Local benefit-cost analysis of recharge enhancement by ephemeral stream-bed structures for crop irrigation in a hard rock area of Rajasthan, India

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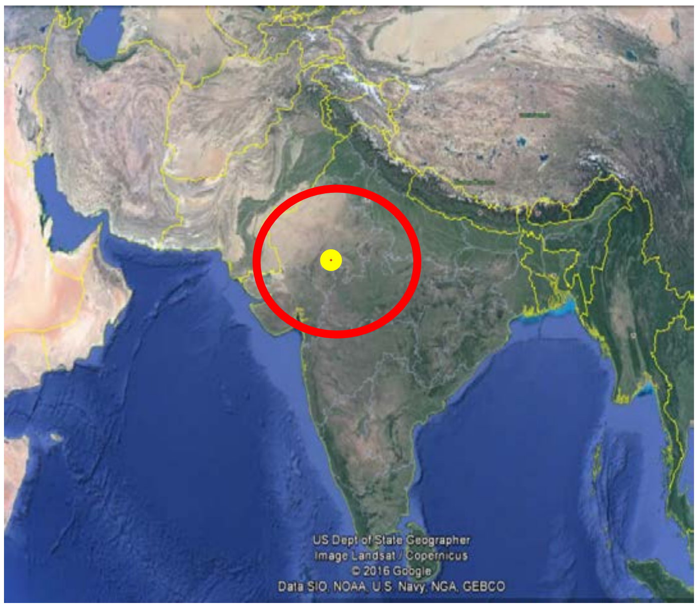
16th BIENNIAL SYMPOSIUM ON MANAGED AQUIFER RECHARGE:
RECHARGE TO THE RESCUE!

Location map



Study Area – Dharta catchment

- Hardrock, semi-arid area in NW India
- Average rainfall 600mm, in months monsoon June-Sept then dry
- Temperatures summer high 40° ‘s winter 20° ‘s
- Mosaic cropping using groundwater in winter dry season, rabi
- Sandy loam soils overly weathered bedrock in gently undulating terrain
- Underlying formation is Granite gneiss hard
- Large diameter dug wells to 30 m tubewells to 100m low yielding.
- Check dams built on streams to enhance recharge

Objectives

- Develop farmer understanding of groundwater and how to manage it at village level.

  This included, for MAR:
- Monitor and assess recharge effectiveness of 4 checkdams over 3 years
- Evaluate effectiveness of maintenance
- Estimate capital and maintenance costs and crop yield increase
- Do benefit-cost analysis of recharge augmentation at local level

Characteristics of the 4 selected check dams

Recharge structure	Total depth#, m	Water spread area##, m^2	Capacity##, m^3	Catch-ment Area, ha	Check dam area## as % of catchment	Check dam capacity## as mm over catch-ment
Badgaon	1.57	39,000	*42,000	338	1.15	12.4
Dharta	1.82	136,600	*140,000	1705	0.80	8.2
Hinta	2.62	127,200	223,000	851	1.49	26.2
Sunderpura	2.05	62,800	64,400	109	5.77	59.1

depth from weir crest to concrete apron at stream bed level which is the base of gaugeboard

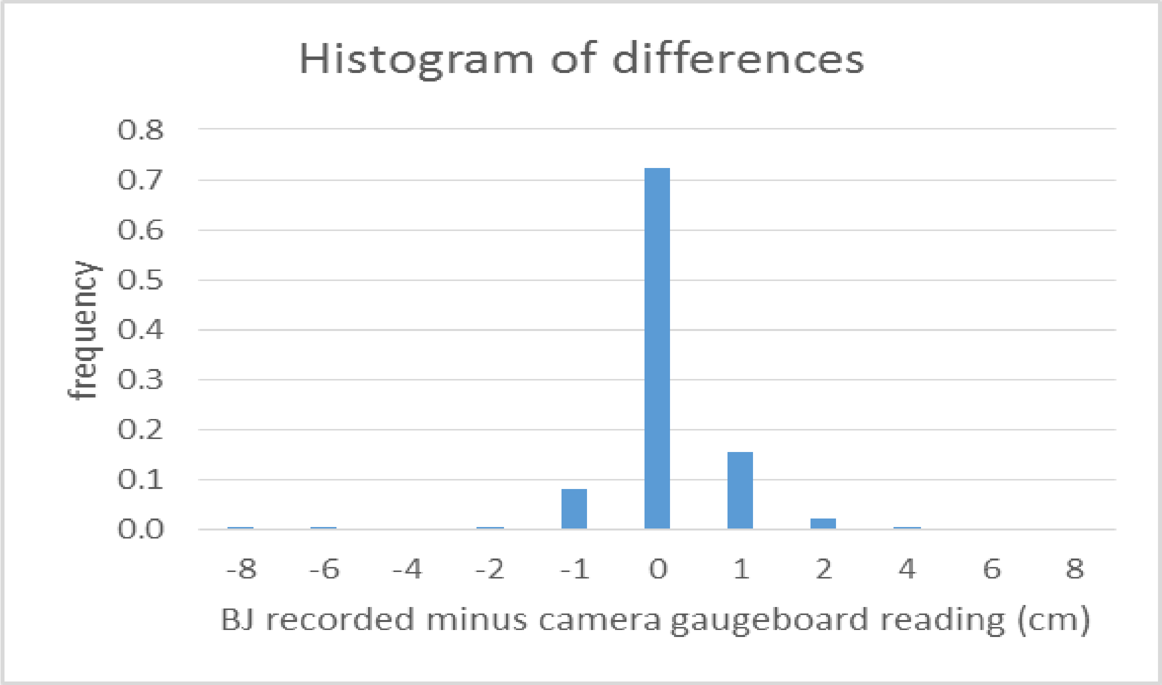
calculated from area- and volume- elevation curves when water elevation is at weir crest

* mean of pre- and post-scraping volumes

Field Monitoring

- Students did level surveys to produce area and volume-elevation curves

- Gaugeboards and water level loggers were installed, and farmers ttrained to read raingauge, groundwater level in dug wells and check dam water level.



96% farmer checkdam readings within +/- 1cm of concurrent mobile phone photos

Source: Dashora et. al. (2017)

Hydraulics of checkdam

Water Balance Equation

$$\Delta V = V_i - V_{i-1} = Q_{in} - Q_{out} - 0.5 * (A_{i-1} + A_i) * (R_i + E_i - P_i) - U_i$$

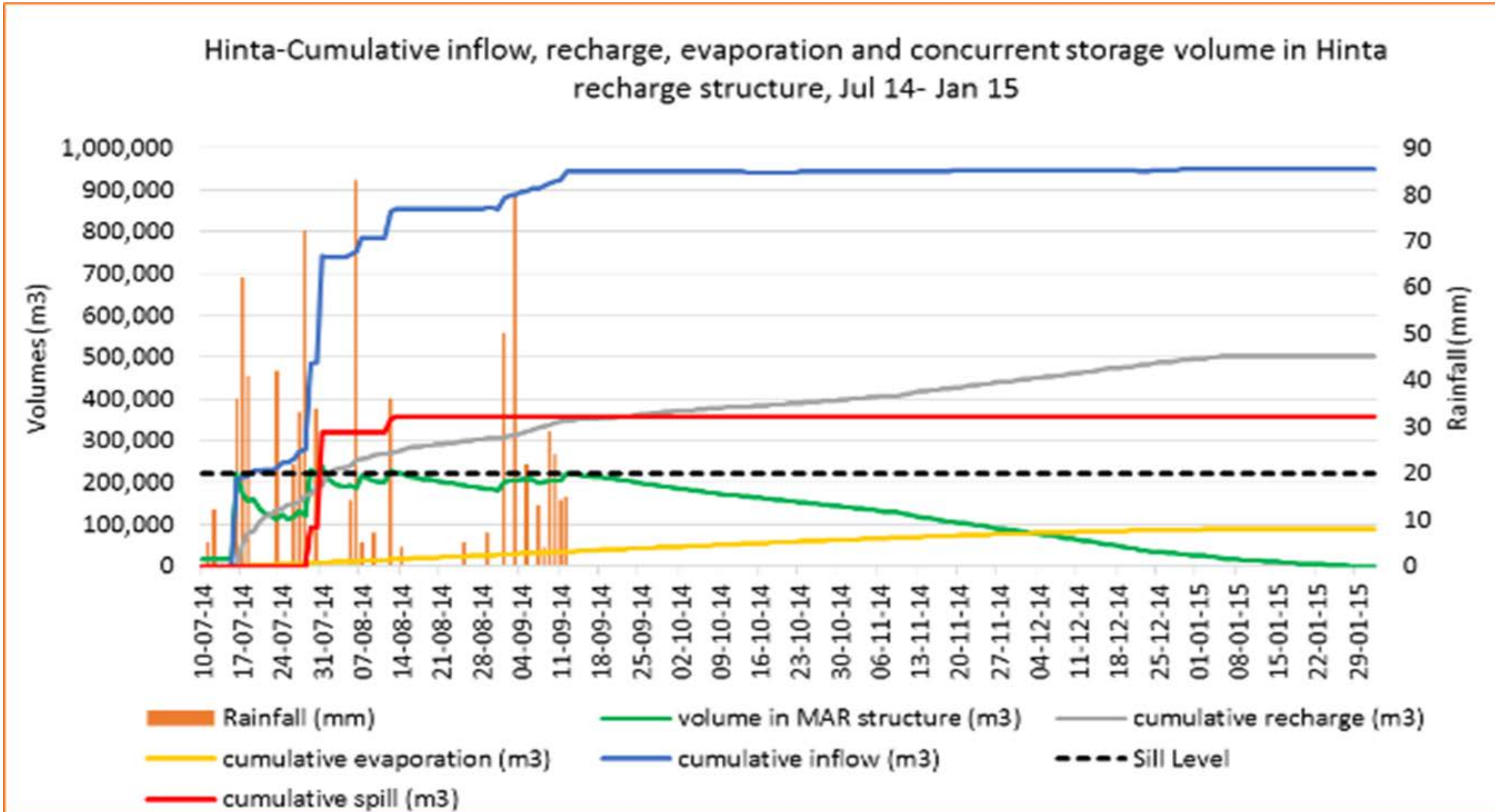
Dry weather Infiltration rate

$$R_i = h_i - h_{i-1} - \bar{\bar{E}}$$

Spill

$$q_{out} = C_d \, B \, H^{\,1.5}$$

Hinta 2014



Hinta-Cumulative inflow, recharge, evaporation and concurrent storage volume in Hinta recharge structure, Jul 14- Jan 15
Volumes (m3)
Rainfall (mm)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
90
80
70
60
50
40
30
20
10
0
10-07-14
17-07-14
24-07-14
31-07-14
07-08-14
14-08-14
21-08-14
28-08-14
04-09-14
11-09-14
18-09-14
25-09-14
02-10-14
09-10-14
16-10-14
23-10-14
30-10-14
06-11-14
13-11-14
20-11-14
27-11-14
04-12-14
11-12-14
18-12-14
25-12-14
01-01-15
08-01-15
15-01-15
22-01-15
29-01-15
Rainfall (mm)
volume in MAR structure (m3)
cumulative recharge (m3)
cumulative evaporation (m3)
cumulative inflow (m3)
Sill Level
cumulative spill (m3)

Water Balance Summary

Village	Year	Rainfall, mm	Total Inflow, m³	Total Recharge, m³	Total Spill, m³	Total Evaporation, m³	Total Recharge/Total Inflow, %	Total Recharge/ Capacity	Catch-ment area, ha	Emptied
Badgaon	2014	505	349,000	113,000	218,000	19,000	32%	2.86	338	Oct-14
	2015	614	189,000	56,000	129,000	4,700	27%	1.34		Aug-15
	2016	1161	1,145,000	143,000	980,000	26,000	12%	3.4		Dec-17
Dharta	2014	535	1,312,000	299,000	954,000	64,000	23%	2.19	1705	Dec-14
	2015	596	192,000	157,000	0	44,000	81%	1.12		Nov-15
	2016	1151	6,502,000	180,000	6,228,000	94,000	2.8%	1.27		Jan-17
Hinta	2014	771	949,000	518,000	358,000	91,000	55%	2.32	851	Jan-15
	2015	673	331,000	286,000	0	63,000	86%	1.28		Nov-15
	2016	1387	750,000	388,000	246,000	115,000	52%	1.48		Feb-17
Sunder-pura	2014	485	54,000	46,000	0	8,000	85%	0.71	108	Oct-14
	2015	406	13,000	11,000	0	1,600	88%	0.17		Aug-15
	2016	1069	360,000	139,000	177,000	44,000	39%	2.16		Jan-17
Mean or Total		***779***	**12,146,000**	**2,336,000**	**9,290,000**	**574,300**	**19%**	**1.66**	**3003**	

Two Desilting Methods

Check dam	Year of scraping	Volume increased by scraping, m^3	Percent capacity restored after scraping
Badgaon	2015	2,408	5.7%
Dharta	2015	2,981	2.1%
Dharta	2016	2,676	1.9%
Hinta	2016	936	0.4%

Manual

Mechanical

Mean Dry Weather Infiltration Rates (MDWIR)

	Mean Dry Weather Infiltration Rate, m/d			**Mean DWIR, m/d**
Checkdam/*Year*	*2014*	*2015*	*2016*	*2014-16*
Badgaon	0.031	0.057	0.029	**0.039**
Dharta*	0.022	0.018	0.010	**0.017**
Hinta	0.026	0.026	0.018	**0.023**
Sunderpura	0.028	0.035	0.019	**0.027**
Mean	**0.027**	**0.034**	**0.019**	**0.027**

manual

mechanical

Costs: Construction & Maintenance

- Costs are discounted to 2014, accounting for actual dates and costs of construction.
- Annual maintenance costs were considered unreliable due to large differences between check dams and lack of a regular planned maintenance program.
- Hence the annual maintenance cost was assumed to be the mean of the costs determined for the four check dams studied.

Results: Economics

Costs

For the smallest and largest check dams the capital and operating costs are shown per m^3 recharge:

Check Dam	Present Value (PV) Capital Cost, Rs.	Annual Maintenance cost, Rs.	Average Annual Maintenance cost, Rs.	Average Annual Recharge 2014-2016, m^3	Annualized PV capital Cost, Rs.	Annualized PV of Costs, Rs.	Cost per unit Recharge Rs/m^3
Badgaon	407,944	9,921	17,958	104,000	36,237	54,194	0.52
Hinta	1,321,737	21,433	17,958	397,333	117,407	135,364	0.34
Mean of 4							**0.51**

Capital and operating costs of two check dams (Indian Rupees, expressed as present values in 2014).

Economic benefit of check dams

- Water use of the local mix of crops was estimated based on some monitored reference crops,
- Local sales prices and cost of production figures for each crop to estimate the net increase in income attributable to the crop mix grown if the recharge volume was recovered for irrigation.

**This was a reasonable assumption given that at the end of each dry season most wells were dry, so all accessible water was used, and that the transmissivity of the fractured rock aquifers were low, so it was considered unlikely that recharge would have escaped the drawdown zone.

Benefits:

Crop produce

Crop Mix	Average Area of each crop, ha	Average Water use, mm	Profit, Rs/ha	Net income per m^3 by crops, Rs/m^3
Wheat	1032	450	8,000	1.7
Sorghum	53	500	4,400	0.9
Mustard	835	297	8,400	2.8
Isabgol	242	540	14,000	2.6
Opium	16	720	80,000	11.1
Onion	5	640	39,000	6.1
Fodder	48	750	32,000	4.3
Fenugreek	4	240	19,000	7.9
Barley	40	240	4,400	1.8
Gram	9	300	9,900	3.3
Cumin	44	724	25,000	3.4
Ajwain	2	720	18,000	2.6
Weighted Mean	*2331*	**510**	**21,842**	**2.4**

Benefit Cost Ratio = 2.4/0.51 =4.7

Conclusions…

- Farmers can produce highly reliable information for recharge estimation.
- The 4 check dams contribute on average ~800,000 m^3/year of recharge over these three years, 8 to 16% of total local rabi crop.
- Recharge estimates are considered reliable as 74% estimated recharge occurs in dry weather.
- Based on these few data manual scraping appears to be superior to mechanical scraping for maintaining recharge.
- In these examples the benefit cost ratio exceeds 4 suggesting that their construction and maintenance costs are easily justified by benefits to farmer livelihoods.

Way forward

- Monitoring and evaluation of a larger cohort of check dams is needed to inform investment in MAR.
- A mobile phone app My Well has been developed to facilitate upscaling of monitoring.
- New digital technologies can be used to quickly produce area and volume-elevation curves and to quantify siltation rates at research sites.
- Templates for spray painting gaugeboards would speed up expansion of monitoring.
- Natural tracer techniques can also be employed to validate water-balance-derived recharge rates at research sites.
- Extend economic analysis to whole of catchment (accounting for downstream impacts) and include recommendations for check dam placement and density.

Acknowledgements and References

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Thank You

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