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Cost Effectiveness of Rainwater Harvesting for Groundwater Recharge in Micro-Watersheds of Kolar District of India: The Case Study of Thotli Micro-Watershed

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This study has estimated the supply augmentation of groundwater recharge due to creation of water harvesting structures and has assessed the cost-effectiveness of rainwater harvesting for groundwater recharge on watershed basis in one of the sub-watersheds of the Kolar district, Peninsular India — a typically hard-rock area. The study is based on the primary data for the year 2008-09 collected from a sample of 90 farmers having irrigation bore-wells in the selected watershed named Thotli. The study has indicated that the annual draft of irrigation water exceeds the annual recharge, causing a negative balance. On an average, the returns per rupee investment have been found to be ` 1.80 on farm pond, ` 1.78 on recharge pit and ` 1.39 on field bund. The cost incurred to impound a metre cube of water has been found as ` 3.01 in the case of field bund, where estimated recharge benefit is 5.6 m3, ` 1.67 /m3 in the case of recharge pit (with an estimated recharge benefit of 720 m3), and ` 1.33 /m3 in the case of farm pond (recharge benefit of 1350 m3). The discounted cost-benefit analysis of the investment on water harvesting structures has indicated that the investment on water harvesting structures is cost-effective and financially-viable.

Keywords

Rainwater harvesting, Economic feasibility, Groundwater recharge, Watershed

Disciplines

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Cost Effectiveness of Rainwater Harvesting for Groundwater Recharge in Micro-Watersheds of Kolar District of India: The Case Study of Thotli Micro-Watershed[§]

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Abstract

This study has estimated the supply augmentation of groundwater recharge due to creation of water harvesting structures and has assessed the cost-effectiveness of rainwater harvesting for groundwater recharge on watershed basis in one of the sub-watersheds of the Kolar district, Peninsular India — a typically hard-rock area. The study is based on the primary data for the year 2008-09 collected from a sample of 90 farmers having irrigation bore-wells in the selected watershed named Thotli. The study has indicated that the annual draft of irrigation water exceeds the annual recharge, causing a negative balance. On an average, the returns per rupee investment have been found to be ₹ 1.80 on farm pond, ₹ 1.78 on recharge pit and ₹ 1.39 on field bund. The cost incurred to impound a metre cube of water has been found as ₹ 3.01 in the case of field bund, where estimated recharge benefit is 5.6 m^3, ₹ 1.67 /m^3 in the case of recharge pit (with an estimated recharge benefit of 720 m^3), and ₹ 1.33 /m^3 in the case of farm pond (recharge benefit of 1350 m^3). The discounted cost-benefit analysis of the investment on water harvesting structures has indicated that the investment on water harvesting structures is cost-effective and financially-viable.

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JEL Classification: Q 15, Q 25

Introduction

Of the total irrigated area in India, around 60 per cent is irrigated with groundwater. In addition to direct contribution of groundwater for increasing agricultural production and productivity, around 80 per cent of the domestic water supply in the rural areas and over 50 per cent in the urban areas is met through groundwater. Further, in drought years, groundwater acts as a buffer for maintaining agricultural productivity. Of late, groundwater resource in hard rock area is exhibiting signs of overdraft, indicating a rapid decline in the watertable, threatening groundwater-based agriculture. Surface irrigation is also subjected to higher vulnerability due to frequent failures of monsoon. In the context of arid and semi-arid regions where groundwater is a lifeline, its sustainability is at stake due to secular overdraft. Since more than 70 per cent of the total irrigation requirement is met through groundwater, its sustainable use is the key issue needing policy support.

In the state of Karnataka some parts are under typical hard rock area where groundwater depletion is a major problem because recharge levels are extremely

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low. As a result, groundwater scarcity is emerging on a large scale affecting not only agriculture but also livestock and drinking water needs of rural and peri-urban people. In response, there has been an alarming increase in the private investment on groundwater wells for irrigation and drinking purposes, exerting too much pressure on groundwater leading to over-exploitation. In order to address these concerns, significant emphasis is being accorded to the augmentation of groundwater recharge on watershed basis.

Objectives

The major focus of watershed development is groundwater recharge through water harvesting structures. In this regard, the watershed programme has been criticized on two counts, viz. higher emphasis on supply augmentation of resources and little attention on the economic use of resource (demand management), and hence this needs to be addressed (GOI, 2011). Also, the creation of water harvesting structures in a watershed entails capital investments which need to be evaluated for cost-effectiveness and other benefits. Thus, it is imperative to address the supply and demand management issues and also evaluate the investment on different water harvesting structures for improving groundwater recharge and attaining associated benefits. Thus, the specific objectives of the study were: (i) to asses the supply augmentation of groundwater with water harvesting structures, and (ii) cost effectiveness of rainwater harvesting for groundwater recharge on watershed basis

Materials and Methods

Selection of Micro-Watershed, Villages and Beneficiaries

Choice of District

The study was carried out in the Kolar district of Karnataka state, which has highest (1.35 lakh) concentration of surface deep bore-wells (Nagaraj *et al.*, 2009). In the district, there are no perennial rivers to recharge groundwater. According to the Mines and Geology reports, the total annual groundwater recharge is of the tune of 4809 hectare million metres (HMM), of which the extraction is around 6554 HMM, leaving a huge gap. The net groundwater available for further irrigation development is virtually nil. The balance groundwater irrigation potential available is also nil. Thus, over-exploitation of groundwater resources has been a serious problem in the district (18 bore-wells/sq km, whereas carrying capacity is only 5 bore-wells/sq km). Currently, the depth of the bore-wells has increased considerably, from 500 ft to 1200 ft. Thus, watershed development has become the major intervention towards groundwater recharge in the district.

In consonance with the objectives of the study and consultation with MYRADA, an NGO, the Thotli micro-watershed in the Kolar district was selected for this study, as most of the watershed activities were completed in this watershed. There are two villages in the micro-watershed, viz. Kakinatha and Thotli with 90 bore-wells. All the watershed beneficiaries possessing bore-wells (90) were chosen for the study. In order to monitor the fluctuations in groundwater table, a 'dip meter' was installed in failed bore-wells and monthly observations were recorded for the year 2008-09. The primary data were collected through personal interviews with the help of pre-tested and structured questionnaire for the year 2008-09. By using Rainfall Infiltration Method, groundwater recharge from water harvesting structures was estimated. The capital investments on water harvesting structures were also amortized to arrive at the annual cost of the watershed structures. The standard procedure of discounting cash flow technique was used to appraise the investments on water harvesting structures.

Results and Discussion

The Thotli micro-watershed has 1,577 acres of geographical area, of which the cultivated area forms 66.7 per cent. Out of the total cultivated area, the groundwater-irrigated area was 28 per cent. The well inventory in the watershed indicates that there were 69 open-wells and 158 bore-wells. Most of the open-wells were dried and defunct, while 62 per cent of the total bore-wells were functioning. The depth of bore-wells varied from 500 feet to 1200 feet. It was observed that around one-third of the wells were yielding 1000-1500 gallons/hour. Only 10 per cent of the functional wells yielded >2000 gallons, as indicated in the Table 1.

Table 1. General features of study area — Thotli micro-watershed

Particulars	Thotli micro-watershed
No. of villages in the micro-watershed	2
Watershed area (acres)	1577
Total cultivated area (acres)	1052
Irrigated area (acres)	295
(i) Tanks	2
(ii) Open-wells	69
(iii) Bore-wells	158
(iv) No. of functioning bore-wells	98 (62.02)
Yield of the existing bore-wells	
(a) < 1000 gallons per hour	19
(b) 1000-1500 gallons per hour	38
(c) 1500-2000 gallons per hour	31
(d) > 2000 gallons per hour	10
(v) No. of non-functioning bore-wells	60
(vi) Depth of bore-wells (feet)	500-1200

Note: Figures within the parentheses indicate percentage to total

Demand for and Supply Augmentation of Groundwater

Groundwater Draft (Demand)

In the Thotli watershed area, the groundwater extracted (draft) for different uses was estimated and the results are provided in the Table 2. Out of the total groundwater extracted, annual domestic-use was meagre (77.21 acre-inches), accounting for around 1 per cent of the total draft. The maximum annual draft was towards the perennial crops, which was to the tune of 4,335.7 acre-inches, accounting for 63 per cent of the total water-use. This was followed by the annual crops to the tune of 2,510 acre-inches (36%) and dairy activity (0.5%). Thus, there is scope for saving water in agriculture since agriculture is the bulk user of groundwater in the rural area. The overall draft (demand) from groundwater was to the extent of 6,956 acre-inches (71.5 ha-m). Out of the total groundwater extracted annually, about 98 per cent is put to agricultural use and only 2 per cent is accounted for other uses such as dairy and domestic purposes.

Recharge (Supply) from Water Harvesting Structures

By using the standard methodology (Rainfall Infiltration Method) given by Groundwater Estimation Committee, the amount of recharge was estimated and the results are provided in Table 3. The recharge of groundwater was maximum through precipitation, accounting for 63 per cent (4898 acre-inches) of the total recharge, followed by return flow irrigation with 22 per cent share (1703 acre-inches), water harvesting structures (11%; 866 acre-inches) and irrigation tanks (3.6%; 275 acre-inches) (1 acre-inch = 0.0102790153 ha-m). On an average, the cost incurred to recharge one acre-inch of groundwater through water harvesting structures was ₹ 114.

The water level in the failing bore-wells acts as a barometer of the watertable status. In addition, any change in the watertable either due to recharge or excess draft can be recorded and accordingly the results can be interpreted. In the study area, in order to assess

Table 2. Present groundwater use (draft) by the sample farmers

(acre-inches/annum)

Particulars	Small farmers	Medium farmers	Large farmers	Draft	Percentage share
Domestic	43.1	21.4	12.2	77.2	1.1
Dairy	10.1	12.6	10.3	33.0	0.5
Annual crops	1179.4	656.3	674.3	2510.0	36.1
Perennial crops	1146.3	1726.5	1462.5	4335.7	62.3
Total (acre-inches)	2378.9 (34.2)	2416.8 (34.7)	2159.3 (31.0)	6955.9 (100) ≈ 71.5 ha-m or 71500 m^3	

Note: Figures within the parentheses indicate percentage to total

Table 3. Estimated annual recharge (supply from water harvesting structures)

Particulars	Quantity recharged (acre-inches/annum)
Recharge from rainfall	4898 (63.3)
Recharge from return flow irrigation	1703 (22.0)
Recharge from tanks	275 (3.6)
Recharge from WH structures	866 (11.2)
Grand total	7742
Cost incurred to recharge one acre-inch of groundwater through water harvesting structure (₹)	114

Note: Figures within the parentheses indicate percentage to total

the status of groundwatertable, 'dip meter' was used in all the 90 failed bore-wells and month-wise measurements were recorded.

If the level of watertable goes down, it implies excess draft over recharge. On the contrary, coming up of the watertable level reveals the recharge effect. The basic assumption is that the rise in watertable is primarily due to either rainfall recharge or watershed effect. The fluctuations in the level of watertable recorded over the months in the failed bore-wells are shown in Table 4. These fluctuations show that the draft during rainy season was lower, because the irrigation requirement was low, while during summer (after March), the draft increased to the peak level, accordingly there was a fall in the watertable. This could be true in the case of functional wells.

Table 4. Variation in depth of watertable over the period in the study area

Month	Depth of watertable (metre)
July 2008	45.35
August	60.23
September	54.53
October	54.29
November	49.64
December	45.62
January 2009	52.34
February	63.53
March	75.42

Table 5. Status of groundwater balance in Thotli micro-watershed

Net annual recharge	= 85 % of total annual recharge
	= 66.93 ha-m
Annual groundwater draft	= 70.67 ha-m
Groundwater balance	= Net annual recharge – Net annual draft
	= 66.93 -70.67
	= -3.73 ha-m

Status of Groundwater Balance

The annual groundwater recharge due to water harvesting structures in the micro-watershed was to the tune of 6,587 acre-inches, while the draft was 6,951 acre-inches. The annual draft (extraction) exceeded the annual recharge, causing a negative balance of 364 acre-inches (Table 5). The present stage of groundwater development is 105.5 per cent.

Impact of Watershed Development Programme on Groundwater Recharge

The impact of water harvesting structures was assessed in terms of the number of failed irrigation wells rejuvenated, increase in water yield, and reduction in water extraction cost (Table 6). Before watershed development, out of the total bore-wells, functioning wells formed 63.23 per cent and failed wells were 36 per cent. But after the introduction of watershed activities, the functioning wells increased from 63.2 per cent to 64.7 per cent, while failed wells decreased from 36 per cent to 35 per cent. About 9 per cent of the bore-wells were rejuvenated. The depth of bore-wells before watershed ranged between 160 and 1110 feet with an average depth of 470 feet. After the introduction of watershed programme, the depth of bore-wells was in the range of 500-1200 feet, with an average depth of 512 feet. Thus, the physical access to groundwater in terms of availability of groundwater before the implementation of watershed and after has been increasing. About 75 per cent of the bore-wells in the hard rock areas of Karnataka were rejuvenated due to the recharge effects of the recharge pits facilitated by adequate rain in the previous year (Nagaraj *et al*., 2008). Studies also indicated that watershed development activities have a significant impact on groundwater recharge and hence policy focus must be on the development of water harvesting structures (Palinisami and Kumar, 2006).

Table 6. Impact of water harvesting structure on groundwater irrigation

Particulars	Quantity
Number of farmers owning irrigation wells	90
Total number of bore-wells	142
Number of functioning bore-wells before watershed	86 (63.23)
Number of functioning bore-wells after watershed	92 (64.78)
Number of failed bore-wells before watershed	47 (36.00)
Number of failed bore-wells after watershed	50 (35.23)
Total number of dug cum bore-wells	2
Average age of the irrigation wells (years)	7.8
Average life of the irrigation wells (years)	10.2
Average depth of the irrigation wells in feets before watershed (Range)	470 (160-1110)
Average depth of the irrigation wells in feets after watershed (Range)	512 (500-1200)
Amortized cost per well (₹)	9,063
Amortized cost per functioning well (₹)	13,988
Irrigation cost per acre inch of water (₹)	169
Average yield of bore-wells before watershed (gallons /hour)	1,512
Average yield of bore-wells after watershed (gallons /hour)	1,875
Increase (%)	24

Note: Figures within the parentheses indicate percentage to total

Net Returns Realized by Sample Farmers Possessing Farm Pond

In the sample watershed 15 farm ponds were established with dimensions of 15m × 15m × 3m, entailing an investment of ₹ 23,200 per farm pond. An economic analysis was carried out to compare the additional gains realized. The additional cost incurred on the farm pond-based activities was around ₹ 366 and the annualized amortized cost per farm pond was ₹ 1805. Thus, the total cost of farm pond was ₹ 2,171. The additional gains accrued from each farm pond, including estimated returns from perennials, were ₹ 3,925. Thus, the net gain realized was of the order ₹ 1,754. The cost incurred to impound per metre cube of water was ₹ 1.33. Most of the small farmers failed to utilize pond water towards protective irrigation, as they could not afford to invest on lifting devices.

Eight sample households constructed recharge pits nearby their bore-wells. The dimension of the recharge pit was 4m × 4m × 3m, entailing an investment of ₹ 15,500. Due to construction of recharge pit, there was improvement in the water yield of bore-wells of the tune of 362 gallons/hour. This additional water yield enabled to irrigate about 0.56 acres additional area. This extra-irrigated area generated an additional income of ₹ 18,060 per annum. The annualized amortized cost on recharge pit was ₹ 1,206, while the net gain per recharge pit was of the order of ₹ 7,920, after accounting for the opportunity cost of returns foregone from the dryland cultivation of 0.58 acres.

Net Returns Realized by Sample Farmers due to Improved Bunding

There were 55 farmers in the sample households whose lands were treated with improved bunds with an investment of ₹ 1,600 per acre, upon amortizing the investment, the annual share of fixed cost worked out to be ₹ 339. The annual maintenance cost was ₹ 200, thus the total additional cost on improved bunding was ₹ 539. Improved bunding facilitated better soil and water conservation, resulting in marginal increase in productivity, which increased net returns modestly to the tune of ₹ 210.

The returns realized per rupee of investment were calculated for the water harvesting structures in private land for the sample farmers (Table 7). These were ₹ 1.80 on farm pond, ₹ 1.78 on recharge pit and ₹ 1.39 on field bund (per acre). The creation of water harvesting structures (WHS) enabled the groundwater recharge, which in turn increased productivity and profitability. Thus, rainwater harvesting through different WHS is cost-effective.

Estimated Cost of Artificial Recharging of Water

The cost incurred to impound a cubic metre of water was estimated and it is given in Tale 8. The cost incurred to impound a cubic metre of water was around ₹ 3.01/M^3 in the case of field bund (where estimated impounded water was 5.6 m^3), ₹ 1.67 /m^3 in the case of recharge pit (with an estimated impounded water of 720 m^3) and ₹ 1.33 /m^3 in the case of farm pond (where water impounded was 1350 m^3).

Table 7. Summary of cost and returns from water harvesting structures of sample area

Water harvesting structures	Total cost	Returns	Returns to cost ratio
Farm pond (₹ /unit)	2,171	3,925	1.80
Recharge pit (₹ /unit)	10,139	18,060	1.78
Field bund (₹ / acre)	539	750	1.39

Table 8. Estimated cost to impound a cubic metre of water

Type of recharge structure	Water impounded (m^3)	Annul amortized cost of the structure(₹)	Cost incurred to impound per m^3 of water(₹/ m^3)
Farm pond	1350	1805	1.33
Recharge pit	720	1206	1.67
Field bund	5.6	17	3.01

Table 9. Results of benefit-cost analysis of water harvesting structure in Thotli micro-watershed

Particulars	Realization of assumed returns
Initial investment on water harvesting structures (₹)	14,67,650
Annual maintenance cost (₹)	41,000
NPV@ 5%	4,47,530
Discounted benefit-cost ratio	1.21
Internal rate of return (%)	12.12

Economic Feasibility of Investment on Water Harvesting Structures

The economic feasibility of investment on water harvesting structures was evaluated by using standard discount cash flow techniques (Table 9). In addition, economic impact WHS on groundwater recharge was analyzed through reduction in the cost of groundwater irrigation, additional area brought under irrigation and increased net returns.

The analysis revealed that the investment on WHS yielded a net present worth (NPV) of ₹ 4,47,536 for the sample area of the micro-watershed. The discounted cost-benefit ratio (BCR) at five per cent discount rate was 1.21. This indicates that for every one rupee of the present value of the cost, the investment yielded, on an average, ₹ 1.21 of the present value of the return, over the economic life span of the assets of watershed. The IRR was 12 per cent. Considering the lending rate of five per cent on long-term loans, the IRR of 12 per cent, on an average, is economically worthwhile and a reasonable pointer of a higher average earning power of money investment on the water harvesting structures. While considering the investment on watershed, only direct benefits were considered in the economic analysis. If indirect benefits were also included, the IRR would have increased, since the indirect benefits were not included, the IRR was modest. Similar studies relating to the investment analysis of WHS in hard rock areas indicated that for every rupee of present investment on water harvesting structure, there was a return of ₹ 2.79 in farm pond and ₹ 2.19 in recharge pits. IRR was around 14 per cent in farm pond and 56 per cent in recharge pits (Nagaraj *et al.*, 2008).

Conclusions

The study has indicated that the annual draft (extraction) exceeds the annual recharge, causing a negative balance and indicating over-exploitation of groundwater even with watershed development. However, the physical access to groundwater in terms of availability of groundwater has increased marginally after the implementation of watershed development programme due to improved recharge. The creation of water harvesting structures has enabled groundwater recharge, which in turn has increased productivity and profitability from groundwater-based enterprises. The discounted cost-benefit analysis of the investment on WHS has indicated that the investment on water harvesting structures is financially viable. Thus, rainwater harvesting through different water harvesting structures is cost-effective in the study area.

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