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ORIGINAL ARTICLE

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Catchment, storage and command relationship in the micro-watershed farm pond to enhance crop productivity under rainfed agriculture

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ABSTRACT

In the western Vidarbha zone, characterized by medium-deep black soil and an average slope of 1%, the runoff from a 5 ha catchment area was monitored and harvested in a farm pond over a period of 10 yrs. This harvested water was subsequently used for supplemental irrigation in soybean and chickpea crops. Research indicates that approximately 450 m^3 of runoff can be collected from a 1 ha catchment, which can irrigate about 0.91 ha during the *kharif* or *rabi* seasons with a protective irrigation depth of 5 cm. Using water from harvested farm ponds for micro-irrigation can increase soybean yields by 22% and chickpea yields by 45%, with one or two instances of protective irrigation. Water use efficiency (WUE) for vegetables ranges from 1.88 to 3.33 kg m^3. Given India's uneven rainfall distribution, harvesting runoff in rainfed areas through farm ponds tailored to specific catchment areas is crucial. This study provides useful insights into the runoff collected from a one-hectare catchment and offers guidance on the dimensions needed for effective farm pond construction.

1 | INTRODUCTION

Rainwater harvesting through farm ponds is becoming increasingly important for agriculture and domestic and industrial purposes (Adhikari *et al.,* 2009). Projections indicate that the water required for drinking and other municipal utilities will increase from 3.3 million hectares meter (M ham) in 2020 to 7 M ham in 2025. Similarly, the demand for industrial water is expected to quadruple, rising from 3 M ham to 12 M ham. Many rivers are drying up, and the groundwater table is declining in most areas, with some regions experiencing a drop of about 30 to 50 m over the past 30 to 40 yrs (Sivanappan, 2006). Several states in the region face floods and droughts within the same year (Jalal Uddin *et al.,* 2017). This issue arises from ineffective actions to preserve, collect, and manage runoff rainwater (Sharma *et al.,* 2010). Therefore, it is essential to implement rainwater recharge techniques through conservation and harvesting structures (Freebairn *et al.,* 1986). In many rainfed areas, existing practices do not effectively conserve all runoff water, resulting in some runoff escaping the micro-watershed (Taley *et al.,* 2009). Protective irrigation for dryland crops can be provided using harvested and stored runoff in tanks (Bangar *et al.,* 2003). The western Vidarbha zone of Maharashtra receives an average annual rainfall of about 800 mm, with 84% of this rainfall occurring during the southwest monsoon. Annual rainfall in this region can vary spatially from 732 to 1273 mm across different sub-districts. A catchment area of 5 ha can yield approximately 2500 m^3 of runoff annually. These areas may experience dry spells during July, Aug and Sept, coinciding with the vegetative and reproductive phases of major rainfed crops, significantly reducing crop yields (Rejani *et al.,* 2022). In the Akola river basin, private and public organizations have deemed it essential to research water resource planning to implement soil and water conservation activities and create adequate storage (Moharir *et al.,* 2021). Given these considerations, research was initiated under the All India Coordinated Project for Dryland Agriculture (AICRPDA) at the experimental farm of Dryland Agriculture at Dr PDKV Agricultural University in Akola.

2 | MATERIALS AND METHODS

The study area is located at 20°42'N latitudes and 77°02'E longitudes, with an altitude of 307 m above mean sea level (amsl). It is situated in the western Vidarbha zone. The average annual maximum temperature ranges from 30°C to

42°C, while the minimum temperature ranges from 13°C to 28°C. The annual average rainfall is 760 mm, primarily during the south-west monsoon from June to Sept, with approx. 40 rainy days each year. The average annual evaporation rate is 7.2. The soil in the area is mostly clayey, with a depth of about 72 cm. The field capacity of the soil is recorded at 37%, and its hydraulic conductivity is 8.08 × 10^-6. The organic carbon content was measured at 5.3 g kg^-1. Based on the observed runoff from the catchment, the storage capacity for farm ponds was determined. Accordingly, as noted by Sthool *et al.* (2013), a farm pond was constructed in the experimental field of the AICRPDA. A catchment area of 5 ha was used to determine the dimensions of the farm pond. Additional details are provided in Table 1. An H-flume equipped with a stage-level recorder was employed to measure and estimate the runoff collected in the farm pond. Water losses were calculated based on evaporation data. A sequence cropping pattern was implemented, featuring soybean followed by chickpea. Accordingly, protective irrigation was provided to soybean during the *kharif* season and chickpea during the *rabi* season, based on the available water in the farm pond and the actual water requirements of the crops. A sprinkler irrigation method was utilized to maximize the efficient use of farm pond water. Additionally, the available pond water is being used for vegetable demonstrations through micro-irrigation systems.

2.1 | Computation of Runoff

The subsequent formula was used to calculate the amount of runoff from the catchment, and the dimensions were worked out (Singh, 1986).

$$R = \frac{kPA}{10}$$

Where, R = Runoff in cum, k = Expected per cent runoff of the total rainfall, P = Average annual rainfall in mm, A = Catchment area, ha.

2.2 | Treatments

2.2.1 | *Kharif* season (Soybean)

T_1 - One protective irrigation system with sprinklers at 50 mm depth with stored pond water at the flowering stage.

T_2 - Two protective irrigations, each of 50 mm depth, with stored pond water at sowing (1 DAS) and at the flowering stage with sprinklers.

T_3 - No irrigation.

HIGHLIGHTS

- In the western Vidarbha zone, about 450 m^3 of runoff can be collected from one hectare of medium-deep black soil with a 1% slope.
- Runoff recycling from each ha can irrigate 0.91 ha, improving soybean and chickpea grain yields by 22% and 45%, respectively.
- Vegetables irrigated with farm pond water achieve high WUE. Promoting the installation of farm ponds in this region can stabilize crop production and rural livelihood.

2.2.2 | *Rabi* season (Chickpea)

T_1 - One protective irrigation of 50 mm depth after sowing (1 DAS) with a sprinkler set from stored pond water.

T_2 - Two protective irrigation of 50 mm depth each after sowing (1 DAS) and at crop growth (flowering initiation stage) with sprinklers from pond water.

T_3 - No irrigation

3 | RESULTS AND DISCUSSION

3.1 | Catchment -Storage-Command Relationship

During the *kharif* season 2022, events of runoff were noted and depicted in Table 2. Runoff causing rainfall through the area of the catchment (5 ha) in the farm pond was 617.8 mm, which helped to accumulate 3151.6 m^3 runoff in a storage

TABLE 2 Runoff during 2022 from the catchment of 5 ha

Event date	Event wise rainfall, mm	Event runoff
		Stored in pond, m^3
17-06-22	77.7	427.4
20-06-22	47.5	261.3
28-06-22	32.0	160.0
05-07-22	51.0	255.0
06-07-22	29.4	147.0
08-07-22	58.0	290.0
13-07-22	31.5	157.5
14-07-22	43.0	215.0
18-07-22	45.0	225.0
19-07-22	43.3	216.5
14-09-22	51.7	258.5
18-09-22	64.5	322.5
07-10-22	43.2	216.0
Total	617.8	3151.6

TABLE 1 Dimensions of farm pond worked out at AICRPDA, Akola

Area of catchment considered (ha), A	Runoff expected as a fraction of total rainfall (%), k	Generation of runoff through an area of catchment cum	Storage capacity cum	Dimensions of top (m × m)	Dimensions of bottom (m × m)	Height / Depth (m)	Slopes of sides
5.0	13	5154	2753	45 × 27	36 × 18	3.0	1.5:1

TABLE 3 Year wise storage, seepage, evaporation, total losses and seasonal water availability in the farm pond (2013-14 to 2022-23)

Year	Seasonal rainfall (mm)	Runoff water stored in the farm pond (m^3)	Seasonal water losses (m^3)			Available water in a storage farm pond, m^3	Runoff accumulation through 1 ha area, m^3
			Seepage	Evaporation	Total storage losses		
2013-14	498.1	1254.10	45.10	110.66	155.76	1098.34	274.6
2014-15	504.0	1776.96	55.00	141.12	196.12	1580.84	395.2
2015-16	539.1	2579.20	66.30	156.70	223.00	2356.20	471.2
2016-17	554.3	2014.80	56.10	134.57	190.67	1824.13	364.8
2018-19	605.7	2351.70	64.26	156.46	220.72	2130.98	426.2
2019-20	613.9	2540.90	68.34	125.10	193.44	2347.46	469.5
2020-21	595.5	2192.30	59.16	220.89	280.05	1912.25	382.5
2021-22	848.0	3002.60	70.38	175.53	245.91	2756.69	551.3
2022-23	1040.6	3151.60	71.40	155.62	227.02	2924.58	584.9
Average	644.36	2318.24	61.78	152.96	214.74	2103.50	457.3

Note - During 2017-2018, runoff events did not occur.

farm pond. After deduction of evaporation and seepage losses, 2924.58 m^3 of runoff water was stored in the pond. With this stored water (2924.58 m^3), if one protective irrigation (5 cm depth) is given, then around 5.84 ha area would be possibly irrigated.

Year-wise runoff accumulation, seepage, evaporation, total losses and seasonal water availability in the farm pond (2013-14 to 2022-23) are given in Table 3. It was observed that during 2013-14 to 2022-23, on an average, 2318.24 m^3 of runoff water was stored in the farm pond, and the average seepage losses (61.78 m^3), average evaporation losses (152.96 m^3) and total losses (214.74 m^3) were observed. The average seasonal water available was 2103.5 m^3. The average runoff accumulation of 457.3 m^3 from a 1 ha area was found.

Based on the data from 2013-14 to 2022-23, the inference would be drawn that from 1 ha of the catchment, 450 m^3 rainwater was collected in a farm pond, which ultimately was utilized to command (irrigate) about 0.91 ha of the area with protective irrigation (one) of a depth of 5 cm.

The rainfall-runoff relationship during 2013-14 to 2022-23 is presented in Fig. 1. The total number of observations (n) is 82. It was observed that the R^2 value is 0.98. This means that rainfall in this linear model can explain 98 % of the variability in runoff. Thus, the relationship holds true for the areas of similar agroecological zones. Based on the observed values of runoff during the particular year rainfall and catchment area, for the west Vidarbha zone on medium deep black soil having an average grade of 1% (slope), it is recommended as from catchment area (1.0 ha) average 450 m^3 runoff was collected and utilized to irrigate around 0.91 ha during *kharif* or *rabi* as per need with protective irrigation (one) of 5 cm (depth).

The rainwater collected and stored in the farm pond was utilized to provide (protective) irrigation for crops during the *kharif* and *rabi* seasons as needed, depending upon the available soil moisture.

3.2 | Grain Yield and Economics of Soybean during 2013-14 to 2022-23

The average grain yield, net monetary returns (NMR) and B:C ratio for soybean crops from 2013-14 to 2022-2023 are presented in Table 4. It was observed that treatment with two protective irrigations, each with a depth of 50 mm, through sprinklers with pond water (T_2), has resulted in better yield than other treatments. For soybean crop, the highest average yield (1643 kg ha^{-1}), highest NMR ₹ 27023 ha^{-1} and highest B:C ratio (2.02) was observed in treatment with two protective irrigations applied at appropriate growth stages of crop. On average, a 21.98% and 11.16% increase in grain yield of soybean crops was noticed in T_2 and T_1, respectively, over without irrigation treatment. In stressed conditions, if any crop acquires water, its progress in growth, yielding, and monetary returns will be higher (Vora *et al.,* 2008; Wani *et al.,* 2003).

3.3 | Grain Yield and Economics of Chickpea during 2018-19 to 2022-23

Average chickpea yield, NMR and B:C ratio of chickpea during 2018-19 to 2022-23 are presented in Table 5. Regarding chickpea, treatment of 2 protective irrigations with depth of 50 mm each, with sprinklers from stored pond water (T_2), has a better average yield, NMR and B:C ratio. For chickpea, from 2018-19 to 2022-23, the highest average grain yield (1987 kg ha^{-1}), highest NMR (₹ 37953 ha^{-1}) and highest B:C ratio (2.23) was observed in the treatment of two protective irrigations applied at appropriate growth stages of crop. Around 44.71% and 22.05% increases in the yield of chickpeas were observed in T_2 and T_1, respectively, over and without irrigation treatment. Similar results are reported (Vora *et al.,* 2008) in their research substantial increment of 30 to 50% with one irrigation (supplemental) of 6 cm depth in cotton crop, wheat crop, chickpea and cumin were observed.

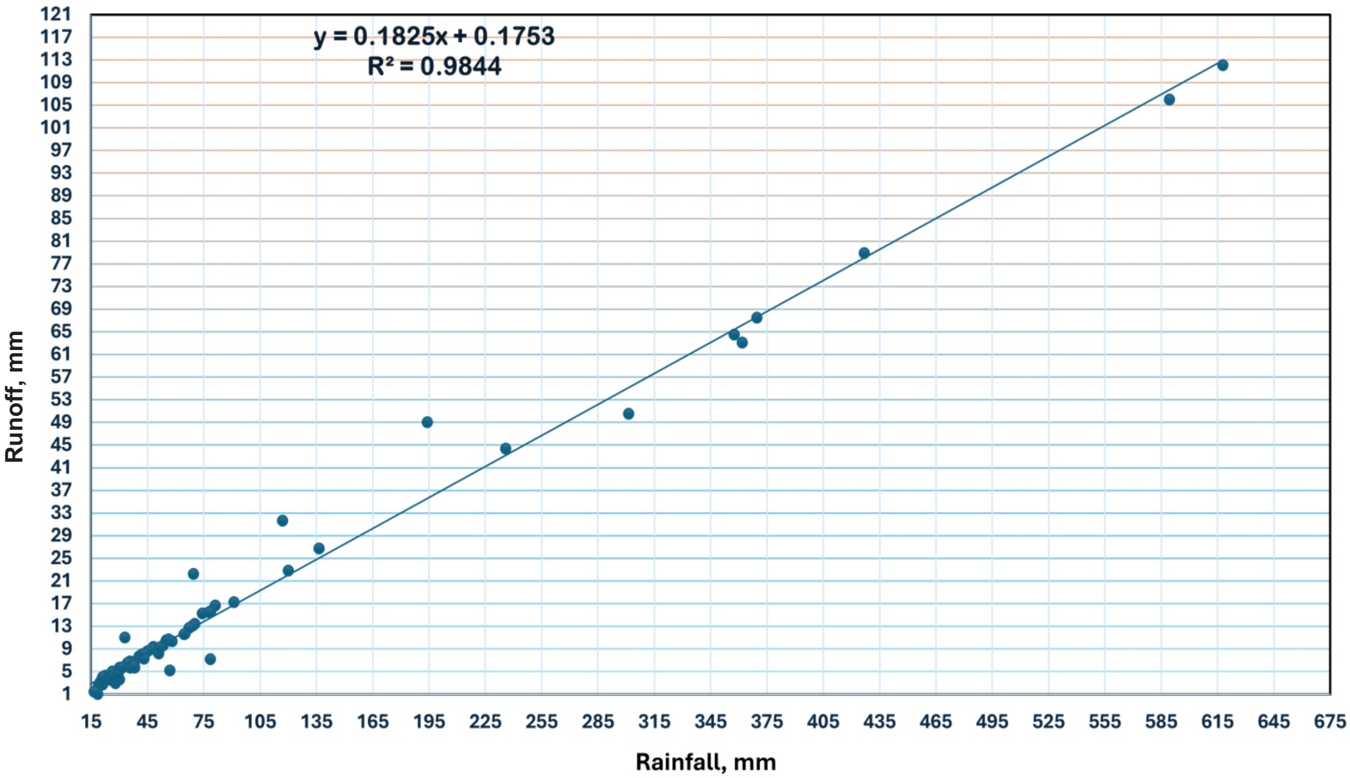

FIGURE 1 Rainfall-runoff relationship (2013-14 to 2022-23)

TABLE 4 Average grain yield, NMR and B:C of soybean crop during 2013-14 to 2022-23

Treatments	Yield (Grain) of soybean (kg ha^{-1})										
	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23	Average
T_1	1892	474	910	1399	1291	1768	1927	1771	1753	1596	1478
T_2	1901	1021	1055	1848	1268	1936	1955	1910	1927	1607	1643
T_3	1859	422	802	1247	1175	1364	1892	1597	1527	1589	1347
LSD	403.76										
($p<0.05$)	0.34										
	Net monetary returns (₹ ha^{-1})										
T_1	16382	543	12355	12113	11496	22414	27727	30646	35175	32025	20088
T_2	24912	20089	17285	24217	10616	28269	28777	35215	43528	37325	27023
T_3	11952	-	8700	8017	7554	12329	26426	22335	24534	25530	16375
	B:C ratio										
T_1	1.83	1.03	1.49	1.44	1.39	1.81	1.99	2.10	2.11	1.92	1.71
T_2	2.12	2.20	1.84	1.88	1.38	2.01	2.02	2.25	2.37	2.09	2.02
T_3	1.77	-	1.34	1.19	1.12	1.45	1.94	1.81	1.80	1.87	1.59

Various vegetables were cultivated using micro-irrigation systems to explore the potential for income maximization from the surplus water available in the farm pond. Weekly irrigations were applied to the vegetable crops as needed. The amount of water supplied was quantified, and details regarding the micro-irrigation system, yields, and water utilization are provided in Table 6. For vegetable crops such as coriander, fenugreek, spinach, brinjal, lady's finger, cowpea, bottle gourd, and cluster bean, the WUE was observed to range from 1.88 to 3.33 kg m^3. The average income from vegetable plots was approx. ₹ 66000 ha^{-1}, which would provide supportive income for the research farm. If farmers adopt this approach of growing vegetables on small plots or adjacent land near the farm pond, their earnings could increase significantly. Proper utilization of rainwater at critical stages of the crop for optimum produc-

TABLE 5 Average yield (grain), NMR and B:C of chickpeas during 2018-19 to 2022-23

Treatments	Chickpea grain yield (kg ha^{-1})					
	2018-19	2019-20	2020-21	2021-22	2022-23	Average
T_1	1067	1808	1652	1932	1680	1628
T_2	1560	2120	2044	2208	2005	1987
T_3	-	1420	1286	1452	1335	1373
LSD		354.32				
(p<0.05)	0.012					
	Net monetary returns (₹ ha^{-1})					
T_1	14201	29440	23530	27620	36047	26168
T_2	31333	38670	33680	36696	49387	37953
T_3	-	18764	11689	11873	11516	13461
	B:C ratio					
T_1	1.58	2.11	1.84	1.86	2.08	1.89
T_2	2.24	2.40	2.10	2.04	2.39	2.23
T_3	-	1.56	1.38	1.48	1.46	1.47

TABLE 6 Economics of vegetables during 2022-23 through MIS

Grown vegetables	Used MIS	Applied water (m^3)	Area of plot (m^2)	Produce (kg ha^{-1})	Income gained (₹ ha^{-1})	B:C ratio	WUE (kg m^{-3})
Coriander	In-line drip	6	120	1667	50000	3.22	3.33
Fenugreek	In-line drip	8	120	1750	70000	2.58	2.63
Spinach	In-line drip	8	120	1500	45000	2.21	2.25
Brinjal	Micro-sprinkler	9	150	2000	60000	2.34	3.33
Lady's finger	Micro-sprinkler	9	120	2500	100000	3.46	3.33
Cow pea	Micro-sprinkler	10	120	1833	73333	2.39	2.20
Bottle gourd	In-line drip	8	96	1563	46875	4.68	1.88
Cluster bean	In-line drip	8	120	2083	83333	3.07	3.13

tion is still a challenge to rainfed farmers. Adopting olericulture (vegetable production) on different irrigation methods under rainfed condition is a suitable technology to minimize the risk for stability in vegetable production (Sahoo *et al.,* 2023).

4 | CONCLUSIONS

Numerous farm ponds are being constructed in the fertile Vidarbha region of Maharashtra, particularly within the western Vidarbha zone. However, many of these projects lack a comprehensive understanding of the ponds' catchment areas that contribute surface runoff. To maximize the efficiency of these water harvesting systems, it is crucial to conduct a thorough assessment of the developed catchment area and its connection to the ponds. This analysis will allow us to accurately determine the potential for runoff harvesting from a 1 ha plot of land. Based on our findings, we recommend constructing farm ponds with dimensions of 18 m in length, 18 m in width, and 3 m in depth. Over the past decade, extensive research has highlighted the significant benefits of implementing protective irrigation sourced from these farm ponds. Farmers have experienced a remarkable 45% increase in crop yields and a staggering 59% boost in net returns when cultivating soybean and chickpea. These well-designed ponds play a vital role in enhancing the sustainability of rainfed agriculture, providing a reliable water source during dry spells. The cost to harvest a single cubic meter of water stands at ₹ 83, but the potential income generated from utilizing that same cubic meter can reach ₹ 173. This demonstrates the economic viability of investing in farm ponds, making them an invaluable resource for farmers in the region.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the manuscript's contents and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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