper catchment is inducing more recharge during heavy and normal rainfall years thereby storing lot of water which otherwise drain as heavy flood to the downstream.

Figure 15 Krishna basin storage and run off



Source: Biggs et al. (2007)

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