Agricultural Water Management 158 (2015) 112–119

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Solar powered micro-irrigation system for small holders of dryland agriculture in India

M. Kumar*, K.S. Reddy, R.V. Adake, C.V.K.N. Rao

Division of Resource Management, Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh 500 059, India

ARTICLE INFO

Article history:
Received 25 October 2014
Accepted 5 May 2015
Available online 15 May 2015

Keywords:
Solar energy
Micro-irrigation system
Dryland agriculture
Small holders

ABSTRACT

Small water harvesting ponds are crucial to sustain productivity by providing supplemental/life saving irrigation in the small holdings of Indian dryland agriculture. Applications of such water however, are always a major issue in these regions, since efficient and cost effective pumping system is generally not available. In order to achieve the holistic utilization of water resources, a gravity-fed type micro-irrigation system integrated with low cost solar based pumping system was designed. The system was designed considering the properties of flow characteristics derived from hydraulic study of different components of drip irrigation system. The system thus developed, has the capability to provide uniform emitter discharge over the small plot of 18 m × 6 m. The star configuration of micro-tube layout where the lateral line feed four rows as devised by Bhatnagar and Srivastva (2003), was successfully integrated in the developed irrigation system. The field experimentation and testing suggested that the system performance was found satisfactory as the flow rate variation, Christiansen uniformity coefficient and distribution uniformity were 18.96%, 93.65% and 91.55% respectively.

1. Introduction

Dryland agriculture is most prominent in arid, semi-arid and sub-humid regions of Indian subcontinents. These regions are home to about 81% rural poor in the country. 55% of Indian agriculture pertains to dryland agriculture where majority of farmers are practicing subsistence farming due to over dependency on rain. The major ecological and economical factors that make agriculture unsustainable in this region, includes rainfed cultivation, small and fractured land holdings, insufficient crop yield and limited scope to adopt intensive agriculture. Many government funded watershed development program in this region are currently practiced and are mostly emphasized to increase the water availability in the vicinity through various activities involving surface water harvesting and utilization. The water harvesting mostly achieved in small ponds (capacity < 1000 m^3 and depth less than 4 m) and recycled as life saving irrigation/supplemental irrigation to attain sufficient soil moisture for successful crop production (Anbumozhi et al., 2001).

The major impediments in realizing the potential of water harvesting and recycling in dryland agriculture of India however, is the economical and effective means to lift water and distribute the same in the field. Namara et al. (2007), in their studies in Maharashtra and Gujarat state of India found significantly positive effect of ownership of well and high horsepower pumps on likelihood of adaptation of micro-irrigation technologies. This directly or indirectly suggests that the cost of energy in irrigation is the major factor. Several energy efficient interventions in micro irrigation have been reported in the literature such as bucket kits (Fandika et al., 2012), IDE low-cost drip irrigation (Polak et al., 1997a,b; Van Westarp et al., 2004), Drum kit (Karlberg et al., 2007; Kulecho and Weatherhead, 2005), gravity-fed micro irrigation (Bhatnagar and Srivastva, 2003; Kumar et al., 2009) and Pepsee system (Verma et al., 2004).

The existing pumping system adopted in the region depends upon the supply of either electricity or fossil fuels. Additionally, the existing lifting pumps for drawing water from bore-well have high suction:delivery head ratio, are uneconomical for small-scale applications. Affordability of these systems to the smallholding farmers is a major concern as the operational cost overshadowed the profitability. Thus to avoid these economic liabilities associated with existing pumping system and increase the profitability from limited land and climate resources, this class of farmers usually goes for hand watering. Thus, in these conditions, the most befitting pumping system should have low suction:delivery ratio.

Micro-irrigation technologies are widely considered as one of the most effective and efficient method of irrigation (Keller and Bliesner, 1990). Several studies in the past have been carried out

* Corresponding author at: Central Research Institute for Dryland Agriculture, Santoshnagar, Saidabad PO, Hyderabad 500059, Telangana, India. Tel.: +91 40 24532243; fax: +91 40 24531802.

E-mail addresses: mano@crida.in (M. Kumar), ksreddy@crida.in (K.S. Reddy), aravikant@crida.in (R.V. Adake), cvknrao@crida.in (C.V.K.N. Rao).

http://dx.doi.org/10.1016/j.agwat.2015.05.006
0378-3774/

to demonstrate higher water use efficiency and water productivity. Some of those from studies from Indian subcontinent suggested as typical yield increases of 20–50% for a variety of crops namely, cotton, sugarcane, grapes, tomatoes, banana etc. (Indian National Committee on Irrigation and Drainage, 1994; Sivanappan, 1994). In practice, these techniques are often associated with capital intensiveness and thus suitable for commercial farming on large field for big farm holders and at large, unaffordable for smallholders since these systems are not available in sizes matching small plots. However, these technologies have undergone through technical and innovational interventions to make low cost micro-irrigation system (Polak et al., 1997a,b; Verma et al., 2004; Upadhyay, 2003) viable.

The micro-irrigation in Indian dryland agriculture are promoted with the single or combined objective as listed by Namara et al. (2007), (i) to save the irrigated agriculture from crises of water scarcity, (ii) to increase water productivity to achieve increase in household income and eventually poverty reduction and (iii) to address the issue of food and nutritional security. Namara et al. (2007) using random sampled data of 448 farmers in Maharashtra and Gujarat state of India, concluded that the drip irrigation was adopted by those farmers who has access to ground water and own higher capacity of pumps (6.6 hp against 3.8 hp and 4.01 hp against 0.6 hp in case of adopters against non-adopters for Maharashtra and Gujarat respectively). The carry-and-irrigate scheme, introduced in Andhra Pradesh state of India in 2005 under state funded micro-irrigation project (APMIP scheme) where the farmers are supplied with five sprinkler heads, which is sufficient to cover 0.4 ha land to enhance water use efficiency. These systems however, grossly used ground water as a source that caused depletion of ground water in the region.

The present work describes the work attempted to develop solar powered micro-irrigation system with the strategies to address the limitations of drip irrigation for smallholders. These includes, (1) development of micro-irrigation system that operates with low pressure, (2) matching pumping scheme to draw water from small-scale water harvesting ponds and (3) introducing an economical and efficient alternative micro-irrigation system by attaining the perfect match between water available and area under command for extensive small-scale vegetable production. Due consideration of the techno-socio-economic situation of the small and marginal farmers of the regions were considered while developing this system.

2. Material and methods

2.1. Location of study

The research was conducted at the research farm (located at 17°37′N and 78°48′E) of Central Research Institute for Dryland Agriculture, Hyderabad located at south-central India. Location typically represents the dryland farming situation of semi arid region with Alfisols and vertisols being the major soil prevailing in the region. The region receives average annual rainfall of 750 mm in which 80% rainfall is received during monsoon months (15^{th}June to 15^{th} October) allowing to practice one crop. However, second and third crops are also practiced in some pockets of the area where intensive irrigation facility (mostly ground water) exists.

2.2. Development of micro-irrigation system

The proposed micro-irrigation system essentially employs principles of hydraulic characteristics of pressurized pipe flow. The micro-irrigation system is the assembly of several components that convert the continuous flow of water into drop flow to achieve higher water use efficiency. Conventionally, micro-irrigation system directly connected to delivery head of the pump requiring high pressure at the delivery head for proper functioning. For these systems, usually the source of water being the ground water and therefore a pump of capacity of 5 hp or more running on either electricity or fossil fuels is essential for successful operation. Thus the conventional irrigation system prohibits the use of surface water and demands the compulsory choice of higher capacity pump causes gross mismatch between size of pump and available plot size. The solar version for this configuration further requires huge investment making this a costly preposition. In view of these facts, the present innovation was derived addressing the three major issues to substantiate the sustenance farming of dryland agriculture practiced by small and marginal farmer.

1. Utilization of surface water from small scale water harvesting.
2. Minimizing the dependency on energy either from electricity, fossil fuels or both and so enabling in reducing the carbon footprint.

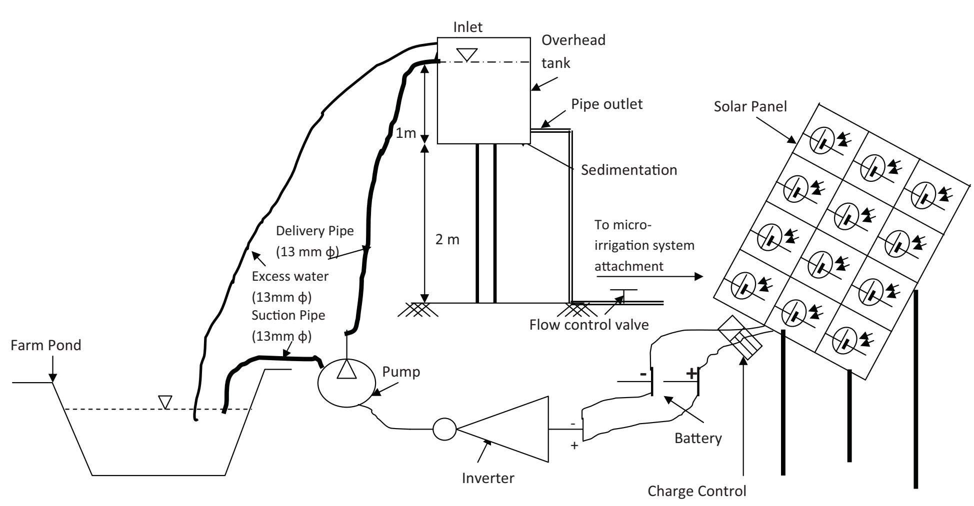

Fig. 1. Schematic diagram of solar powered micro-irrigation system.

3. Increasing the cropping intensity for food and nutritional security by enabling the farmer to intervene into vegetable cultivation after monsoon season.

The novelty of this developed system lies in the management of natural forces for maximum benefits. The developed system operates using low discharge small pump unit. This pump operated using electricity generated from small scale solar power. The low discharge further elevated to the temporary water storage to provide optimum pressure for irrigation system. The introduction of elevated water storage provision in this system is novel in the sense that it enables the system to respond to the extreme of less power low discharge conditions which otherwise is not possible with the existing conventional irrigation system. Another novelty lies in designing the irrigation system such that the water applied from the system is equated to the inflow to the storage tank. This helped in providing constant hydraulic pressure that invariably increased the overall system performance. Provision of star configured micro-tube irrigation system was another novel idea implemented in this invention which reduced the overall material cost of irrigation system as compared to conventional drip based micro-irrigation system. The conventional drip based irrigation system employs dripper connected to the laterals and thus one lateral pipe is required for every row of crop. The present system with star configured micro-tube enables the lateral to commands two rows crop and thus reduces the requirement of lateral pipe up to 50%. Thus the above mentioned facts establishes the novelty of the present development of solar power operated micro-irrigation system to address the issue of water use efficiency coupled with energy in agriculture and environment.

Considering the issues discussed earlier, the irrigation system developed by integrating three broad components namely, solar power generation system, and water lifting system and water distribution using water-emitting devices operated through gravity. The complete set up of the system is presented in Fig. 1 and the detail technical description is provided in Table 1.

The solar power generation unit consists of solar panel, solar charge control unit, battery and inverter. These components were selected after considering the compatibility and optimality to achieve higher efficiency and better economics. The solar panel charges the battery through solar charge control unit. The solar panel of size 1.44 m^2 has the capacity to generate 148 W power from solar energy. The energy stored in the battery is supplied to the small pump through inverter. The small pump that is connected to the inverter operates with 110 W input power and 0.06 kW shaft power lift water at the rate of 900 L/h (0.22 lps) at 4.5 m delivery head. The water is lifted to the elevated temporary water storage tank of 1000 L capacity. This water storage tank is placed at elevation such that the water level in the tank is 3 m above the ground. Hence, in this process a gravity head of 3 m is obtained which is equivalent to 0.3 kgf/cm^2 hydraulic pressure.

The water storage tank attached with water distribution system, consists micro-tubes as water emitting devices. This water distribution system however is most suitable for vegetable cultivation in small plot size of 2000 m^2 or less. The attachments are designed such that the water application rate should be equal to the water inflow rate to the storage tank resulted from pump. In this way, the water level in the storage tank remains in equilibrium and provides constant pressure to the attached irrigation system ensuring maximum uniformity in the water application for the attached irrigation system. The overall cost to this system was INR 24,640 (equivalent to $410). The cost of different components is presented in Table 2. The pictorial view of the installed system is presented in Fig. 2.

Table 1
Components wise minimum specifications.

Components	Specification details
Solar panel	Category: high efficiency Power output: 148 W Minimum power voltage: 15 V Power current: 4–5 A Dimension: length and width preferably be less than 1200 mm (wind velocity point of view) Maximum wind load: 60 m/s
Charge control unit (CCU)	Normal input solar cell array voltage: 15 V Max input solar cell array voltage: 25 V Maximum charging current: 30 A Maximum current consumption: 25 mA Constant voltage for lead-acid battery: 14.5 ± 0.3 V
Battery	Rated voltage: 12 V Normal capacity: 10 A for 5 h Charging voltage: 14–15 V Charging environment: up to 50 °C
Inverter	AC type, micro processor controlled 300 W continues power handling Input voltage: 10–15 V Output voltage: 220 V Rated capacity: 500 VA Output frequency: 50 Hz Auto shutdown in case of short circuit, raised temperature and overload
Small capacity electric pump	Type: AC Drive power: 60 W Input power: 110 W Pipe size: 13 mm Discharge: 15 L/min (at suction head and delivery head of 1.5 and 4.5 m respectively)
Overhead tank	Capacity: 1000 L, outlet: 25 mm diameter and 300 mm long mouthpiece connected to main pipe line (50 mm diameter PVC pipe) with matching flow control valve
Micro-tube irrigation system	Submain: 40/50 mm diameter PVC pipe Lateral: 16 mm diameter LDPE (low density polyethylene pipe) Micro-tube spacing: 50 cm row to row and plant to plant Micro-tube discharge capacity: 1 L/h at given pressure head (equivalent to 3 m hydraulic head) Coverage: 200 m^2/h. 1000 m^2 per day for 5 h application Overall command for this system: 0.5 acre with alternate day irrigation

Table 2
Cost of developed irrigation system (conversion: INR 60 = $1).

Sr. no.	Items	Cost (INR)
1	Solar panel with cable	8640
2	Solar charge control unit	1000
3	Battery with accessories	5000
4	Inverter	3500
5	Pump	1000
6	Overhead tank	2500
7	Civil work	3000
Total		24,640 ($410)

2.3. Design of micro-tube (MT) irrigation system

The gravity-fed MT irrigation system as suggested by Bhatnagar and Srivastva (2003) were integrated in present irrigation system. In present study, the micro-tubes of diameter 1.0 mm and 2.0 mm were hydraulically evaluated for discharge and pressure drop due to frictional losses in designing star configured MT irrigation

Fig. 2. Pictorial view of different components of developed irrigation system.

system. This frictional losses act as energy dissipater that reduces the flow velocity to the nominal discharge. The system was designed such that the flow condition remains laminar in lateral and connecting and emitting MT so that minimum head is lost in transporting the water. Thus in order to maintain laminar flow, the Reynolds number defined as the ratio between inertia force and friction force, must be kept less than 2100 and is given as

$$R_e = \frac{D \times v \times \rho}{\mu} \quad (1)$$

where, D is diameter of the tube (m), v is velocity (m/s), ρ is density of water (kg/m^3) and μ is viscosity of water (N m^2/s).

Rewriting Eq. (1) by substituting velocity as a function of discharge and cross section area

$$R_e = \frac{D \times (Q/(\pi/4)D^2) \times \rho}{\mu} \quad (2)$$

Solving for discharge at Reynolds number equal to 2100

$$Q = \frac{1650 \times \mu \times D}{\rho} \quad (3)$$

So maximum allowable discharge from connecting micro-tube in order to maintain laminar state

$$q_{mt} = 3.6 \times \frac{1650 \times \mu \times d_{mt}}{\rho} \quad (4)$$

where, q_{mt} is discharge from micro-tube (L/h) and d_{mt} is diameter of the micro-tube (mm), ρ is density of water (kg/m^3) and μ is viscosity of water (N m^2/s). This discharge further delivered through four emitting micro-tube in star configuration.

Similarly maximum allowable flow from laterals

$$q_l = 3.6 \times \frac{1650 \times \mu \times d_l}{\rho} \quad (5)$$

where q_l and d_l are discharge and diameter for lateral respectively. The discharge from lateral must be equally distributed through the connecting micro-tubes and thus

$$q_l = n \times q_{mt} \quad (6)$$

in which, n is the number of micro-tubes.

Maximum allowable discharge meeting the laminar flow conditions from main pipe can be obtained as by substituting, discharge (Q_m) and diameter (D_m) for main pipe, in Eq. (5).

Using Eq. (4) the maximum allowable discharge for laminar flow in 1 mm micro tube was computed as 4.6 L/h.

Theoretically, the discharge from main pipe must be equally distributed to the laterals i.e.

$$Q_m = m \times q_l = m \times n \times q_{mt} \quad (7)$$

where, m is the number of laterals.

2.4. Computation of discharge and head loss in lateral and mains

The head losses while flow of water in mains and laterals were calculated using Darcy–Weisbach equation as suggested by Keller and Bliesner (1990) for small diameter smooth plastic pipe.

$$h = k_1 \frac{Q}{D^4} L \quad \text{for laminar flow i.e. } Q \le k \times D \quad (8)$$

$$h = k_2 \frac{Q^{1.75}}{D^{4.75}} L \quad \text{for turbulent flow i.e. } Q > k \times D \quad (9)$$

where, h is friction loss (m), Q is the discharge (L/s), D is diameter of pipe (mm). The values of constant are $k_1 = 4197$, $k_2 = 7.89 \times 10^5$ and $k = 1.587 \times 10^{-3}$ for the units of different parameters of the equation.

The head loss due to flow in main and lateral were calculated using Eqs. (8) and (9) by substituting relevant values. Where, D is diameter of the tube (m), v is velocity (m/s), ρ is density of water (kg/m^3) and μ is viscosity of water.

Since the water flow vertically down into the main from overhead storage tank, maintaining laminar flow condition was difficult and hence the flow in this section remained turbulent. For different sections, the values of critical flow limits are calculated and presented in Table 3.

The head loss in micro-tube was estimated using orifice formula.

Table 3
Critical flow limit to maintain laminar flow in different pipe section.

Section	Pipe diameter (mm)	Critical flow limit for laminar flow (L/h)	Head loss per running meter at critical flow limit (m)
Main	50	284.4	0.0001
Lateral	16	91.4	0.0016
Micro-tube	2	11.42	0.832
Micro-tube	1	5.71	6.660

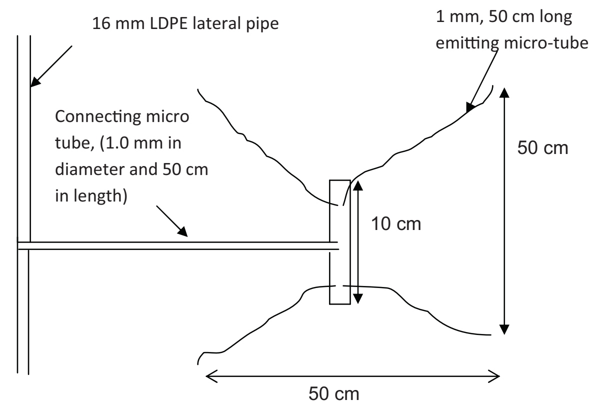

Fig. 3. Details of micro-tube irrigation system.

The discharge from the micro-tube was calculated using orifice formula, given as

$$q_{mt} = k \cdot k_q \cdot A_e \cdot \sqrt{2 \cdot g \cdot (H - H_m)} \tag{10}$$

where, q_{mt} is discharge, L/h; $k = 3.6$ for converting flow into L/h; k_q discharge coefficient taken as 0.61 for smoothly cut micro-tube; A_e is cross sectional area of micro-tube, mm^2; H is the head available at the emitter inlet, m; H_m is the head loss in the micro-tube and g is the acceleration due to gravity taken as 9.81 m/s^2.

The discharge from the emitting MT was designed such that the sum of head loss from different section is equal to available head of 3.0 m. The discharge, Q was optimized using the Darcy–Weisbach and orifice formula for emitter discharge such that the flow in all the section remains laminar. Discharge characteristics for different combination of connecting and emitting micro-tube were determined. The combination include (1) 2 mm connecting micro-tube and 1 mm emitting micro-tube; (2) 2 mm connecting micro-tube and 2 mm emitting micro-tube and (3) 1 mm connecting micro-tube and 1 mm emitting micro-tube. The length of different micro-tubes (connecting as well as emitting) kept as 50 cm since 50 cm × 50 cm crop spacing are widely adopted for different vegetable cultivation. The optimal emitter discharge from this combination is presented in Table 4. The schematic arrangement of the micro-tubes as emitting devices is shown in Fig. 3. Fig. 4 presented the pictorial view of such arrangement.

The micro-tube irrigation system was configured using the option C. The connecting MT was attached to the 16 mm diameter lateral on both sides. The number of connecting MT was such that the flow in the lateral should not exceed 91.4 L/h, the critical discharge to maintain laminar flow. Hence 22 connecting MT was attached to one lateral at 50 cm spacing. Thus, the length of the lateral was 5.5 m. Nine such laterals further connected to the 50 mm main PVC pipe at 2 m interval. This 50 mm main pipe also connected to the overhead tank in which flow was turbulent. The length of the main pipe is 30 m, the head loss due to turbulent flow was computed as 0.01 m which is negligible to the 3.0 m operating head. It is therefore, one unit of such irrigation system covers 198 m^2 plot, say 200 m^2 (18 m × 11 m) that applied 800 L water in 1 h. Thus, this system has the potential to cover 0.5 acre vegetable field with 0.5 × 0.5 m spacing and 1 L per plant per day, if operates for 5 h per day. However, these figures are indicative and actual acreage depends on the type of crop, its planting geometry and water requirement.

2.5. Hydraulic evaluation of the irrigation system

The functional evaluation was carried out for this irrigation system. In functional analysis, standard evaluation parameters such as emitter flow rate variation, Christiansen uniformity coefficient and distribution uniformity were considered.

The equation of emitter flow rate variation in which maximum and minimum flow rate are taken into the account, is described as following (Camp et al., 1997)

$$q_{var} = \frac{q_{\max} - q_{\min}}{q_{\max}} \times 100 \tag{11}$$

where, q_{var}, q_{max} and q_{min} are variation in emitter flow rate, maximum flow rate and minimum flow rate respectively.

The Christiansen uniformity coefficient (CUC), is described by the following equation (Kang et al., 1999)

$$CUC = \left[1 - \frac{(1/n)\sum_{i=1}^{n}|q_i - \bar{q}|}{\bar{q}}\right] \times 100 \tag{12}$$

where, q_i and $\bar{q}$ are ith emitter flow and average flow respectively, n is number of emitter on the lateral.

The distribution uniformity (D_u) suggested by Kang and Nishiyama (1996) was considered as the third parameter to evaluate the irrigation system functionally. D_u is given as

$$D_u = \frac{\text{Average Low Quarter Discharge}}{\text{Average Discharge}} \times 100 \tag{13}$$

2.6. Sediment content in pond water

The sediment content in water affects the irrigation efficiency particularly water application efficiency and uniformity as it influence to water emitting devices the most. It also determines the clogging behavior of the micro-irrigation system. Generally low discharge emitters are more prone to clogging than high discharge due to low velocity and fine hole. Water sample at four depths i.e. at mean depth of 0–0.75, 0.75–1.50, 1.50–2.25 and 2.25–3.00 m respectively were collected and sediment contents were measured accordingly. It was assumed that the particle distribution were discrete, thus individual settling had occurred. The water sampling

Table 4
Computed average discharge (L/h) and head loss (m) corresponding to different star configuration of MT.

Combination options	Micro-tube diameter (mm)		Optimal discharge (L/h)		Head loss (m)	
	Connecting MT	Emitting MT	Connecting MT	Emitting MT	Connecting MT	Emitting MT
A	2.0	2.0	50.7	12.68	1.847	0.462
B	2.0	1.0	15.1	3.78	0.550	2.201
C	1.0	1.0	4.09	1.02	2.386	0.597

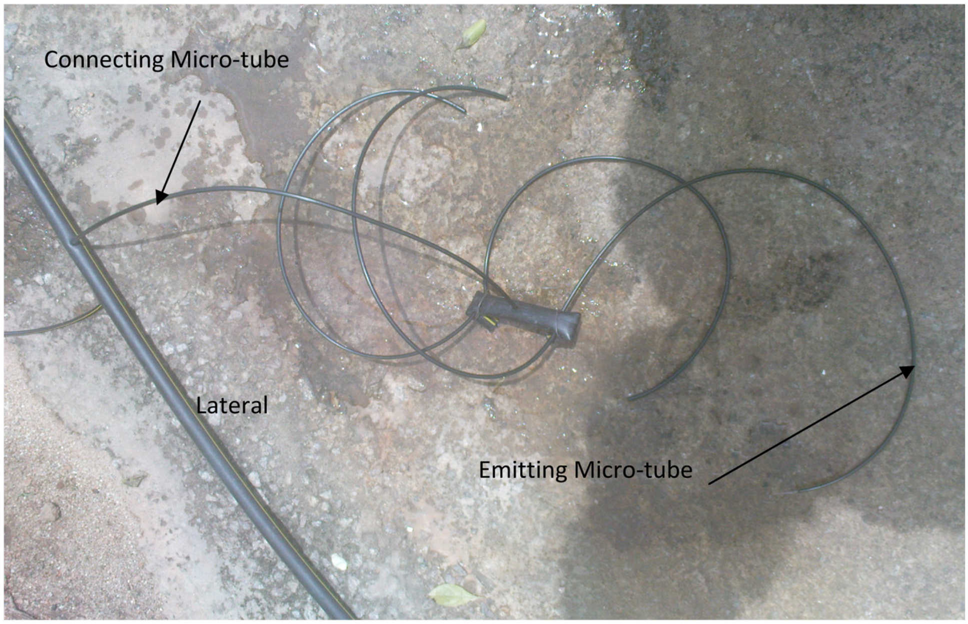

Fig. 4. Star configuration of micro-tube emitters.

was done after 72 h so that the stored runoff water does not contain any apparent particles.

3. Results and discussion

3.1. Functional evaluation of irrigation system

The emitter discharge recorded in the experimental studies was analyzed and presented in Table 5. The emitter discharge was found to vary between 0.801 L/h and 1.034 L/h. The average discharge from the emitting micro-tube was normally less than the design discharge (0.92 L/h against design discharge of 1.0 L/h). The average emitter discharge from lateral no. 2 and 8 was significantly different with respect to mean discharge (critical difference, CD at $\alpha = 5\%$ was calculated as 0.16). However, no specific trend in flow variation could be observed. The variations in different evaluation parameters are presented in Fig. 5.

3.2. Emitter flow rate variation

The overall emitter flow variation, q_{var} was 18.96% which is within the prescribed limit of 20% suggested by ASAE (1985). However, the q_{var} was slightly exceeds the prescribed limit in case of lateral no. 7 and 9. No specific trend was observed in q_{var} with the relative distance of the emitter down the lateral from main. The lateral wise emitter flow variation is presented in Table 5.

Table 5
Hydraulic evaluation of irrigation system.

Lateral no.	Mean (L/h)	q_{var} (%)	*CUC* (%)	D_u (%)
Lat 1	0.916	19.11	92.89	92.23
Lat 2	0.954	17.52	95.19	91.17
Lat 3	0.904	17.86	96.17	94.55
Lat 4	0.922	19.41	93.89	91.69
Lat 5	0.908	17.42	93.25	92.45
Lat 6	0.934	17.34	94.19	92.99
Lat 7	0.927	20.36	92.81	90.48
Lat 8	0.891	19.01	93.56	90.32
Lat 9	0.923	22.57	90.88	88.03
System average	0.920	18.96	93.65	91.55
CD ($\alpha = 5\%$)	0.160	–	–	–
CV	5.40%	–	–	–

3.3. Christiansen uniformity coefficient (CUC)

The *CUC* of various lateral was found to vary between 90.9 and 96. 2%. No specific trend in *CUC* was observed for various lateral like emitter flow variations. The overall *CUC* of the system was computed as 93.65% which is within the permissible limit of ASAE criteria of minimum 85%. Thus the system qualifies the *CUC* criteria. Lateral wise variation in *CUC* is presented in Table 5.

3.4. Distribution uniformity (D_u)

The overall distribution uniformity was 91.55%. Similar to *CUC*, no specific trend was observed in D_u for the respective laterals. The distribution uniformity over the different laterals was in the range of 88.3–94.6% (Table 5) and hence the system qualifies D_u criteria. In the entire system, the average discharge collectively from lower one fourth emitters was 9.2% less than the overall average flow of 0.92 L/h.

3.5. Sediment content and Water quality

The bottom 1/4th of the found contains substantially higher sediment content which was 6.58 mg/cm^3 and so the water from this profile is not safe for irrigation point of view because of risk of frequent clogging. The sediment content in the upper 3/4th was in the range of 0.47–0.52 g/cm^3 and could be used for micro-irrigation system. The other irrigation water parameters namely EC and pH were varied 0.3–0.4 and 6.7–7.4 respectively and thus water can be used for irrigation (Table 6).

4. Discussion

The present system was designed for small capacity water harvesting ponds in dryland area, where system has to be installed on small field of small holders. Since the system was installed on

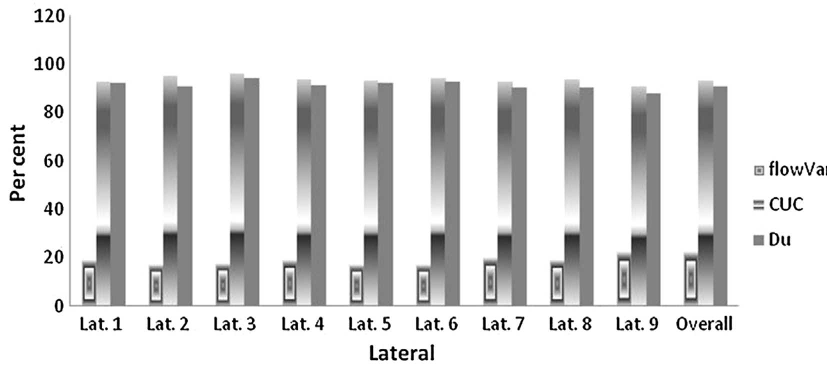

Fig. 5. Variation in q_{var}, *CUC* and D_u for different lateral and overall.

Table 6
Sediment content in pond water.

Water depth (m)	Fine sediment (mg/cm^3)	EC (dS/m)	pH
0–0.75	0.49	0.4	6.7
0.75–1.00	0.47	0.3	7.4
1.0–2.25	0.52	0.3	7.1
2.25–3.00	6.58	0.3	7.2

small plots, the length of mains and laterals are substantially small and thus the overall head loss caused during conveyance of water was very small, almost negligible (Table 2). The maximum head loss was observed in the connecting micro-tube and emitter micro-tube and so the flow variation in the main and lateral was minimum that resulted into lower variation in the emitter flow.

The star configuration of micro-tubes was found easy to handle and economical, since one lateral manages four rows. This system also has the similar issue of clogging as is the case with dripper type drip irrigation system. It is easy to maintain against clogging caused by physical particles by simply blowing air through the micro-tube. The risk of clogging due to physical particles is, however, less in present system since it usage surface water unlike dripper type system which uses ground water where occurrence of suspended particles are more. In case of surface water stored in small farm ponds, the water mostly used during dry spell when most of the suspended particles settles down. Also the pumping system is of very low capacity and so it does not cause suction of sediments through foot valves while pumping. However, to reduce the risk of clogging further, the water from top 3/4*D* (where *D* is the depth of the pond) should be used. Secondly, this system should be used after 72 h of runoff generating rainfall events, the time during which the sediments settle perfectly. It is suggested to run the system during 11 am to 3 pm (4 h in a day) in order to achieve the full potential. However, the timings can be changed as per the geographical locations of the site to achieve the full potential. The design of this system is specific to the farm size. Any change in farm size eventually demanding changes in one or more design parameters including pumping system, solar power generation unit, hydraulic head, diameter of different pipe section and accordingly configuration. However, the basic principle remains same that laminar flow should be maintained in different pipe section.

5. Conclusions

The major problem in effective utilization of the potential of the water harvesting and utilization in dryland agriculture of India is the economical and effective means to lift water and distribute the same at the field. Keeping in view of socio-economic conditions and limitations of small holder in the dryland agriculture of India, small scale solar powered micro-irrigation system was developed. The system includes solar pumping unit which lift water at higher elevation and then redistribute water through gravity-fed micro-tube irrigation system to the plant. The one such system is sufficient to provide irrigation in up to 0.5 acre of land. The system's functional parameters were computed as 18.96, 93.65 and 91.55% respectively for emitter flow variation, *CUC* and D_u respectively. Though the study was carried out specifically at the location representing typical dryland agriculture of India, this simple solar powered irrigation system can be effectively replicated in similar ecosystem of other part of the world to address the most important issue of water management and water productivity in dryland agriculture. Adoption of such system would help in conservation of energy and mitigate the climate change as the most farming is among small holders.

Acknowledgement

Authors are thankful to the Director, Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh, India, for extending necessary facility including funding (Project reference No. IXX01620).

References

American Society of Agricultural Engineers, 1985. Design, Installation and Performance of Trickle Irrigation System. ASAE Engineering Practice.
Anbumozhi, V., Matsumoto, K., Yamaji, E., 2001. Towards improved performance of irrigation tanks in semi-arid regions of India: modernization opportunities and challenges. Irrig. Drain. Syst. 15 (4), 293–309.
Bhatnagar, P.R., Srivastva, R.C., 2003. Gravity-fed drip irrigation system for hilly terraces of the north-west Himalayas. Irrig. Sci. 2 (4), 151–157.
Camp, C.R., Sadler, E.J., Busscher, W.J., 1997. A comparison of uniformity measures for drip irrigation systems. Trans. ASAE 40 (4), 1013–1020.
Indian National Committee on Irrigation and Drainage, 1994. Drip irrigation in India, New Delhi.
Fandika, I.R., Pakeni, D.K., Zingore, S., 2012. Performance of bucket drip irrigation powered by treadle pump on tomato and maize/bean productivity in Malawi. Irrig. Sci. 30, 57–68.
Kang, Y., Nishiyama, S., 1996. Analysis of microirrigation systems using a lateral discharge equation. Trans. ASAE 39 (3), 921–929.
Kang, Y., Yuan, B.Z., Nishiyama, S., 1999. Design of microirrigation laterals at minimum cost. Irrig. Sci. 18 (3), 125–133.
Keller, J., Bliesner, R.D., 1990. Sprinkler and Trickle Irrigation. Chapman and Hall, New York.
Kulecho, I.K., Weatherhead, E.K., 2005. Reasons for small holders farmers discontinuing with low cost micro-irrigation: a case study from Kenya. Irrig. Drain. Syst. 19 (2), 179–188.
Kumar, M., Kumar, N., Singh, K.P., Kumar, P., Srinivas, K., Srivastva, A.K., 2009. Integrating water harvesting and gravity-fed micro-irrigation system for efficient water management in terraced land for growing vegetables. Biosyst. Eng. 102 (1), 106–113.
Karlberg, L., Rockstrom, J., John, G., Annandele, J., Steyn, M., 2007. Low cost drip irrigation – a suitable technologies for southern Africa? An example with tomatoes using saline irrigation water. Agric. Water Manage. 89, 59–70.

Namara, R.E., Nagar, P.K., Upadhyay, B., 2007. Economic adaptation determinants and impact of micro-irrigation technologies: empirical results from India. Irrig. Sci. 25, 728–739.
Polak, P., Nanes, B., Adhikari, D., 1997a. The IDE low cost drip irrigation system. J. Appl. Irrig. Sci. 32 (1), 105–112.
Polak, P., Nanes, B., Adhikari, D., 1997b. A low cost drip irrigation system for small farmers in developing countries. J. Am. Water Res. Assoc. 33 (1), 119–124.
Sivanappan, R.K., 1994. Prospects of micro-irrigation in India. Irrig. Drain. Syst. 8 (1), 49–58.
Upadhyay, B., 2003. Drip irrigation: an appropriate technology for women. Approp. Technol. 30 (4), 31–37.
Van Westarp, S., Chieng, S., Schreier, H., 2004. A comparison between low cost drip irrigation, conventional drip irrigation and hand watering in Nepal. Agric. Water Manage. 64 (2), 143–160.
Verma, S., Tsephal, S., Jose, T., 2004. Pepsee systems: grass root innovation under ground water stress. Water Policy 6, 1–16.