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Low-Cost Groundwater Recharge through Open Wells in Indian Semi-Arid Tropical watersheds

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ABSTRACT

The traditional runoff harvesting facilities in Indian semi arid tropics (SAT) have degenerated due to lack of proper management and policy support. Due to vagaries of monsoon and scarcity of surface water in Indian SAT, dependence on groundwater has increased tremendously and water resource has transformed from community resource to a private resource. Farmers have dug open wells to draw groundwater from shallow aquifers. With advent of bore well technology and subsidized power, there has been shift in groundwater extraction from shallow aquifers to deeper aquifers creating mining effect. Intensity of rainfall in Indian SAT is grossly adequate to adequately charge the aquifers. A study was made in a watershed at Kothapally, Rangareddy district, AP, to recharge groundwater thru diversion of clean rain runoff in 35 failed (dry) open wells. Quantity of groundwater recharged thru diversion of the runoff was estimated which averaged 96100 m³ over two year of study. To store same quantity of runoff on land surface, it would have required approximately 4 ha land area, Rs 20 lakhs as construction cost and Rs 20,000 as annual maintenance cost. The enhanced water availability in open wells resulted into increased irrigated area in rabi and post rabi seasons. It resulted into increased area under fodder cultivation, milch animals, marketable milk production, area under flowers and vegetables. Area under irrigation and yield increase of annual crops was affected. Increased water availability culminated into increased income and livelihood opportunities for farmers in the watershed.

INTRODUCTION

The semi-arid tropics (SAT) are defined in the context of Troll's (1965) vegetation zone delineation as the region within the tropics where the mean monthly rainfall exceeds mean potential evapotranspiration during 2-7 months of the year. Within the region of the areas where this excess lasts for 2 to 4.5 months are called dry SAT and those where it lasts for 4.5 to 7 months are called wet SAT. SAT includes regions that are characterized by variable, high intensity and low rainfall. Rainfall in the SAT generally occurs in short torrential downpours; its large portion results into runoff eroding productive topsoil. It leads to low productivity and frequent droughts.

Increase in population and greater demand on food mean that farmers must have the capability to increase the production. Integration of conservation and management of soil and water resources including irrigation is one obvious method. However, even if all irrigation potential is exploited, vast area of the SAT will remain dependent on rainfall.

Water is most limiting factor for agricultural production in rainfed agriculture. About two third of country's net cropped area, 86.4 million hectare (mha) out of 141.1 mha, is rainfed. The rainfed lands in India produce 42.3% of the country's food. Nearly 91% of sorghum, 92% of pearl millet, 63% of cotton, 86% of pulses and 90% of oilseeds are grown in these areas (Agricultural Statistics at a Glance, 2007).

There is strong case for improving yields of rainfed lands, which are unlikely ever to be irrigated by conventional canal irrigation system for sustainable growth and spatial equitable growth. The runoff from large catchments collected in tanks has been used traditionally in SAT for irrigating crops grown downstream the tanks. However, tank irrigation system has degenerated over the years due to siltation, absence of proper management and policy support. Silted tanks have been converted into percolation tanks for recharging groundwater. Over the years water resource has transformed from community resource to a private resource.

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Groundwater plays an immense role in meeting domestic, irrigation and industrial demands. As on March 2004, the annual replenishable groundwater resources were estimated to be about 432 billion cubic meter. The net annual groundwater available was 399 billion cubic meter and annual groundwater draft for irrigation domestic and industrial uses was around 231 billlion cubic meteR in 2004 (Cental Groundwater Board, 2006).

Groundwater exploitation, particularly in India, has increased by leaps and bounds over the last 20 years along with the expansion of shallow, mostly private, wells. The growth of groundwater abstraction structures from 1982 to 2001 clearly depicts the increasing use of ground water utilization across sectors. As per available published statistics, the number of dug wells increased from 5.38 million in 1982 to 9.61 million in 2001 shallow tube wells from 460,000 to 8.36 million and total wells from 5.88 million to 18.5 million in the same period (Report of 3rd Minor Irrigation Census, 2000-2001). In Indian subcontinent groundwater use soared from around 10-20 cubic kilometers per year before 1959 to 240-260 by 2000 (Tushar et al. 2003).

In many parts of India especially in SAT, due to vagaries of monsoon and scarcity of surface water, dependence on groundwater resource has increased tremendously in recent years. Easy availability of tube well drilling technology, credit from financial institutions for sinking tube wells coupled with provision of subsidized/ free electricity for pumping in many states has exacerbated the increased extraction of groundwater. Over years there has been gradual shift from exploitation of shallow aquifers towards extraction of groundwater from deeper aquifers. Land use changes have also decreased drastically the infiltration rate into the soil and has diminished the natural recharging of aquifers by rainfall. These factors have contributed to lowering of the water table that many dug wells and tube wells giving previously sufficient water yield are decreasing now in their yield and ultimately drying up. As on March 2004, a total of 1445 out of 5723 assessment units (development blocks) are categorized as semi critical, critical, over exploited and saline (Central Groundwater Board, 2006).

Augmentation of groundwater resources through artificial recharging of aquifers, which supplements the natural process of recharging, has become relevant in situations witnessed in India, where the rainfall is seasonal and is not spread uniformly across the country, and the quantum of natural recharge is inadequate to meet the increasing demand of ground water resources. Artificial recharging of groundwater has been taken up as one of the supply side corrective measures to compensate for this overexploitation and to retard drying of open and tube wells.

In India, activities aimed at augmenting groundwater resources through artificial recharge generally form part of a wider set of activities aimed at developing, or rehabilitating watersheds. All watershed interventions aim to reduce runoff and store rainwater into soil profile and deep percolation beyond the profile in groundwater aquifer. Irrespective of the intervention the aim is to significantly reduce surface runoff and evaporation in order to enhance agricultural production and, often unintentionally, enhance groundwater recharge. Very limited efforts have been made to recharge groundwater at local field level.

Other than natural groundwater recharge methods there are numerous methods to artificially recharge groundwater and they are as varied as the ingenuity of those involved in their construction and operation. (UNESCO, 2005; Central Ground Water Board; 2000, CGWB/ UNESCO; 2000, National Institute of Hydrology; 1998; American Society of Civil Engineers; 2001, O'Hare et al.; 1982, Huisman and Olsthoorn; 1983, Pacey and Cullis; 1986 and United Nations, 1975).

OBJECTIVES OF THE STUDY

There are large numbers of open wells - failed and functional - in various watersheds that can be used for groundwater recharging through diversion of clean rain runoff by using their storage capacity. The study was aimed to

- Use and quantify existing failed (dry/ non-functional) open wells storage capacity for rainwater harvesting to minimize cost and evaporation losses

- To revitalize non- functional wells for groundwater recharge and benefit farmers thru increased irrigated area and agricultural production

MATERIAL AND METHODS

A farmers' participatory watershed management project was initiated in 1999 at Kothapally village (longitude 78 deg 5′ E to 78 deg 8′ E and latitude 17 deg 20′ N to 17deg 24′ N) in Ranga Reddy district of Andhra Pradesh. Check dams (14 nos), gully control structures (97 nos), mini percolation tanks (60 nos), gabion structures (1 no), diversion bunds (500 m), and structures for diversion of runoff in dry open wells (35 open wells) were constructed at suitable locations for efficient soil and water management (Wani et al., 2002).

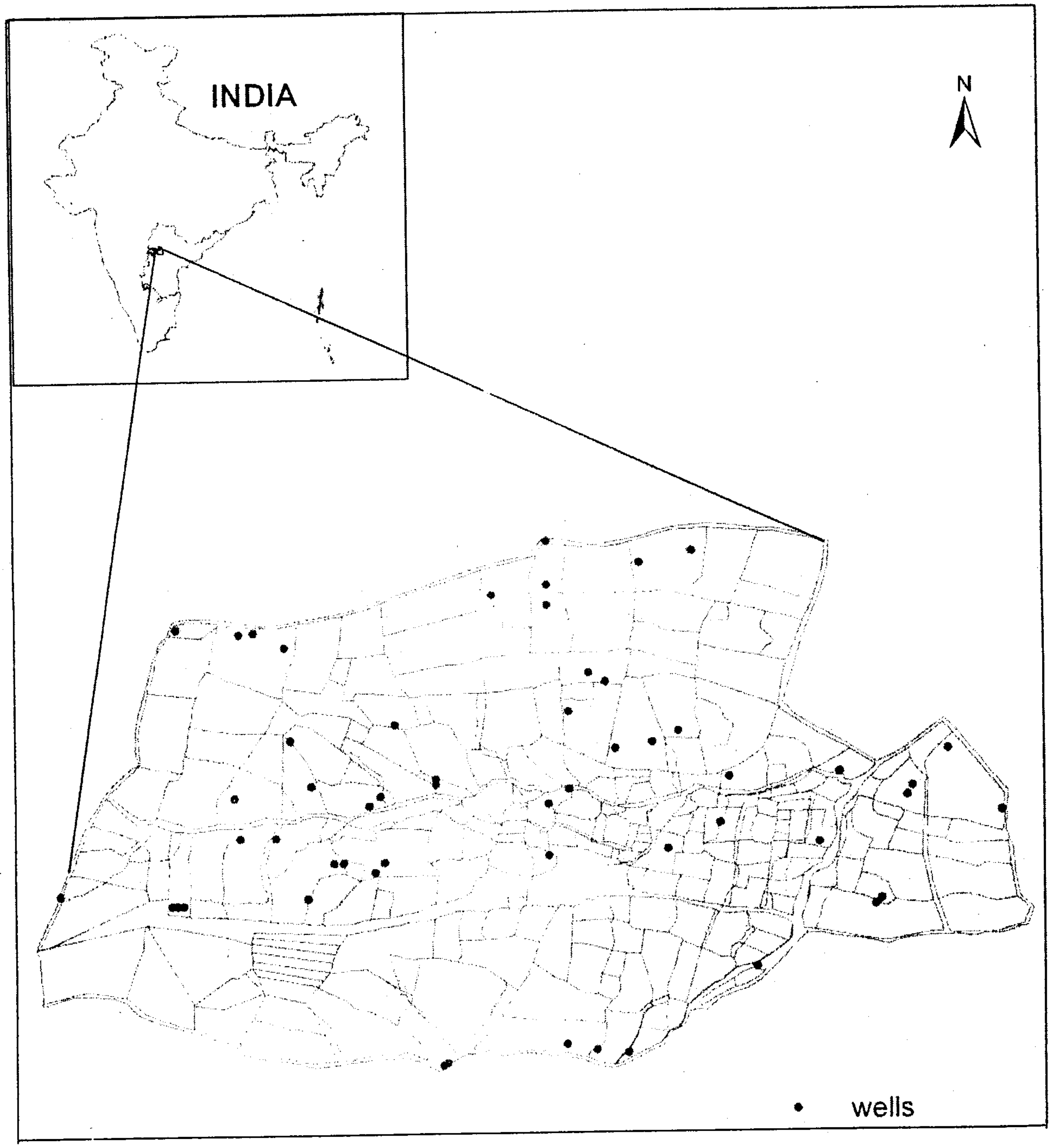

Fig. 1. Location of Kothapally Watershed

TABLE 1. DEPTH, EQUIVALENT DIAMETER AND STORAGE CAPACITY OF OPEN WELLS

Depth, (m)		Equivalent Mean Diameter, m		Volume, m^3	
Range	No	Range	No	Range	No
8.5-9.5	5	8.0	2	<600	4
9.5-10.5	18	9.0	7	600-800	12
10.5-11.5	14	9.5	1	800-100	10
11.5-12.5	7	10.0	12	1000-1200	14
12.5-14	5	10.5	3	1200-1400	10
14.0-15	6	11.0	13	1400-1600	5
15.0-16	3	11.5	10	1600-1800	3
16.0-18.0	3	12.0	10	1800-2000	3
> 18.0	1	12.5-14.5	4	>2000	1
Mean	11.7	10.8	1122		

A survey of failed and functional open wells was made. There were 62 open wells in the 465 ha watershed (Fig 1). Due to advent of extraction of groundwater from deeper aquifers, 35 open wells were dry and non-functional and only 27 open wells were functional. Even among functional wells, few of them provided poor water yield.

Information from local wells

Open wells that have run dry may be used to recharge shallow phreatic aquifers. The walls of the structures may need to be supported to avoid collapse in unconsolidated sediments. Artificial groundwater recharge schemes are site-specific and even the replication of the proven techniques are to be based on the local hydrogeological and hydrological conditions. Depth of unsaturated thickness of rock formation in all open wells in Kothapally watershed was more than 3 meter. Also the post- monsoon depth of water level was much below this depth. Approximately 3m thickness of unsaturated thickness of rock formation is minimum to minimize adverse environmental impacts such as water logging, salinity, etc and for saturating the unsaturated zone. It was observed that the open wells were suitable at Kothapally watershed for storing rainwater and ground water recharging.

The mean depth, equivalent diameter and storage capacity of 62 open wells in Kothapally watershed was 11.7 m, 10.8 m and 1122 m^3 respectively. The range and number of open well depth, equivalent diameter and storage capacity of the wells are given in table 1. Large number of wells had depth within 9.5 –12 m, diameter within 10.0- 12.0 m and storage capacity within 600- 1400 cubic m. Cumulative storage capacity of all open wells totaled 69565 m^3.

Flow estimation / measurement

The rain-runoff diversion to open wells at Kothapally watershed was estimated in rainy season of 2003. Bunds were made in downstream of the channel to create about 30 cm head over PVC inlet pipe where the pipe was laid by the farmer to divert rain runoff on 5 open wells. It was planned to measure water levels in the wells before and after each runoff-producing storm. However, the bunds were washed out during the intense runoff producing storms. In absence of measured information, an indirect method, as described below, was adopted to estimate the volume of diverted rain runoff in to open wells.

A 100 mm diameter PVC pipe in the channel have been laid by farmers to divert water on 35 open wells which had been abandoned for use because they were not providing adequate water yield. Assuming approx 6 m length of pipe and approx 30 cm total hydraulic head (which includes water head over the pipe inlet and head gain due to slope along the pipe length, the flow velocity was estimated using following equation for gravity flow in pipes.

V = [2gh / {1+ (4f l /d)}] ^ 0.5, where, V is velocity in cm/sec, g - gravitational force cm/sec^2, h- the hydraulic head in cm, l - length of the pipe in cm, d- the diameter of the pipe in cm, and f- frictional resistance of pipe (0.011for PVC).

The total time of runoff duration of the runoff flow was taken from the two-runoff gauging stations, which averaged 72.833 hr for the entire 2003 rainy season. Using above equation, the total volume was estimated as 91617 m^3 assuming the total pressure head (water head + elevation difference between pipe inlet and outlet) for the water flow was 30 cm all time during the runoff flow and rain runoff is available for diversion in the open wells for total duration of the runoff generation.

It is understood that in absence of any bund downstream the pipe inlet the head above the inlet pipe is not constant and the runoff flow in the pipe was not for entire duration of runoff flow. Also, the runoff flow duration in the well varies for each well and may not be same as that estimated at runoff gauging station.

Flow duration measurement

The runoff flow duration measuring device had a magnetic float switch, installed on a T section of 100 mm diameter PVC pipe and an hour meter/ counter with LCD display (Fig 2). The counter ranges from 1- 9999 hours. The unit is equipped with ON/OFF, reset and test switch and it is powered with a 3 volt DC battery cell. The hour meter received input signal from float switch, which is activated when water flows in the PVC pipe.

Clogging in its various forms of an aquifer can make an artificial groundwater recharge scheme inoperative. Clogging can affect all types of recharging methodologies and can vastly decrease the amount of water that can be recharged into the aquifer. In the case of aquifer storage and recovery, it can also decrease the amount of water that is recovered from the aquifer. A sediment trap pit and filter pit should be designed considering expected runoff for maximum 30 minutes intensity, recurrence interval of 25 years and settling velocity of soil particles. Figure 3 presents schematic diagram details of runoff filtering system used for groundwater recharging thru diversion of rain - runoff in open wells.

During 2004 and 2005 rainy season we installed 8 devices to measure cumulative time duration of rain- runoff flow in open wells (table 2). The 100 mm diameter PVC pipe was used to divert runoff

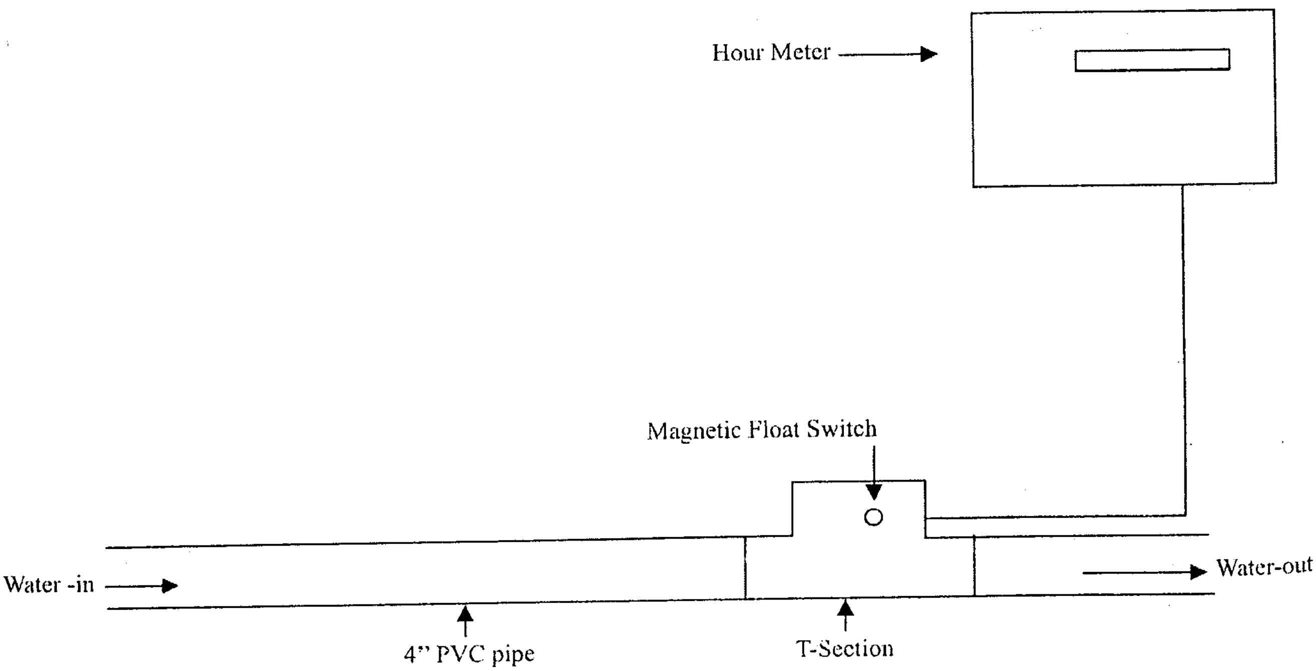

Fig. 2. Schematic diagram device for runoff diversion measurement into open well

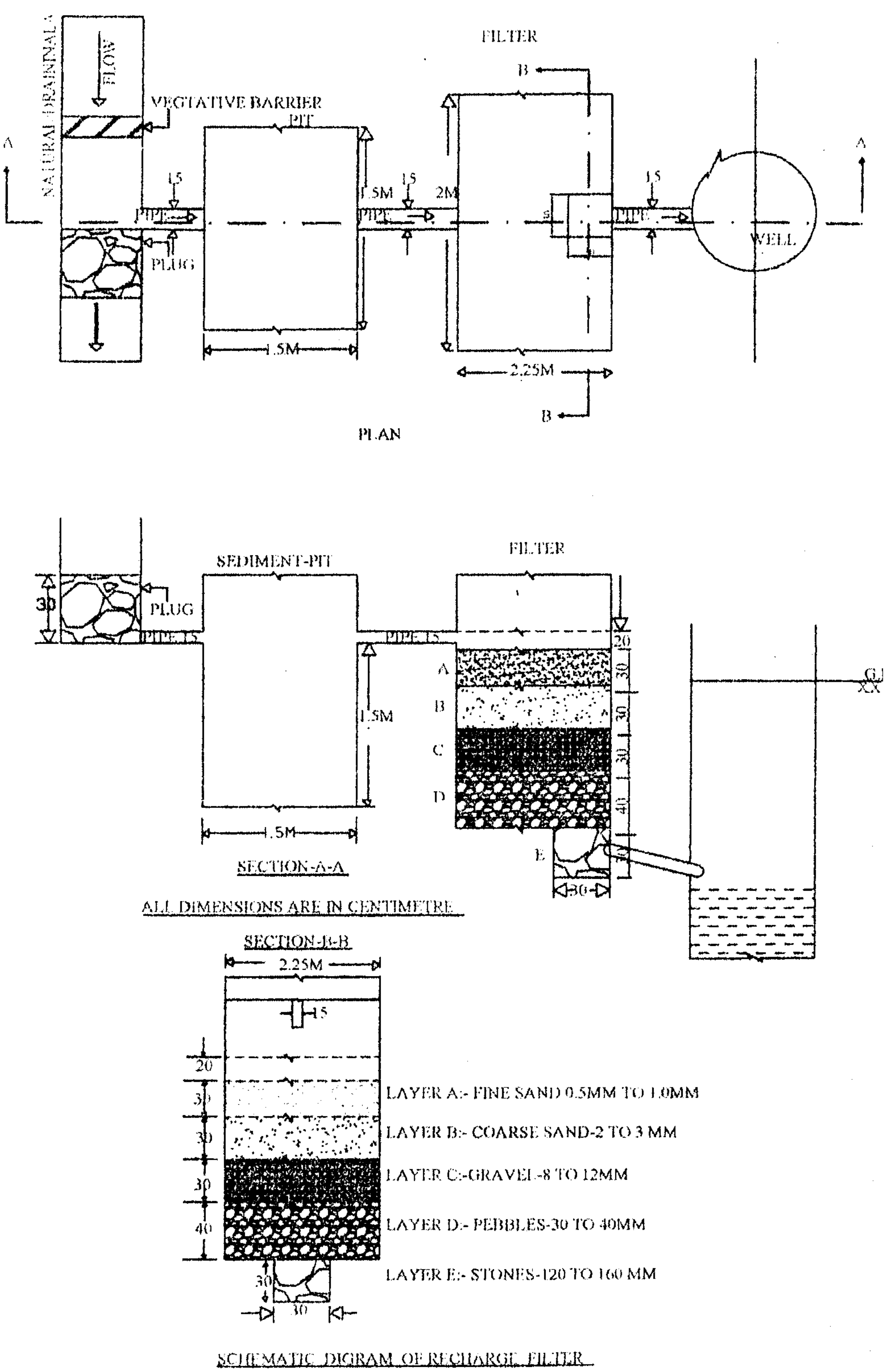

Fig. 3. Schematic diagram of runoff diversion drain, recharge filter and open well

TABLE 2. CUMULATIVE TIME OF RUNOFF DIVERSION DURING RAINY SEASON 2004 AND 2005 IN OPEN WELLS, KOTHAPALLY WATERSHED, RANGA REDDY DISTRICT, ANDHRA PRADESH

Well No.	Cumulative time of runoff diversion (h)	
	2004	2005
1	70.15	78.2
2	85.12	89.1
3	87.39	79.3
4	74.41	75.39
5	91.19	87.3
6	71.54	85.3
7	83.07	87.15
8	85.47	81.4
Average	81.04	82.89

from the drain. An earthen plug with stone pitching in the drainage channel, downstream of inlet pipe, was constructed to provide 30 cm hydraulic head over the inlet. The PVC pipes discharged the runoff into a sediment trap pit and then thru another pipe to a filter pit consisting of graded filter materials. The runoff was withdrawn from the bottom of the second pit for recharging open wells.

RESULTS AND DISCUSSION

The cumulative duration of the runoff flow during 2004 and 2005 in eight open wells was observed (table 2).

Based on measured average duration of runoff flow in the open wells, the average flow was estimated using equation given above for gravity flow in pipes. Estimated average runoff diversion in the open wells, where the duration of flow was measured, was 2912.67 and 2579.2 m^3 for 2004 and 2005 rainy seasons. Based on measured duration and estimation of runoff the total runoff diversion in 35 open wells in Kothapally watershed was estimated as 101943 and 90272 m^3 in 2004 and 2005 rainy seasons respectively.

If an average depth in a surface reservoir were assumed as 2.5 m, the storage of 100,000 m^3 of runoff would require more than 4 ha area. The construction cost of such reservoirs would cost approximately Rs 2 million and a minimum of Rs 20,000 as maintenance cost/year.

It is worth noting that the minimum average dimensions of open wells in Kothapally watershed are 11.7 m equivalent diameter and 10.8 m depths. Thus average storage capacity of the open wells is approx 1122 m^3. Also these wells are charged whenever there is rain runoff and discharged throughout the year. The fact is significant for diversion of storage of rain runoff and its storage in the open wells.

Cost of artificial recharging

Average cost of run off filtering system was approximated as Rs 3000 and maintenance cost per year was estimated as Rs 300. If average volume of runoff diversion in each well is approximated to 2860 m^3 /year and life of the structure as 15 years, the cost of water recharging is approximated as Rs 300 per 1000 cubic meter. Rushton and Phadtare (1989) describe artificial recharge pilot projects in both alluvial and limestone aquifers in Mehsana area of Gujarat, India. Recharge was accomplished using spreading channels, percolation tanks and injection wells. Table 3 presents a summary of the initial and operational costs for the various schemes. The most expensive scheme, an injection well feeding an alluvial

TABLE 3. COSTS OF VARIOUS ARTIFICIAL RECHARGE SCHEMES IN INDIA (RS/1000M^3)*

Artificial recharge structure	Initial cost	Running cost
Injection well (alluvial area)	4500	4500
Spreading Channel (alluvial area)	405	450
Percolation Tank (alluvial area)	90	315
Injection well (limestone area)	270	945
Spreading channel (limestone area)	215	270

Source: Rushton and Phadtare (1989)

* *Cost quoted in US dollar in original reference (conversion rate assumed: 1 US $ = Rs 45.00)*

aquifer, had initial and operating costs per unit volume of recharged water of Rs 4500 / 1000 m^3.

Utilization of conserved water

Various soil and water conservation practices such as mechanical structures (small check dams, gully control structures, mini percolation pits, diversion bunds, etc) on community lands, various land forms (broadbed land form contour planting, field bunding) on farmers lands, improved cropping system, wasteland development and tree plantation and diversion of rain- runoff in 35 open wells were implemented as soil and water conservation measures.

Data on use of available additional water were collected from 20 farmers who had open wells with (15) and without (3) rain runoff diversion for ground water recharge and bore wells (2) for evaluation of benefits of additional availability of water on irrigated area (total no of families - 270, open wells -62, bore wells -35), fodder growing area, number of milch animals and milk production before and after runoff diversion into open wells and other water conservation interventions in the watershed Fodder area increased by 850 % , milch animal by 363 % and production of daily milk production was increased by 862 % (table 4).

Community -based water conservation measures described earlier and farmer-based water conservation measures such as broadbed land configuration, *gliricidia* plantation on field bunds and field bunding including runoff diversion into open wells increased groundwater recharge substantially, a total of 200 ha were irrigated in post- kharif season and 100 ha in post -rabi season (Wani, et al, 2003), mostly vegetables.

Data were also collected on cropping area, irrigated area and production of crops (vegetables and spices, flowers and food grain crops) grown by the sampled farmers before and after water conservation interventions were made in the watershed (Table 5).

Post intervention cotton area decreased though irrigation was not applied to cotton, its yield increased probably due to better in- situ soil conservation measures, improved variety, and integrated pest management and other improved crop management practices. Sampled farmers did not grow pearl millet and area under sorghum decreased and no irrigation was applied to the crop after implementations of watershed management i.e. post intervention of water conservation measures. Maize, pigeonpea, chickpea cultivation and irrigated area increased by more than 30%. No irrigation was given to maize and pigeonpea before initiation of the watershed management interventions. However, water application to these crops as introduced after the intervention of the conservation measures. Irrigated area under chickpea increased by 200%. Maize yield increased by 14.4%, pigeonpea by 96% and chickpea by 15.6%. However, there was marginal decline of paddy productivity and both cultivated and irrigated area under paddy increased by 300%.

Availability of additional groundwater increased cultivation of vegetables and spices (turmeric and coriander) and flowers which were mostly, irrigated. Cultivation of cucumber and coriander was introduced which gave gross monetary return of over Rs 35200 / ha and Rs 38350 / ha respectively. Farmers discontinued brinjal cultivation, probably, because of unfavorable net profit after implementation of watershed

TABLE 4. IRRIGATED AREA, FODDER AREA, NUMBER OF MILCH ANIMALS AND MILK PRODUCTION FOR SAMPLED FARMERS BEFORE AND AFTER INTERVENTION OF VARIOUS WATER CONSERVATION MEASURES IN KOTHAPALLY WATERSHED, RANGA REDDY DISTRICT, ANDHRA PRADESH

	Before intervention	After intervention	Percent increase
Irrigated area, ha	8.6	24.6	186
Fodder area, ha	0.16	1.52	850
Milch animals	11	51	363
Milk production, kg/day	35	337	862

TABLE 5. PRODUCTION OF VEGETABLES, FLOWERS AND FOODGRAINS BEFORE AND AFTER INTERVENTION OF WATER CONSERVATION MEASURES IN KOTHAPALLY WATERSHED, RANGA REDDY DISTRICT, ANDHRA PRADESH.

	Before intervention			After intervention		
	Total area ha	Irrigated area ha	Production (Q/ha) or gross return (Rs/ha)	Total area ha	Irrigated area ha	Production (Q/ha) or return (Rs/ha)
Vegetables/spices						
Tomato	2.6	1.6	41,750(Rs/ha)	4.2	4.2	36,768(Rs/ha)
Cucumber	0	0	0	3.2	3.2	35,228(Rs/ha)
Carrot	0	0	0	0.4	0	100
Cabbage	0.2	0.2	50,000(Rs/ha)	0.4	0.4	75,000(Rs/ha)
Beans	0.2	0.2	12,500(Rs/ha)	0.4	0.4	25,000(Rs/ha)
Brinjal	0.2	0.2	20,000(Rs/ha)	0	0	0
Coriander	0	0	0	0.6	0.6	38,350(Rs/ha)
Onion	0.4	0.2	7.5(Q/ha)	2.8	2.8	87.5(Q/ha)
Turmeric	1.4	1.4	50(Q/ha)	2.23	2.23	50(Q/ha)
Flowers						
Marigold	0.4	0	8,750(Rs/ha)	1	0.2	18,875(Rs/ha)
Crossandra	0.2	0.2	75,000(Rs/ha)	0.2	0.2	75,000(Rs/ha)
Chrysanthemum	0.6	0.6	17,500(Rs/ha)	0.6	0.6	34375(Rs/ha)
Cotton	8.8	0.8	18.88(Q/ha)	6.2	0	26.5(Q/ha)
Food grains						
Pearl millet	0.2	0	10(Q/ha)	0	0	0
Sorghum	3.4	0.4	16.13(Q/ha)	1.5	0	13.38(Q/ha)
Maize	1.6	0	40.63(Q/ha)	2.2	2.2	46.5(Q/ha)
Pigeonpea	0.8	0	6.25(Q/ha)	3.2	1	12.25(Q/ha)
Chickpea	1.2	0.8	10.38(Q/ha)	1.6	1.6	12.00(Q/ha)
Paddy	1	1	63.33(Q/ha)	4	4	61.25(Q/ha)

management. Carrot cultivation, a new introduction, without irrigation resulted in yield of 10 tons/ha. Onion cultivated area and irrigated area increased by 600% and 1200% respectively with yield increase by 1066%. Cultivated and irrigated area under turmeric increased by 59.3% after increased availability of water, however, there was no increase in its yield. Cropped area both under cabbage and beans increased by 100% and monetary gross returns increased by 50% and 100% respectively. Tomato cultivated and irrigated area increased by 61.5% and 62.5%. However the gross monetary return decreased during period of increased availability of water, probably because of larger availability and low price prevailing in the market for tomato.

There was no change in cultivated area, irrigated area and gross monetary return for crossandra flowers cultivation. Farmers did not irrigate marigold flowers before intervention of watershed management practices. Increased availability of water resulted in large increase (150%) in cultivation area under marigold flowers. Cultivation of marigold and chrysanthemum flowers resulted in increased monetary return of 116% and 96% respectively

CONCLUSION

Surface groundwater recharge methods have relatively low construction costs and are easy to operate and maintain. However direct surface recharge is governed by factors governing the amount of water that will enter the aquifer, the amount of sediment in the recharge water, the area of recharge and length of time that water is in contact with soil are the most important.

Direct subsurface recharge methods thru open wells access vadoze zone (zone between land surface and water table). Experience at Kothapally watershed has shown that the open wells can be used very effectively for making dry wells functional and recharging groundwater thru functional wells for raising water level of unconfined aquifer. The ground water can be extracted thru open wells and shallow bore wells and can be used for increasing area under irrigation, increasing crops productivity and income of the farmers. The experience has demonstrated that substantial amount of rain runoff can be used for ground water recharge which would have needed large land area to store it on surface reservoirs necessitating large initial cost and annual maintenance cost.

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