Environment and Ecology 40 (2B) : 806—814, April—June 2022
ISSN 0970-0420

Design and Construction of Rainwater Harvesting Plastic Lined Pond

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Received 24 February 2022, Accepted 19 March 2022, Published on 10 May 2022

ABSTRACT

A 1359 m^3 pond was constructed at Ranchi, Jharkhand in the premises of Birsa Agricultural University to harvest rainwater from the 3 ha catchment area. The design of plastic lined pond for selected catchment area was based on the variable factors such as runoff from catchment area, size of catchment area, land cover, treatment or practice, hydrological condition, AMC and irrigation water requirement (size of cultural command area, crop, irrigation system, cultural practices and ET of command area). The plastic lining method, consisting of 500 micron black LDPE (low density polyethylene) was used for lining the pond with adhesive sealing. The pond attained a maximum capacity of water (1359 m^3) during monsoon season (June to October). Seepage and evaporation losses were minimized by using plastic lining and crop management practices, respectively. The peagon pea and okra was cultivated on the top width of embankment of the pond which also gave additional income. Pond water can be used for irrigating cultivated vegetables round the year with the help of drip irrigation system.

Keywords Water harvesting, Plastic lining, Seepage, vaporation loss.

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INTRODUCTION

Indian agriculture is highly susceptible to climate change impact such as rising temperature, occurrence of extreme weather events and increasing variability of rainfall. In India it is observed that due to climate change average surface temperature has increased by 2-3°C (Mahato 2014). This adverse impact changing the distribution of rainfall, decreasing the number of rainy days and increasing the intensity of rainfall. Weather fluctuation which includes delay or early withdrawal of monsoon, presence of long dry spells is also affecting crop growth and strongly influence productivity levels due to less or no availability of rainfall. The higher average annual temperature and water stress can have serious impact on crop production. In India, it is projected that due to climate change and uneven availability of water a reduction in yield is seen by 4-9% between 2010 and 2039 and greater loss is expected in *rabi* crops (Rao *et al.* 2017). Focusing on these problem, concerted effort are required for mitigation and adaptation to reduce the vulnerability of Indian agriculture to the adverse impacts of climate change.

Agriculture in Jharkhand is mainly depends upon rainfall and its land is categorized by undulating terrain, shallow soil depth, low water retentive capacity, poor soil fertility. Rainfall and temperature are two most significant factors in term of suitability, adaptability and productivity of crops in any region. The quantitative increase in rainfall (from 1250.5 mm in 1961-70 to 1623.5 mm in 1991-2000) may be considered as a positive change in Jharkhand but it is connected with synchronized increase in inconsistency which is increasing the level of uncertainty of rainfall and possibility of irregular prolonged dry spells (Wadood and Kumari 2009). In this scenario rain water management is emerging as one of the most critical components of rainfed farming and successful production of crops without any water stress even in long consecutive dry spell.

In India, farmers traditionally use small constructed water bodies called pond, since ancient time. These water bodies have proper catchment/ harvesting system and are used for domestic as well as agriculture purposes. Theses ponds are located on an open environment and variety of soil type, which exhibit a wide range of evaporation and seepage characteristics. In research it is found that water loss through seepage is 1.21 to 10.54 m^3 per second per million square meter area from heavy clay loam to porous gravelly soils in earthen ponds is the major constraints to its failure (Reddy *et al.* 2012). In other study the seepage losses in some soil types are as high as 11 m^3 per second per million square meter area (Samuel and Mathew 2007). Seepage losses not only mean loss of useful water but it also leads to other problems such as trench in the embankments, water logging or increased salinity in the adjacent area.

Manikandan *et al.* (2020) suggested that if ponds drop its water level more than 12 to 28 cm in one month it is considered as a severe leakage. The major portion of stored water in pond is lost due to seepage. There is a need to provide alternative lining material which has to be cost effective, durable and with good workability. Seepage losses from pond can be reduced by using clay materials or laying a plastic sheet over the surface of soil. Conventional lining materials like brick with cement and bentonite clay are not proved successful as a result of high cost. High Density and Linear Low Density Polyethylene (HDPE and LLDPE) are commonly used as lining materials over conventional method for high efficiency and cost reduction.The surface of the soil on which the plastic sheet is to be placed must be smooth, compacted and free of clods, stones, roots, sticks or other objects that could puncture or tear the plastic sheets. Because in a study it found that the seepage rate in the ponds lined with polythene was 3.8 cm/day (76.37%) and it was slightly increased after two weeks. This may be due to the puncturing effect or poor mechanical strength of polythene material (Jayanthi *et al.* 2004). Sealing of film is done with different method some of them are clay material such as bentonite, strong adhesive gel and tapes or heat sealing technology in which laps of films are kept adjoined and then jointed with heat sealer of hot iron (Haman *et al.* 1990).

The main focus of this study was to design and construct rainwater harvesting plastic lined pond for round the year cultivation of drip irrigated vegetables.

MATERIALS AND METHODS

The research was conducted at PET research farm, Birsa Agricultural University, Ranchi, Jharkhand. The amount and distribution of rainfall is good in Jharkhand and rainfall amount range from 1230 mm (2013) to 2450 (2011) at kanke, Ranchi, Jharkhand as per record of previous four year. Size of catchment area was 181 m x 170 m (3.077 ha) while 1000 mm average rainfall was considered for design of farm pond (average rainfall of Kanke, Ranchi, Jharkhand).

Runoff water from catchment area

The Curve Number Method was used to estimate the direct runoff depth from the catchment area to find the runoff collecting capacity of water harvesting pond. It was originally developed by the Soil Conservation

Service (Soil Conservation Service 1964, 1972) for conditions prevailing in the United States. Since then, it has been adapted to conditions in other parts of the world (Cronshey 1986).

Following mathematical expression (Eq. 1) was used to estimate depth of direct runoff from the catchment area.

$$Q = \frac{(P - Ia)^2}{P - Ia + S} \quad (1)$$

Where, Q is accumulated runoff depth (mm), P is accumulated rainfall depth (mm), Ia is initial abstraction (mm) and S is potential maximum retention (mm).

Further, the potential maximum retention S was estimated by using the Curve Number (CN) defined by the US Soil Conservation Service (1969) given in Eq. 2.

$$CN = \frac{25400}{254+S} \quad (2)$$

As the potential maximum retention S can theoretically vary between zero and infinity, Eq. 2 shows that the Curve Number (CN) can range from one hundred to zero. For paved areas, for example, S will be zero and CN will be 100; all rainfall will become runoff. For highly permeable, flat-lying soils, S will go to infinity and CN will be zero; all rainfall will infiltrate and there will be no runoff. In actual field condition, the reality will be somewhere in between. Runoff depth of a catchment area depends on the variable factors such as size of catchment area, land cover, treatment or practice, hydrological condition group and antecedent moisture content (AMC). For selected location the detail of these factors is given in Table 1.

Water requirement for vegetables in command area

For designing a water harvesting pond for meeting irrigation needs, the irrigation requirement of the cultivated crops has to be calculated. The information of relevant factors such as effective rainfall, evapotranspiration (ET), application efficiency and leaching requirements, if any, are essential for calculating the irrigation requirement of the crops. In this study irrigation was considered through drip irrigation system hence other factors such as application efficiency and leaching requirements were not consider due to high performance efficiency of drip irrigation system (Camp 1998, Jamrey and Nigam 2018).

The crop water requirement (ETc) was determined by one of the widely used method in which crop coefficient (Kc) values was multiplied with reference evapotranspiration (ETo) (Doorenbos and Pruitt 1975).

$$ETc = kc\ ETo \quad (3)$$

The weather data required to calculate the reference evapotranspiration (ETo) was taken from Department of Metrology and Environmental Science. The data was collected through weather station established near the PET research farm, BAU, Kanke. The ET_0 was calculated using ETo calculator version 3.1, developed by the Land and Water Division of FAO. The ETo calculator assesses ETo from meteorological data by means of the FAO Penman-Monteith equation (Allen *et al.*1998).

The daily ETc were summed for different growth stages (initial, developmental, mid-season and late-season) of crop and seasonal crop water was de-

Table 1. Data required for calculating runoff depth by using SCN method.

Factor	Value						
Catchment area	3 ha						
Antecedent moisture content (AMC)	AMC I (Ia 0.2 S)						
Curve number for given area	Land use or cover	Trcatmentar practice	Hydrological condition	Hydrological soil group			
				A	B	C	D
		Straight row	Poor	65	76	84	88
	Small grain	Straight row	good	63	75	83	87

Table 2. Water requirement under micro irrigation (drip) throughout the year in PFDC (6501 m^2) and PET (600 m^2) field.

Sl.No.	Season	Crop	Crop duration	Days
1.	*Rabi* season	Potato	1st Nov – 14th Feb	105
2.	*Zaid* season	Tomato	21st Feb – 25th June	125
3.	**Kharif** season	Cauliflower	1st July – 18th Oct	120

Table 3. Cultivation detail of pigeon pea and okra.

Crop type	Crop variety	Fertilizer dose N:P:K:S (kg/ha)	Crop spacing (m)	Plant to plant spacing (m)
Pigeon pea	BAU-PP-9-22	25:50:25:20	0.7 X 0.2	-
Osaka	Osaka	120:60:50:0	–	0.2

termined. The vegetable crops which were considered for cultivation round the year under PFDC and PET research farm are given in Table 2.

Technical approach for reducing seepage and evaporation losses

The main problems observed in water harvesting ponds are losses of water from the ponds in the form of evaporation, percolation and seepage. The causes of seepage are either poor site selection (i.e. more permeable soil) or cracks in the embankment. Losses due to evaporation are comparatively minimum and reduction of evaporation loss is little bit difficult too. Evaporation and seepage losses can be minimized by using crop management practices and plastic lining, respectively.

Plastic lining for reducing the seepage loss

The use of plastic films as a lining material has provided an impervious lining thus prevent water losses due to seepage (Anonymous, 1982). In this research, the water harvesting pond was covered with 500 micron LDPE black film. Before covering the pond with plastic, the pond surface is treated with weedicide (Glycel@10 ml/liter) to protect the bottom surface and side embankment from weed growth. Weed can damage the plastic film which can exacerbate the seepage in long term. The plastic film was fixed with synthetic rubber based adhesive, Fevicol SR 998. (Anonymous, 2021).

Cultivation of pigeon & Okra on the top width of embankment for reducing evaporation loss

The peagon pea and okra was sown on the top width of embankment of plastic lined pond to reduce the wind speed & eventually reduce the evaporation loss of water from pond surface. Cultivation details of both the crops are given in Table 3.

RESULTS AND DISCUSSION

Selection of site for rainwater harvesting plastic lined pond

The selection of water harvesting pond site was began with preliminary studies of site which comprises contour survey to identify the slope direction and total area of catchment.The purpose of survey was to select the best location where the largest storage volume could be obtained with the least amount of earth work. Keeping this point in mind, site was selected in PET research farm of Birsa Agricultural University, Ranchi, Jharkhand. In the preliminary survey total size of catchment area was found to be 181 m x 170 m (3.077 ha). Location of water harvesting pond is given in Fig. 1. This location was selected since all the runoff water stored in the pond due to slope direction toward the pond. Additional reason for selecting this site for rain water harvesting pond was its close proximity to command area i.e., research field of PFDC and PET as shown in Fig. 1. The amount of soil excavated was used for making bunds around the pond.

Runoff from catchment area

Runoff depth of catchment area was calculated with the help of Eq. 1 and Eq. 2. The summary of runoff water through catchment area under various hydrological soil groups is given in Table 4. Runoff under hydrological soil group A (Q_I, condition good) was selected for study area which is 677.31 mm out of average rainfall of 1000 mm was considered for design of pond, that means that 67.7% seasonal rainfall was runoff water. Reddy *et al.* (2012) reported that on a conservative estimate, a dependable minimum value of 20% of the seasonal rainfall can be expected to go

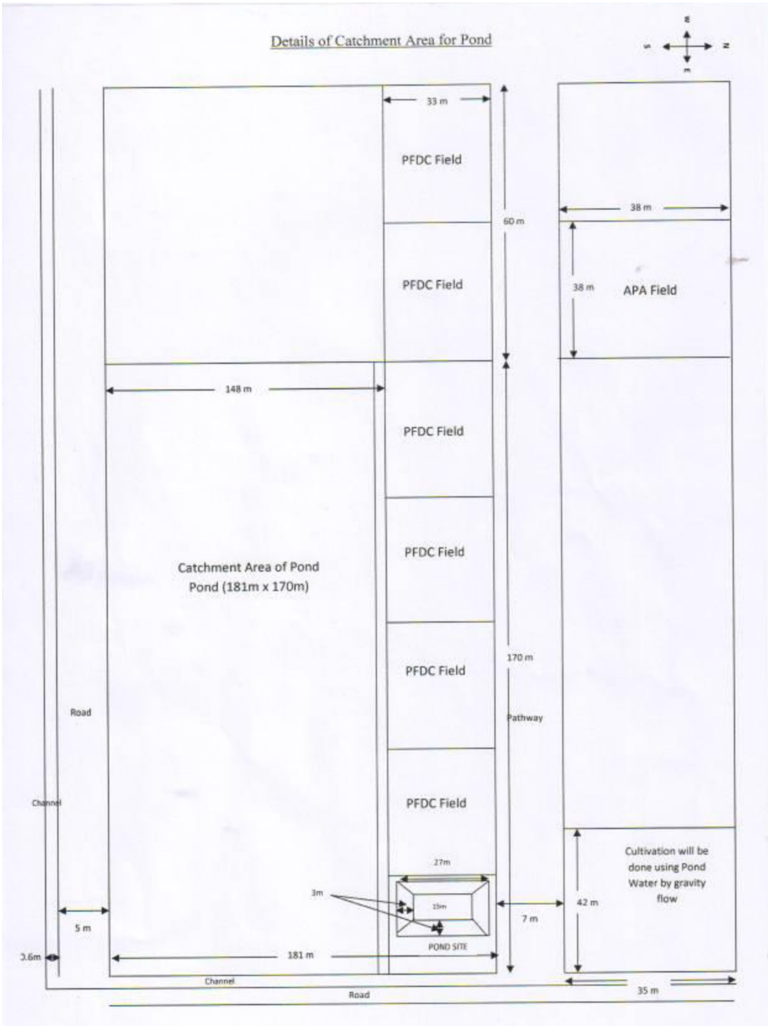

Fig. 1. Location of catchment area and water harvesting lined pond.

as runoff in case of black soils and 10% in case of red soils with mild to medium slopes.

Water requirement for vegetables in command area

The irrigation water requirement for the command area was calculated by using Eq. 3. Value of Kc was taken from Food and Agriculture Organization (FAO) whereas value of ETo was calculated using meteorological data of Kanke, Ranchi. Crop coefficient (Kc) and ETo for different growth stages for entire season

Table 4. Runoff under various hydrological soil groups.

Condition	Runoff (mm)	Hydrologic soil group A	B	C	D
Poor	Q_I	690.71	791.13	860.52	877.75
	Q_{II}	850.04	909.79	944.20	959.59
	Q_{III}	946.19	973.84	986.63	1000.97
Good	Q_I	677.31	785.82	856.03	908.35
	Q_{II}	840.87	905.11	940.17	955.85
	Q_{III}	935.66	969.59	982.88	977.73

Q_I = Runoff under antecedent moisture condition I.
Q_{II} = Runoff under antecedent moisture condition II.
Q_{III} = Runoff under antecedent moisture condition III.

Table 5. Value of K_c and ET_o used in different growth stages.

Vegetable crop	Growth stage							
	Initial		Development		Middle		End	
	K_c	ET_o	K_c	ET_o	K_c	ET_o	K_c	ET_o
Potato	0.45	2.40	0.60	1.96	0.90	1.94	0.90	2.48
Tomato	0.40	2.48	0.75	3.80	1.15	4.37	0.75	5.04
Cauliflower	0.45	4.49	0.75	3.45	1.05	3.74	0.90	2.65

Table 6. Water requirement under drip irrigation system round the year in PFDC (6501 m^2) and PET (600 m^2) field.

Season	Crop	Crop duration	Days	Water requirement
Rabi season	Potato	1st Nov – 14th Feb	105	251.83 m^3
Zaid season	Tomato	21st Feb – 25th June	125	1043.12 m^3
Kharif season	Cauliflower	1st July – 18th Oct	120	4299.58 m^3 (Excess rainfall)

is given in Table 5. The water requirement under drip irrigation system round the year in PFDC (6501 m^2) & PET (600 m^2) field is given in Table 6.

Design consideration of rainwater harvesting lined pond

The design consideration of plastic lined pond was runoff water from the catchment area and water requirement in cultural command area (PET research field and PFDC field). The minimum volume of runoff water from catchment area was 20840.8 m^3 based on command area of 3.077 ha and runoff water of 677.31 mm (Table 4) and water required for cultural command area was 1294.9 m^3 (Table 5) for cultivation of vegetables throughout the year. The volume of runoff water was sixteen times of water required for irrigation, so the size of pond was decided based on the volume of water required for irrigation i.e, 1249.9 m^3 to reduce the construction cost as the pond was only used for irrigation purpose. The actual size of pond (volume of water) was calculated after considering 5% buffer volume (for margin of safety in irrigation water requirement) which was 1359 m^3.

The soil at pond site was found to be sandy loam, so side slope of pond was taken as 2:1 (FAO 2011). The bottom of pond was assumed to be 15 m x 15 m and depth which is usually taken between 2.5-3.5 m (Reddy *et al.* 2012), was taken 3 m (Figs. 2, 3). The top surface of pond was 27 m x 27 m. The calculated length and width of plastic film required was equal

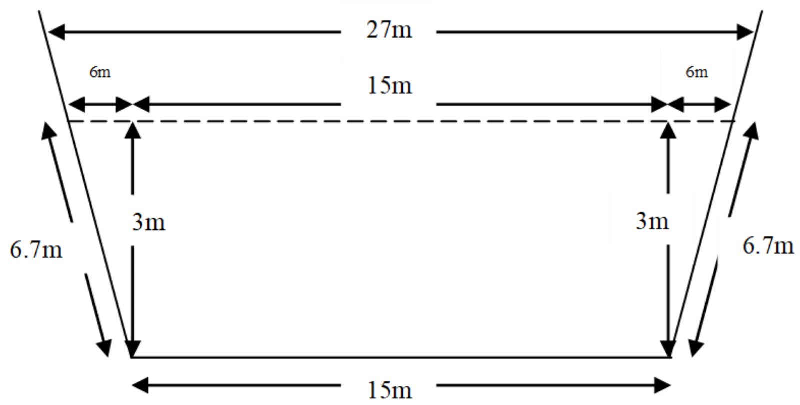

Fig. 2. Dimensions of water harvesting lined pond.

Table 7. Construction cost of plastic lined pond.

Sl.No.	Items	Details	Rate (Rs)	Amount (Rs)
1.	Digging cost of pond	JCB for 48.45 h	800/h	39,000
2.	Weedicide (Glycel)	1000 ml	195/500 ml	3,90
3.	Fevicol (SR-998)	8 liter	350/liter	2,800
4.	Plastic film (500 micron)	32 m x 32 m	169/m^2	1,73,046
5.	Brush	4 piece	75/piece	3,00
6.	Labor charge	60 man days	250/manday	15,000
	Total cost			2,30,536
	Total cost (including other cost)			2,35,000

and it was 30.42 m including 1 m length for bunging in soil and 1 m for shrinkage of plastic film (it is given in section 3.4). The volume of water stored in the lined pond was 1359 m^3 (1359000 liters) calculated by prismoidal formula.

The inlet channel was constructed with a depth of 0.4 m and width of 1 m in such way that, all the surface runoff generated in catchment area should reach the pond. The stone pitching was done to reduce erosion.

Plastic lining of pond

Length of plastic film was calculated according to the dimension of constructed pond (Fig. 2). Following equation was used for calculating total length and width of plastic lined form pond.
The length of plastic film = length of bottom (m) + 2 x length of side (m) + 1 m (for 50 cm length for bunging in soil each side) + 1 m for shrinkage of the film.

The length of plastic film = 15 + 2 x 6.71 + 1 + 1 = 30.42 m

According to calculation, required length and width of plastic film was equal and it is 30.42 m including 1 m length for bunging in soil and 1 m for shrinkage of plastic film. Fig. 4 shows the constructed plastic lining pond in study area. The construction cost of plastic lined pond was around Rs. 2, 35, 000 (Table 7) and water storage cost was around Rs 17.3/ m^3 (considering water harvesting pond is full and life of plastic film is around 10 years).

Cultivation of pigeon pea and Okra

The peagon pea and okra was cultivated on the top

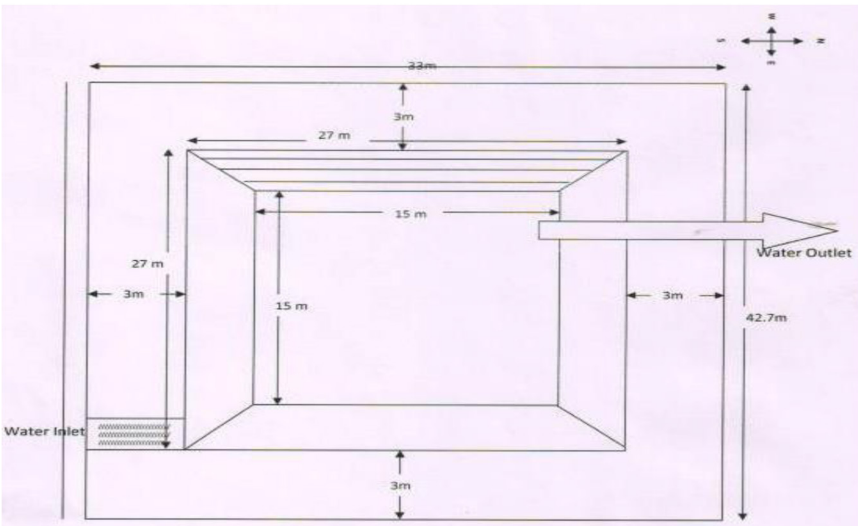

Fig. 3. Schematic view of water harvesting lined pond.

Fig. 4. Plastic lined water harvesting pond.

width of embankment of plastic lined pond to reduce the wind speed and eventually reduce the evaporation loss of water from pond surface, shown in Fig. 5. The cultivated Peagon pea and Okra were worked as windbreaks, which is normally used for reducing the evaporation of water loss from pond surface or any other water body (Benzaghta and Mohamad 2009). Apart from this, cultivation provided an extra financial benefit due to additional income from production of peagon pea and Okra and its yield was 1.8 t/ha and 13.5 t/ha respectively.

CONCLUSION

The design of rainwater harvesting plastic lined pond was based on runoff water from the catchment area or actual water requirement in cultural command area. Finally 1359 m^3 pond was constructed based on the actual water requirement for round the year cultivated vegetables in command area using drip irrigation system. The specification of pond was side slope: 2:1, bottom of pond: 15 m x 15 m, depth: 3 m and top surface: 27 m x 27 m. The pond was lined with 500 micron LDPE black and its length and width was 30.42 m. Before lining the pond, the pond surface was treated with weedicide (Glycel@10 ml/liter). The plastic film was fixed with synthetic rubber based adhesive (Fevicol SR 998). The construction cost of plastic lined pond was around Rs 2, 35, 000 and water storage cost is around Rs 17.3/m^3 (considering water harvesting pond is full and life of plastic film is around 10 years). The peagon pea and okra was cultivated on the top width of embankment of plastic lined pond to reduce the evaporation loss of water from pond surface.

Fig. 5. Pigeon pea and Okra on the top width of embankment of plastic lined pond.

ACKNOWLEDGEMENT

The author express his sincere gratitude to the Indian Council of Agricultural Research, New Delhi for providing financial support through the AICRP on Plasticulture Engineering and Technology (earlier Application of Plastics in Agriculture), BAU, Ranchi to carry out the research work.

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