RESEARCH PAPER International Journal of Agricultural Engineering | Volume 6 | Issue 2 | October, 2013 | 485–491

Groundwater utilization in a hirekere watershed in Raichur district in Karnataka

B. MAHESHWARA BABU, I. MUTHUCHAMY AND **S.S. SHIRAHATTI**

Received : 05.08.2013; **Revised :** 18.10.2013; **Accepted :** 16.11.2013

See end of the Paper for authors' affiliation

Correspondence to :

B. MAHESHWARA BABU
Department of Soil and Water Engineering, College of Agricultural Engineering, University of Agricultural Science, RAICHUR (KARNATAKA) INDIA
Email : babubandamahesh@yahoo.co.in

ABSTRACT : The present study was taken up in Hirekere watershed which is draining to Krishna river through Nallavagu stream and is located near Singanodi and Mandalgeri village in Raichur district, Karnataka. The main objective of the study was to assess the present status of groundwater usage to evolve efficient crop planning on the basis of sustainable groundwater usage. Optimum utilization of groundwater was also planned for the maximum crop benefits. There was recharge of groundwater of 100.90 mm, 26.65 mm, 128.85 mm, 20.35 mm and 113.05 mm during the years 2005, 2006, 2007, 2008 and 2009, respectively. The recharge varied from 4.44 to 17.24 per cent, where as 77.96 mm/year *i.e.*, 11.68 per cent of annual rainfall was found to be the average annual recharge of the study area. The percentage of utilisation of available groundwater resource is 98, 183, 97, 208 and 114 per cent for the years 2005-06, 2006-07, 2007-08, 2008-09 and 2009-10, respectively indicating the area as over exploited zone. Recharge calculated by the water balance and watertable fluctuation method revealed that there was no correlation between the values calculated by the WT fluctuation method and the water balance method. In this contest the recharge calculated by water table fluctuation method is best method for the recharge estimation in the watershed. It is also recommended not to go for new bore wells and non paddy crops at least two to three years by introducing crops like cotton, groundnut and vegetables may be in the study area. It is recommended to reduce the present area under paddy cultivation. Further, rainwater harvesting and augmentation of ground water recharge through artificial recharge structures can be taken to improve the ground water quantity and quality.

KEY WORDS : Groundwater, Groundwater recharge, Water balance method, Watertable fluctuation method, Groundwater draft

HOW TO CITE THIS PAPER : Babu, B. Maheshwara, Muthuchamy, I. and Shirahatti, S.S. (2013). Groundwater utilization in a hirekere watershed in Raichur district in Karnataka. *Internat. J. Agric. Engg.*, **6**(2) : 485-491.

Groundwater comes from the natural percolation of precipitation and other surface waters down through earth's soil and rock, accumulating in aquifers, cavities and layers of porous rock, gravel, sand, or clay. In some of these subterranean reservoirs, the water may be thousand to million of years old; in others, water levels decline and rise again naturally each year. Groundwater levels do not respond to changes in weather as rapidly as lakes, streams, and rivers do. So when the groundwater is pumped for irrigation or other uses, recharge to the original levels can take months or years. Groundwater is being pumped and consumed by human activities principally to irrigate cropland faster than the aquifers can be replenished by natural processes. If measures are not taken to ensure sustainable groundwater usage, consequences may include a collapse of agricultural output and severe shortages of potable water. The status of groundwater use in the country shows the two challenges; first, how to retain groundwater use to sustainable levels in overexploited regions and second, how to develop the large untapped ground water potential in eastern India. Sustainable ground water development and management in the over exploited regions needs to be taken up by incorporating artificial recharge to groundwater, rain water harvesting, management of salinity ingress in coastal aquifers, conjunctive use of surface water and groundwater, management of poor/marginal quality groundwater, water conservation by increasing water use efficiency, regulation of groundwater development, etc. Several micro level studies found that these technologies have been successful. Innovative methods of recharging the groundwater and also storing water in floodplain aquifers along the river banks may enhance the ultimate irrigation potential from groundwater to the tune of more than 64 m ha from the present 35 m ha (Anonymous, 2007). Hence, an attempt was made in Hirekere watershed situated in Raichur district in Karnataka to assess the groundwater recharge, groundwater draft and its optimal utilisation on sustainable groundwater scenario.

METHODOLOGY

The Hirekere watershed having an area of 218 ha which is located in between the villages of Singanodi and Mandelgiri in Raichur Taluk of Raichur district of the Karnataka, India. The watershed is affected by frequent drought conditions and groundwater becomes a scarce commodity. The study area is situated in the N-E dry zone (Zone-2 of Region-1) of Karnataka at $16^0\,12^I 24.29^{II}$ N latitude and $77^0\,28^I\,19.40^{II}$ E longitudes to $16^0\,12^I\,54.77^{II}$ N latitude and $77^0\,29^I\,15.21^{II}$ E longitudes and elevation is from 390 m to 415 m above the mean sea level (MSL). This watershed is draining to Krishna river through Nallavagu stream. The study area is located at about 20 km from the Raichur city on Raichur- Gadwal road. The study area falls under the watershed codification of 4D2D7E2a, in which 4 is the water resource region, Bay of Bengal, D is Krishna basin, 2 is the catchment of Nagarjunasagar to Srisailam confluence of Tungabhadra with Krishna and Bhima with Krishna, D is the subcatchment of Lower Bank Krishna Srisailam to confluence with Bhima, 7 is the watershed of Right Bank of Krishna, E is the subwatershed of Mandalgeri, 2 is the miniwateshed of Mandalgeri and a is the microwatershed of Mandalgeri (Anonymous, 2005). The study area is falling under the Survey of India toposheet of 56 H/8 NE (1:25000). The average slope of the entire watershed is less than 2 per cent that is 1.28 per cent, which depicts that watershed is gently sloping. The soil is *Alfisols* of red sandy loam texture. The watershed has basically granite terrain. Most of the area has shallow basement without fracturing.

Based on the field survey, farmers information and from the Pani reports which contains the farmer's name, survey numbers, area of field (Anonymous, 2005, Anonymous, 2009), the land use, crops, wells details etc. were collected. Using the village maps of Singanodi and Mandalgeri villages collected from the Land Revenue Department of Raichur with the Pani, a field boundary map with survey numbers was prepared by superimposing the watershed map using Arc GIS 9.2 tools. The watershed fields are cultivated both under rainfed cultivation and with well irrigation. The cotton is the major crop of the area, followed by castor, groundnut, redgram and sunflower in rainfed area. Groundwater is one of the main sources of irrigation in the Hirekere watershed area (mainly during *Kharif* and *Rabi/*summer season). Under well irrigation, majority of the area is cultivated with paddy followed by cotton and in small area with groundnut, tobacco, sunflower and vegetables. The geomorphology in the study area is Pediplain, Pediplain weathered/buried. The Lithology is Crystalline rocks with Charnockite rock type. The geology of the structure is lineament (Anonymous, 2005). The groundwater prospect in the study area is moderate to good. The study area is already declared as the over exploited area regarding the groundwater development by Central Groundwater Board (Anonymous, 2008). The watertable level in five selected wells was monitored by Water Level Indicator to know the fluctuation of groundwater table. The availability of source of water, is one of the prime requisites for groundwater recharge, is basically assessed in terms of non committed surplus monsoon runoff, which is as per water resource scenario is going unutilized (GEC, 2007).

Groundwater recharge estimation :

For sustainable development of water resources, it is imperative to make a quantitative estimation of both the surface water and the groundwater resources and then plan their use in such a way that targeted crop water requirements are met with, and there is neither water logging nor excessive lowering of groundwater table. It is necessary to maintain the groundwater reservoir in a state of dynamic equilibrium over a period of time and the water level fluctuations have to be kept within a sustainable range over the monsoon and non-monsoon seasons. Groundwater balance is an important aspect of any study on allocation of water resources, planning and management. It was decided to choose the water balance and groundwater table fluctuation methods for computing the groundwater recharge for the study area.

Groundwater recharge estimation by water balance method :

A most common way of estimating recharge by water budget method is the indirect or residual approach, whereby all of the variable in water budget equation except 'recharge (R)' are measured or estimated, and R is set equal to residual. An advantage of water budget method is flexibility. The major limitation of the residual approach is the accuracy of the recharge estimate depends on the accuracy with which the other components in the water budget equation are measured (Scanlon and Healy, 2002). Several researchers estimated and reported the findings of the groundwater recharge by water balance technique (Srinivas *et al*., 1999 and Szilagy *et al*., 2005). Water balance is defined by the general hydrologic equation, which is basically a statement of the law of conservation of mass as applied to the hydrologic cycle. For calculation of various water balance and their derived components, the Microsoft Excel interactive sheet (Table 1) was developed. All the parameters, except crop evapotranspiration (ET_c), runoff (Q) and draft were calculated based on the Thornthwaite – Mather method.

Daily rainfall data for three years period (2007 to 2009) was considered for all the studies. Daily rainfall data of each month was added and monthly rainfall data was considered for the water balance analysis. The monthly runoff values were computed by using SCS CN method and was used as one of the inputs for water balance model.

From the Regional Agricultural Research Station, Raichur, various monthly climatic data namely maximum-minimum temperature, maximum relative humidity, wind speed, sunshine hours, etc. were collected for three years period from 2007 to 2009. The CROPWAT version 8.0 of FAO, Rome has been used for computing monthly reference evapotranspiration (ET_o).

Pre sowing irrigation for each crop has been accounted for while estimating crop water requirement based on actual measurement. The seasonal demand of each crop was calculated for average cropping area and intensity. Accumulated potential water loss (APWL) is a variable that describes the dryness of soil. It is the highest at the end of summer, *i.e.*, just at the beginning of monsoon season for Raichur region. Its value is around 1768 (Venkatesh, 2003). Its value during the months with a surplus of water becomes zero, indicates no dryness in the soil. As soon as soil moisture reaches water holding capacity, the remaining part is available for runoff either as groundwater and surface runoff. The above calculations should be started from the first wet month. In our study area it is the beginning of monsoon season and hence the first wet month is June. However, in reality, the surplus water percolates in soil layer and is added to a detention. The total surplus water of a current month and detention from previous month constitute the total available water for sub surface runoff. For the present study, water holding capacity was found to be 211.40 mm. It is assumed that in water balance concept, when moisture level reaches field capacity, then excess water percolates to the ground water reservoir.

Groundwater recharge by groundwater fluctuation method :

Water table fluctuation method may be the most widely used technique for estimating recharge; it requires knowledge of specific yield and changes in water levels over time. Groundwater level fluctuation method was applied by several researchers (Hall and Risser, 1993) for assessing the groundwater recharge. The Government of India founded the Groundwater Estimation Committee (GEC) in 2007 to recommend methodologies to estimate groundwater potential in India. In the present study area, high water intensity irrigated crops like paddy, cotton, groundnut, sorghum, tobacco, vegetables and mango are being cultivated, and hence recharge due to irrigation was considered. Regarding groundwater draft from bore wells/open wells through pumps, there is considerable number of bore wells exist. During the monsoon and non monsoon season farmers are also much depending on bore wells. Hence, the groundwater draft is taken in to consideration. The groundwater recharge is calculated by :

$$R = h \times Sy \times A \qquad (1)$$

where,

R = Recharge, m^3

h= Rise in water level, m

A= Area of computation of recharge, sq m

S_y= Specific yield, per cent

In the study area, for the analysis period, non monsoon season rainfall never exceeds 10 per cent of the normal annual rainfall, hence non monsoon recharge is not considered in the analysis. In case of non availability of any data, GEC (2007) has provided the guidelines for computing the recharge on the basis of fixed percentage of the rainfall in the different geological formations.

Recharge from irrigation water :

The estimates of irrigation water applied and the return flow factor as described earlier are used to compute the recharge from irrigation water applied by groundwater irrigation in the non-command area during monsoon and non monsoon seasons of the current ground water assessment year. The recharge due to irrigation water applied through well irrigation was considered from the values recommended by GEC, 2007. The data on monthly water table fluctuations (2005-2009) were collected in the selected wells located in Hirekere watershed. To estimate the change in groundwater storage, the water levels were observed through a network of observation wells spread over the entire area. The water levels were the highest immediately at the end of monsoon *i.e.* during the month of October or November, whereas the water levels were lowest just before the onset of monsoon *i.e.* in the month of May or June. During the monsoon season, the recharge was found to be more than the extraction. Therefore, the change in groundwater storage between the beginning and end of monsoon season indicated the total volume of water added to the groundwater reservoir. The change in groundwater storage between the beginning and end of the non-monsoon season indicated the total quantity of water that withdrawn/pumped from groundwater storage (Kumar and Seetapathi, 2002). The quantities of annual recharge were estimated from the data of recorded levels (h) multiplying with the area of influence equal to the respective area. Further, annual recharge and annual draft were compared to decide whether it was excessive recharge or draft.

Groundwater discharge :

Groundwater discharge consists of draft from wells and evaporation from groundwater.

Groundwater draft :

Bore wells, open wells and dug cum bore wells are being used for pumping the groundwater. The year wise groundwater draft is based on well discharge, number of wells and duration of operation of wells in each season.

Evaporation from groundwater :

In study area groundwater level varies from 6 to 9 m below soil surface. The evapotranspiration from groundwater is assumed negligible due to high depth of watertable from the surface and absence of deep-rooted forest plants.

The groundwater recharge calculated for five years 2005 to 2009 by watertable fluctuation method and return flow due to groundwater irrigation as explained in the above, and groundwater draft from the wells were used. The amount of groundwater pumped from all the wells for each month was measured by 90^o V-notches over the watershed area for study period of three years *i.e.* 2007 to 2009. The pumping test was conducted for six hours at each time. The ground water usage in watershed area was known by taking only six hours of pumping each day due to restriction on power supply in the area. Depending on the percentage of groundwater utilisation the classification of groundwater exploitation was made. If recharge is more than water use that indicates that there is + ve water balance, if recharge is less than the water use, it indicates –ve water balance. If the groundwater draft is more than the recharge, no more bore well will be recommended in the watershed such that groundwater use/ draft should be less than or equal to the groundwater recharge.

RESULTS AND DISCUSSION

Out of 218 ha gross area of the watershed, the area under agriculture and horticulture were 187.5 ha (86.01%) and 6.5 ha (2.98%), respectively. The area under social forestry was 3.5 ha (1.61%), waste land 8.5 ha (3.90%), water bodies 6.00 ha (2.75%) and settlement 2.00 ha (0.92%). Among the land use classes, the cultivated land was found to be dominant land use class in the watershed. The straight row cultivation was practiced in the watershed. The cultivated area in the watershed is partly under rainfed agriculture and partly under well irrigation. The cotton is a major crop of the area, followed by castor, groundnut, redgram and sunflower under rainfed conditions. Under well irrigation, majority of the area was cultivated with long duration paddy (*Sona massurie*) followed by Bt cotton and in small area with groundnut, tobacco, sunflower and vegetables. The farmers always used to go for paddy crop on top priority under bore well irrigation.

There was an increase in the number of bore wells from 34 in the year 2007-08 to 43 in the year 2009-10. It is observed that there was increase in number of bore wells from year to year and the farmers were facing failure of bore wells also. There was no change in number of open wells from beginning of the study 2007-08 to end of the study 2009-10. This indicates that more number of bore wells is used to tap the deep under groundwater than taping the lower groundwater with the open wells. The reason is that only small quantity of water is observed in open wells during the rainy season. Regarding the open wells, only one open well is found working throughout the year because no bore well can be observed nearby. There are a total of 3 dug-cum-bore wells. Two dug cum bore wells dried in the year 2009-10. Failure of bore wells can be seen in the watershed by 6 in the year 2009-10, 5 in 2008-09 and 3 in 2007-08.

Groundwater recharge estimation :

Groundwater recharge by water balance method :

Rainfall data for the study period of five years *i.e.* 2005 and 2006, 2007, 2008 and 2009 were fed in the water balance model on monthly basis. The runoff yield calculated on monthly basis for the selected watershed by SCS CN method. For the water balance analysis, this monthly runoff data were used as the input for the water balance model. For calculation of total crop water requirement in the watershed area, the crops grown under rainfed and under well irrigation is from 2005-06 to 2009-10 were used. The CROPWAT 8.0 model was used to calculate ET_c of the crops, which are grown in the watershed. The water balance was calculated for the study period of five years by using the interactive spread sheets. Thus, totally 5 water balance tables were generated for each year. Actual evapotranspiration is the most important parameter in the water balance model. The results of water balance for 2007-08 revealed that ET_a values varied from 29.89 mm to 97.88 mm from June to October. The highest ET_a was observed from July to September, whereas, the lowest was observed during December to February. The highest ET_a values during these months are attributed to the availability of moisture during monsoon months, while during December to February, the soil was almost dry.

Monthly recharge analysis :

The estimated monthly groundwater recharge values were calculated by water balance. The data revealed that the recharge took place in few months of the concerned year *i.e.* during August, September and October for the year 2005, June and October for the year 2007, and only October for the year 2009. There was no recharge at all during 2006 and 2008, because of the low rainfall during these years. The major part of the recharge was occurred during September and October months only. Whereas June to August months

Table 1 : Various parameters of the water balance model computed for the year 2007-08 (WHC of the soil=211.40 mm)

Months	P	Q	P_{eff}	ET_c	P_{eff}-ET_c	APWL	ST	ST1	ΔST	AE	WD	WS
						1768.00						
May	56.00	2.71	53.29	15.56	37.73	471.60	37.73	37.73	37.73	15.56	0.00	0.00
June	263.40	18.96	244.44	29.89	214.55	0.00	252.28	249.60	211.87	29.89	0.00	2.68
July	86.00	5.77	80.23	85.48	-5.25	5.25	244.41	244.41	-5.19	85.42	0.05	0.00
August	64.00	0.00	64.00	101.24	-37.24	42.49	210.53	210.53	-33.88	97.88	3.36	0.00
September	106.00	0.00	106.00	88.74	17.26	22.82	227.79	227.79	17.26	88.74	0.00	0.00
October	96.00	4.78	91.22	68.64	22.58	0.00	250.37	249.60	21.81	68.64	0.00	0.77
November	0.00	0.00	0.00	38.25	-38.25	38.25	214.13	214.13	-35.47	35.47	2.79	0.00
December	0.00	0.00	0.00	6.31	-6.31	44.56	208.79	208.79	-5.34	5.34	0.96	0.00
January	0.00	0.00	0.00	12.43	-12.43	56.99	198.64	198.64	-10.15	10.15	2.29	0.00
February	0.00	0.00	0.00	13.13	-13.13	70.13	188.46	188.46	-10.18	10.18	2.95	0.00
March	126.00	42.76	83.24	20.23	63.02	0.00	251.48	249.60	61.14	20.23	0.00	1.88
April	0.00	0.00	0.00	20.18	-20.18	20.18	230.22	230.22	-19.38	19.38	0.79	0.00

(P=rainfall, Q=runoff, P_{eff}=effective rainfall, APWL=accumulated potential water loss, ST=moisture storage, ΔST=change in storage, AE=actual ET, WD=water deficit, WS=water surplus, WHC=water holding capacity)

of the year started contributing to recharge the soil profile. The groundwater recharge process is not continuous and is variable with respect to different months depending upon the rainfall pattern.

Annual recharge analysis :

The calculated annual groundwater recharge by water balance method are in the range of 0 to 181.91 mm with average value of 42.87 mm (5.19% of rainfall). The maximum recharge of 181.91 mm (21.37% of rainfall) took place during the year 2005 and no recharge was recorded during 2006 and 2008. This could be due to maximum rainfall (851.3 mm) and minimum rainfalls (304 mm and 458 mm) recorded during these years.

Groundwater recharge by watertable fluctuation method :

The watertable fluctuation was monitored in the five farmer's field wells. For the WT fluctuation study only pre and post monsoon WT data were recorded. For weathered granite, gneiss and schist with low clay content, specific yield (S_y) of 2.5 per cent is considered as per the recommendation of Groundwater Estimation Committee, 2007. There was recharge of groundwater of 100.90 mm, 26.65 mm, 128.85 mm, 20.35 mm and 113.05 mm during the years 2005, 2006, 2007, 2008 and 2009, respectively. On an average the recharge was 77.96 mm which is 11.68 per cent of annual rainfall for the above periods (Table 2). The maximum recharge of 128.85 mm (17.24%) took place during the year 2007 and minimum recharge was recorded during the years 2006 and 2008. It could be due to maximum (747.40 mm) and minimum (304.00 mm and 458.00 mm) rainfall recorded during these years. Further in-depth analysis of the data revealed that during the study period, recharge varied from 4.44 to 17.24 per cent, while about 77.96 mm/year *i.e.*, 11.68 per cent of annual rainfall was the average annual recharge of the study area. The groundwater recharge by rainfall suggested by GEC, 2007 that for the hard rock areas of weathered granite, gneiss and schist with low clay content, a 12 per cent of annual rainfall is considered for the study area. The annual groundwater recharge calculated by watertable fluctuation method is very close to the GEC, 2007 recommended value. Further, the availability of yearly recharge yield was calculated taking the total area of watershed as 218 ha and it was found that 2,19,962 m^3, 58,097 m^3. 2,80,893 m^3, 44,363 m^3 and 2,46,449 m^3 were the available recharge for the years 2005-06, 2006-07, 2007-08, 2008-09 and 2009-10, respectively.

Table 2 : Recharge calculated by watertable fluctuation method from 2005 to 2009

Sr. No.	Year	Precipitation	Recharge by WT fluctuation, mm	Recharge as per cent of 'P'	Annual recharge, m^3
1.	2005	851.30	100.90	11.85	2,19,962
2.	2006	304.00	26.65	8.77	58,097
3.	2007	747.40	128.85	17.24	2,80,893
4.	2008	458.00	20.35	4.44	44,363
5.	2009	703.00	113.05	16.08	2,46,449
	Average	612.74	77.96	11.68	1,69,953

Groundwater recharge analysis :

Comparison of recharge by water balance and water table fluctuation method :

Recharge calculated by the water balance and watertable fluctuation method is presented in Table 3. The results revealed that there was no correlation between the values calculated by the WT fluctuation method and the water balance method. The higher values obtained by the WT fluctuation method could be over estimation of specific yield values in the study area. The estimation of recharge with groundwater table fluctuation method is sensitive to the specific yield parameter which has not been assessed by the pumping test, but taken from the GEC, 2007 recommended values. Anurag *et al.* (2006) compared the recharge values calculated by WT fluctuation method and out of the Soil Water Atmosphere Plant (SWAP) model.

The results showed that there were no good correlation between recharge values obtained by two methods. It is interesting to note that during the years 2006 and 2008 no recharge was recorded in the water balance method, whereas, in the WT fluctuation method, some recharge values were recorded. It could be due to the immediate response of aquifer to rainfall. While, in case of water balance method, recharge could not occur till moisture level reaching the field capacity in the soil profile. Further, it is interesting to note that when annual rainfall was more than 850 mm, recharge calculated by the water balance method was more than watertable fluctuation method. Shirahatti (2008) noticed that when the both methods were compared, in case of Department of Geology monitored wells no good correlation was found.

Return flow due to groundwater irrigation :

For paddy the return flow amount is considered as 45 per cent of water application and for nonpaddy crop 25 per cent of water application (GEC, 2007). The return flow for paddy was 1,03,172 m^3 during *Kharif* and 1,13,547 m^3 during *Rabi*. For nonpaddy crops of cotton, groundnut, tobacco and vegetables it was 5,926 m^3, 812 m^3, 666 m^3 and 297 m^3, respectively, for 2009-10. Therefore the total amount of groundwater recharge due to groundwater application was 2,04,962 m^3 for 2009-10. Similarly the total return flow due to groundwater irrigation were estimated as 1,42,716 m^3, 1,57,692 m^3, 1,79,245 m^3 and 2,17,663 m^3 for the years 2005-06, 2006-07, 2007-08 and 2008-09, respectively.

Groundwater draft :

Regarding the groundwater draft, the actual groundwater pumped from the wells for irrigating the *Kharif* and *Rabi* crops during 2009-10 were 2,29,271m^3 for *Kharif* paddy, 2,52,328 m^3 for *Rabi* paddy, 23,705 m^3 for cotton, 3,249 m^3 for groundnut, 2,664 m^3 for tobacco and 1,188 m^3 for vegetables. Totally 5,12,404 m^3 of groundwater pumped and delivered to the field which was more than the groundwater recharge of 4,51,411 m^3 including the return flow due to irrigation. It means that the percentage of utilisation of available groundwater resource is 114 per cent of estimated recharge leading to the imbalance in groundwater sustainability. This means that the area is coming under overexploited zone (GEC, 2007). The same analysis was done for the year 2005-06, 2006-07, 2007-08 and 2008-09 showed that a total of 3,56,790 m^3, 3,94,230 m^3, 4,48,112 m^3 and 5,44,157 m^3 of groundwater was pumped, respectively to irrigate the crops both in *Kharif* and *Rabi*. The groundwater utilisation was 98, 183, 97 per cent and 208 per cent of estimated recharge for the years 2005-06, 2006-07, 2007-08 and 2008-09, respectively indicating the area under over exploited zone.

Strategy of groundwater planning:

The average groundwater recharge from the watertable fluctuation method for the study period of five years 2005 to 2009 was 77.96 mm. Therefore, on an average the total quantity of groundwater recharge was 1,69,953 m^3. The total quantity of groundwater pumped/draft both during *Kharif* and *Rabi* on an average was 4,51,139 m^3. The return flow due to irrigation was estimated as 1,80,455 m^3. The total annual average groundwater recharge including the return flow due to groundwater irrigation of the study area computed as 3,50,408 m^3. The annual usable groundwater (70 % of available) is only 2,45,286 m^3. From this calculations it was found that the groundwater exploitation was on an average 140 per cent more than the groundwater recharge, indicating that the area was under the over exploited zone. Because of this reason, it was advised not to allow the digging of further bore wells in the watershed for irrigation and also recommended for non paddy crops like cotton, groundnut and vegetables for at least 2-3 years in the study area. This is

Table 3 : Comparison of groundwater recharge calculated by water balance and WT fluctuation method

Sr. No.	Year	Precipitation, mm	Recharge by water balance, mm	Recharge by water table fluctuation, mm
1.	2005	851.30	181.91	100.90
2.	2006	304.00	0.00	26.65
3.	2007	747.40	3.45	128.85
4.	2008	458.00	0.00	20.35
5.	2009	703.00	28.99	113.05

one strategy under groundwater planning. Another option is to reduce the area under high water consuming paddy cultivation and thus reducing the conveyance and application losses by introducing drip and sprinkler irrigation methods for cotton, groundnut, vegetable crops etc. Water use from the existing bore wells must be reduced by participatory groundwater management through creation of awareness regarding the depletion of groundwater table. If the farmers practice drip irrigation using bore well water instead of furrow irrigation, not only additional yields could be achieved, but also with saved water more area could be irrigated. Thus the efficiency of bore well water could be increased.

Recommendations for the well irrigated areas :

A cost-effective electronic remote control mechanism can be used through a mobile phone to switch off the electric motor that drives the water lifting pump. Low water requiring crop verities can be recommended in the study area. Stream beds should not be cultivated and should be used for safe disposal of runoff. The recommended cropping pattern in the present study area using groundwater is cotton-vegetable, cotton-hybrid sorghum, cotton-groundnut, paddy-groundnut, and paddy – vegetable instead of the present cropping pattern of paddy-paddy cultivation. It is recommended not to go for new bore wells and non paddy crops at least 2-3 years by introducing crops like cotton, groundnut and vegetables may be introduced in the study area. It is recommended to reduce the present area under paddy cultivation. Low water requiring crops with drip and sprinkler irrigation systems can be recommended in the study area. Farmers using groundwater are to be educated with groundwater management techniques through capacity building programmes and participatory groundwater management methods. Further, rainwater harvesting and augmentation of ground water recharge through artificial recharge structures can be taken up in the over exploited pockets to improve the ground water quantity and quality.

Conclusion:

Recharge calculated by the water balance and watertable fluctuation method revealed that there was no correlation between the values calculated by the WT fluctuation method and the water balance method. In this contest the recharge calculated by water table fluctuation method is best method for the recharge estimation in the watershed. The study showed that excessive irrigation was practiced by the farmers as they were not measuring the irrigation quantity, thus leading to water logging and additional burden on power requirements. Hence, suitable measuring devices need to be introduced for better scientific irrigation practice.

Authors' affiliations:
I. MUTHUCHAMY, Department of Soil and Water Engineering, Tamil Nadu Agricultural University, COIMBATORE (T.N.) INDIA

S.S. SHIRAHATTI, Department of Natural Resource Management, College of Forestry, SIRSI (KARNATAKA) INDIA

REFERENCES

Anonymous (2005). *Watershed atlas of Karnataka (Sub, Mini and Micro watersheds),* Karnataka State Remote Sensing Application Centre, Dept. of IT, BT and S & T, Govt. of Karnataka, Bangalore, 1-205.

Anonymous (2007). *Eleventh Five-Year plan, Planning Commission of India*, Govt. of India, New Delhi.

Anonymous (2008). *Groundwater information booklet*, Raichur district, Karnataka, Central Groundwater Board, South Western Region, Bangalore (Min. of Water Resource, Govt. of India).

Anonymous (2009). Pani of Singanodi and Madalgeri villages, Dept. of Land Revenue, District Commissioner, Raichur, Govt. of Karntaka.

Anurag, T.S., Ruiz, L., Mohan Kumar, M.S., Sekhar, M. and Leijnse, A. (2006). Estimating the groundwater recharge using land use and soil data, A case study in south India, *Agric. Water Mgmt.*, **84** (1-2) : 65-76.

Groundwater Estimation Committee (GEC), (2007). *Groundwater Estimation Methodology,* Central Groundwater Board, Ministry of Water Recourse, Govt. of India, New Delhi.

Hall, D.W. and Risser, D.W. (1993). Effect of agricultural nutrient management on nitrogen fate and transport in Lancaster country, Pennsylvania, *Water Resour. Bull.*, **29** (1) : 55-76.

Kumar, C.P. and Seethapathi, P.V. (2002). Effect of additional surface irrigation supply on groundwater regime in Upper Ganga Canal Command Area, Part I - Groundwater Balance, National Institute of Hydrology, *Case Study Report No. CS*, **10** (1):1987-88.

Scalon, B.R. and Healy, R.W. (2002). Choosing appropriate techniques for quantifying groundwater recharge, *Hydrogeol. J.*, **10**(1):18-39.

Shirahatti, M.S. (2008), Development of an artificial recharge model using GIS and RS for hard rock area, Ph.D. Thesis, Tamil Nadu Agricultural University, Coimbatore, T.N. (INDIA).

Srinivas, A., Venkateshwar Rao, B. and Gurunadha Rao, V.V.S. (1999). Recharge Process and aquifer models of a small watershed, *Hydrological Sci. J.*, **44**(5): 681-692.

Szilagyi, J., Harvey, F.E. and Ayers, J.F. (2005). Regional estimation of total recharge to groundwater in Nebraska, *Groundwater*, **43** (1): 63-69.

Venkatesh, H. (2003). Rainfall analysis: As a tool in watershed development in Northern Dry zone of Karnataka, *Technical Bulletin*, 26, University of Agricultural Science, Dharwad, 34 p.

6th Year ★★★★★ of Excellence ★★★★★