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Development of Software for Designing Drip Irrigation System for Hilly Terraced Land of India

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Abstract

A user-friendly computer software package was developed for the design of drip irrigation systems in hilly terraced agricultural lands using Visual Basic (Version 6.0). The software enables systematic design of single-lateral and paired-lateral networks, along with submain units, for multiple terraced field geometries including rectangular and trapezoidal terraces under both level and sloping conditions. Key hydraulic and agronomic parameters generated by the software include emitter quantity and spacing, percentage wetted area, plant population, crop water requirement, net and gross irrigation depths, emission uniformity, leaching requirement, application time, emitter pressure head, system discharge, and overall system capacity. The tool further assists in selecting suitable emitter types, distinguishing between pressure-compensating and non-pressure-compensating devices. Performance of the software was evaluated using real-time field data and found to be satisfactory. Design charts for terraced slopes of 10, 30, and 40 percent were prepared to support the system design process, covering relationships between terrace number and discharge, discharge and manifold diameter with head loss, and head loss and inlet pressure requirements. The software also facilitates estimation of materials and cost for terraced plot sizes ranging from 0.2 to 5 ha, based on prevailing market rates of drip system components. The developed tool thus serves as an efficient decision-support system for planning, designing, and economic evaluation of drip irrigation systems in hilly agro-ecosystems, providing comprehensive outputs with minimal user input and supporting optimization for both small and large holdings.

Keywords: Drip irrigation design: Hilly terraced farming: Hydraulic modeling: Decision-support software: Micro-irrigation systems.

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Introduction

India has irrigation potential of 113.5 Mha from major, medium and minor irrigation schemes. The available water will not be able to serve the entire cultivable area of 180Mha (Chauhan, 1995). Greater emphasis must be given for optimum use of available water by efficient methods of application. The only option available to save water, available for crop production, is to use highly efficient irrigation technologies namely, sprinkler irrigation and micro-irrigation instead of conventional methods. Micro-irrigation has emerged as an appropriate water saving technique for row crops specially for widely spaced high value crops in water scarcity, Undulated, sandy and hilly tracts. Drip system or micro-irrigation offers quite an efficient method and water use economy for growing orchards, vegetables and several other crops which will not only save water for future development, but also improve yields (Sivanappan, 1994). Besides high application efficiency, drip irrigation system has adaptability to variable topographic conditions and different types of soils. Such high percentage of water saving, increase in yield, and other important characteristics resulted in increase in the drip irrigated area in India from 1000 ha in 1985 to 170000 ha in 1997 and 12539689 ha in 2020 covering almost all crops (Ministry of Agriculture, 2020).

The efficiency of water application under this system at number of locations in field condition suffers from non-uniformity of water distribution caused due to faulty design. The design of drip irrigation system must be in accordance with the land topographical condition, water source condition, crop demand, and soil type and agro climatic characteristics of the place. Hill constitutes one of the most complex agro-ecological systems. There is tremendous variation in physiographical conditions of land, shape of land, and availability of water source for growing agricultural and horticultural crops.

The land occurs with varying degree (5 to more than 75 %) of slopes, depth of soil and level of fertility. To increase the irrigation potential in hills, it is utmost necessary that existing water resources in the uplands such as springs, streams, and surface/subsurface runoff should be exploited (Shukla et al. 2005). By storing water in tanks, the low discharge springs/streams can be used to provide assured irrigation round the year. A gravity fed micro irrigation system in hills can provide a system through which a smaller depth of water is applied more frequently and in a larger area.

Main /Sub-main (manifold) is the important component of micro irrigation system. It is a multi-outlet pipe lines which supplies water to paired / single laterals and ultimately to the crops through emitters. The flow rate and the difference of sub-main depend on the number and flow rate of the lateral. The design of micro irrigation main/sub-main should be based on the balance between allowable variation in head, friction head loss and the elevation difference in sub-main (Keller and Karmeli, 1974). In the steep sloppy lands, the difference in elevation between the inlet and end points of sub-main is sufficiently high and hence the pressure compensating emitters can be used under this condition to control the head due to higher elevation differences. The design of manifold or sub main depends on both, the capacity and uniformity and it includes the determination of flow rate, inlet location, pipe size to keep the pressure head difference within the desired limit and inlet pressure needed to give the desired average emitter discharge. The design of manifold is commonly based on a balance between friction loss, change in elevation, and allowable variation in pressure. The design of manifold for steep slopes or for terraced land differs from the design of manifolds for the plain and mildly sloping lands. The theoretical concept of drip irrigation in conserving water is quite sound but its implementation in many field conditions may not be practically feasible. Adequate design and management guidelines are essential to minimize the potential problems with drip irrigation under precise water and fertilizer management programs.

Mathematical modelling of drip irrigation system, steady-state flow in multi-outlet pipelines, drip lateral design is taken up by several researchers. Moreno et al. (2016) developed a software tool to support decision-making in optimizing the design of pressurized irrigation systems (sprinkler and drip irrigation) for agricultural fields with sub-plots of any shape or topography. Reddy et al. (2017) studied CT Drip irrigation system, the method of applying uniform and precise amount of water directly to the root zone of the plants as per the need, through emitters at frequent intervals over a long duration, via a low-pressure pipe network comprising of mains, sub mains & laterals. Patel et al. (2018) developed the decision support system (DSS), namely design of micro irrigation systems (DOMIS) to design drip, sprinkler and micro-sprinkler irrigation systems. Keeping above in view, efforts were made to develop design software and design charts for the design of drip irrigation system for hilly terraced land and also estimation of the bill of quantity and cost of installation of drip irrigation system in hilly terraced land.

Material and Methods

The parameters such as number of drippers per plant, system capacity needed to irrigate the given area spacing and flow rates of drippers, irrigation interval etc., were considered for the design of drip irrigation (Keller and Bliesner, 1990). The complete design of drip irrigation system includes the design of drip lateral line, design of manifold and design of main line. The lateral lines are the pipes on which emitters are installed and they receive water from the manifold. The manifold may have single lateral or pairs of laterals, extending in opposite direction from a common point on manifold. On fields where the average slope in the direction of lateral is less than 3 percent, it is convenient to supply laterals to both sides of manifold. The manifolds should be positioned in such a way that the minimum pressure along the pairs of laterals are equal (Keller and Bliesner, 1990). In such cases the manifold should be shifted up hill to shorten the up slope laterals and lengthen the down slope laterals so that combination of pipe friction loss and elevation difference is in balance. Keller and Rodrigo (1979) developed a simple numerical method for the design of single or pairs of non-tapered laterals laid on uniform slopes. Keller (1979) presented a shape factor for any subunit linking the lateral flow rates. These equations were taken while developing the software. Readers may refer to above citation for details on equations.

Design of Submain in Drip Irrigation System

For the case water source at the top of the hill, the situation can be broadly divided into categories such as terraced-rectangular subunits, terraced-trapezoidal subunits, sloping-rectangular subunit and sloping-trapezoidal subunit. The head loss equation for all sub-cases was established. Keeping in view the tediousness of the numerical method of design, the design chart was developed for different ground slopes and shapes of fields. The manifold length in the drip system for hills is not expected to exceed 50 m and thus the design chart was developed for non-tapered manifolds.

The shape factor of the field system, discharge head, loss due to pipe friction and pipe bends for different diameters of pipes, and manifold inlet head was calculated by using the available equations. The design chart was developed for three slopes viz. 10, 30 and 40 percent and the riser height for these slopes was taken as 1.0, 1.5 and 2.0 m, respectively. The design chart was developed for 5 and 10 numbers of terraces separately considering the combination of ground slopes and shape factors of the subunits. Three quadrants from the four quadrants of a plan were taken for the design chart. The first quadrant, relating the terrace number and the lateral flow rate, gives the system discharge.

The second quadrant relates the system discharge, diameter of manifold and the total head loss. Similarly, the third quadrant relates the total head loss to the manifold, inlet heads for different lateral inlet heads. The computer software (flow chart given in Fig. 1) was developed to generate the related data using. This chart can be used for the designing of non-tapered manifold feeding the subunits of any shape of the terraced land having water source at the top or bottom of the hills.

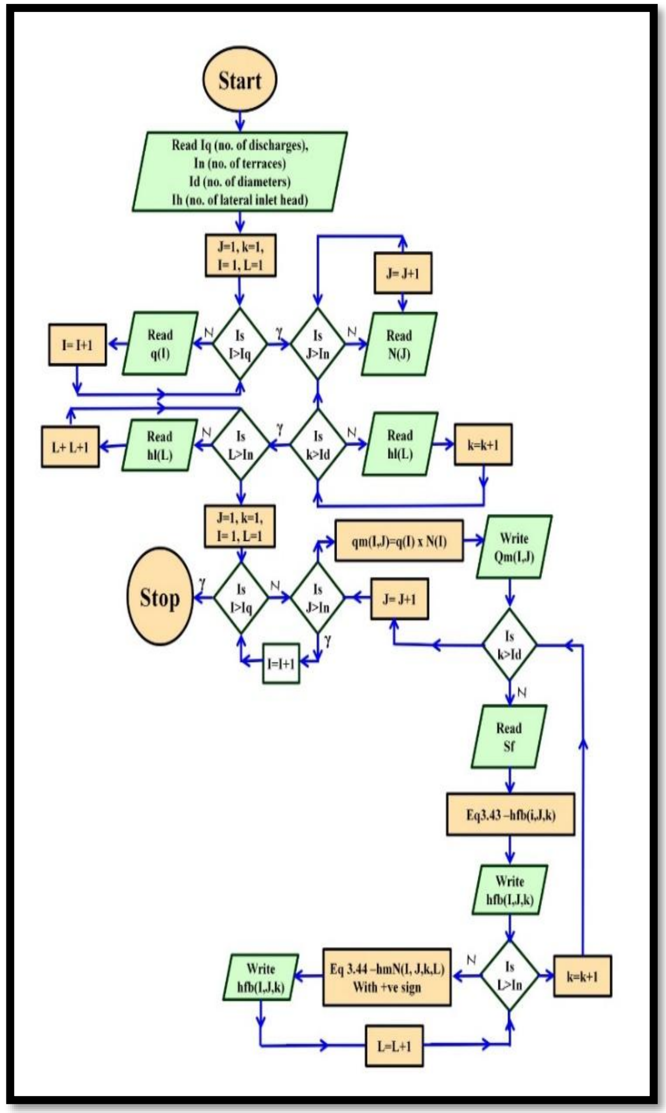
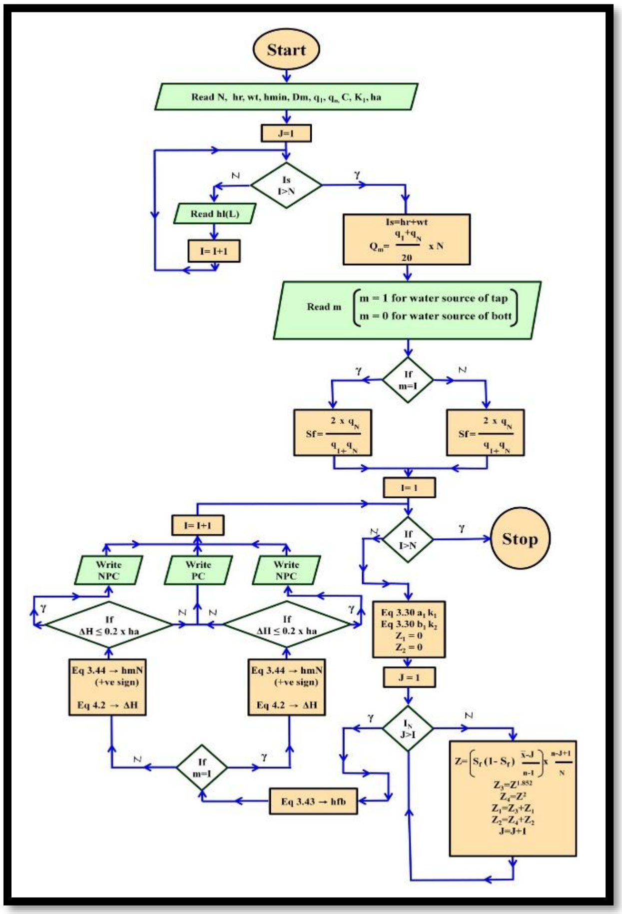
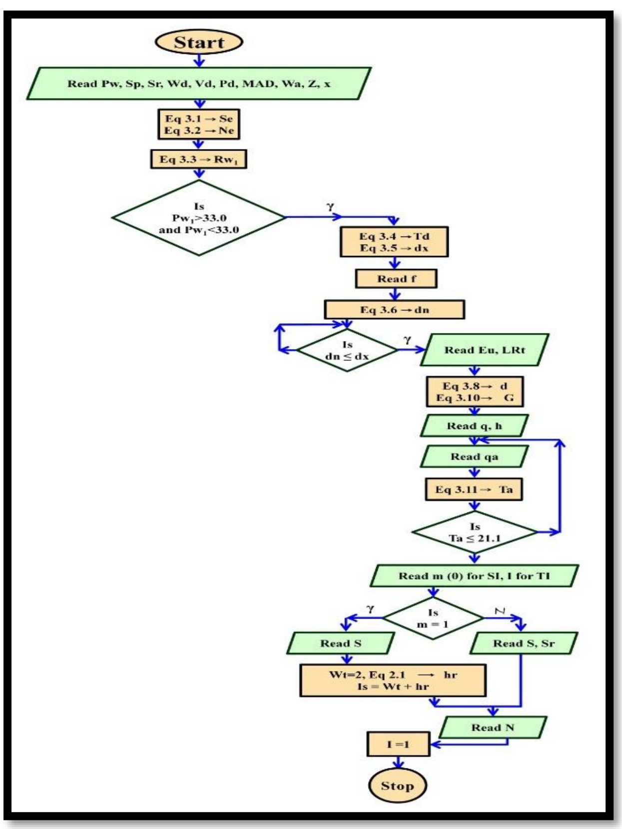


Fig. 1 Computer flow chart for the development of design charts

Development of Computer Program

A micro-computer program was developed in language Visual Basic (version-6) for the design of drip irrigation system for any shape of subunit having any number of terraces and any location of water source. This Program, whose flow chart is given in Fig. 2, was developed using the mathematical equations. Based on the design software and design charts, the material requirement for different size of field (0.2 ha to 5ha) was determined for the hilly terraced land. Considering the prevailing market rate of different components of drip irrigation system, the cost of installation of drip irrigation system was worked out.





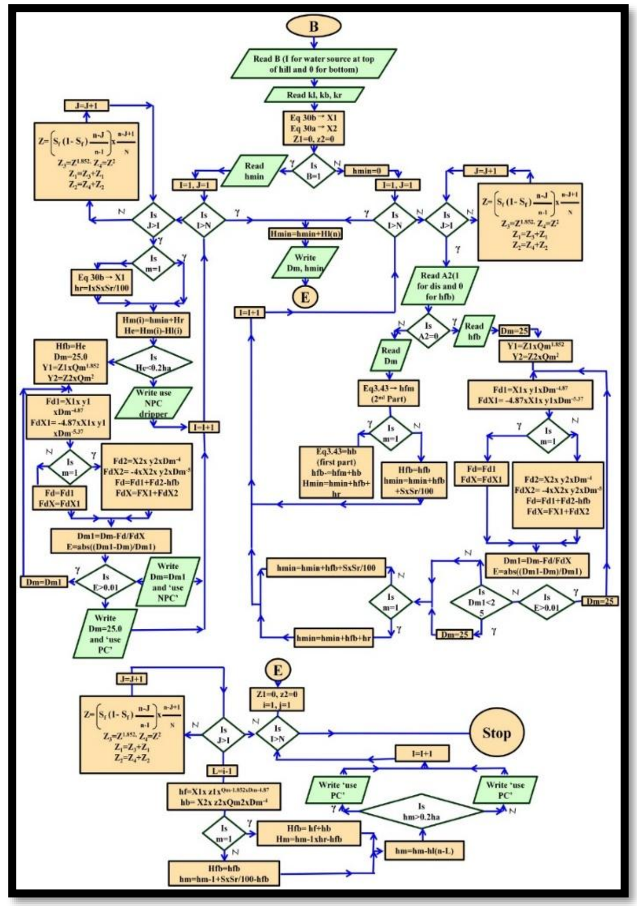


Fig. 2 Computer flow chart for the design of drip irrigation system

Results and Discussion

Development of Software for the Design of Drip Irrigation System in Hilly Terraces

The different design parameters, required to design an efficient and hydraulically balanced drip irrigation system, were arranged in such a way that the estimation of these parameters can be easily done one by one without any problem and cross references. The estimation of these parameters was necessary to design the lateral line which plays an important role in supplying the calculated quantity of irrigation water for each plant at an estimated uniformity and efficiency. To make the design procedure easy and less time consuming the computer program was developed using VISUAL BASIC language based on the equations developed. This program requires only basic inputs related to soil, field conditions, crop and the dripper characteristics. The program helps in determining the water requirement of the crop, percent wetted area within the permissible limit, number of drippers per plant, the application time and other factors related to the hydraulic design of the lateral and submain or manifold. In case the water source is at the bottom of hill, this program will require an additional data related to the total head loss. In this case, the designer must decide either the diameter of manifold or the total head loss to be dissipated in the manifold. It is only with this assumption that the design program has been developed.

Determination of Drip Irrigation Design Parameters using Software

The parameters of drip irrigation system design for given data is obtained using developed software. The user interface to interact with the software was also developed. The different parameters for drip irrigation system design in hilly terraced land were obtained using developed software as illustrated in the Table 1.

Table 1 Inputs given for Drip Irrigation System Design

Parameters	Value Taken
Plant to plant spacing, S_p (m)	5
Emitter Spacing, S_e (m)	5
Row to row spacing, S_r (m)	5
Conventionally Estimated avg., daily consumptive use rate, (during peak use month), U_d (mm/day)	6
Percent soil area covered by crop canopy, P_d (%)	90
Management Allowed Deficit, MAD (%)	25
Rated Emitter Head, H(m) (PCD)	6.25
Rated Emitter Head, H(m) (NPCD)	10
Average Emitter Head, H_a (m)	10
Rated Emitter Discharge, q(lit/s)	.00111`
Emitter discharge Exponent, x (PCD)	0
Emitter discharge Exponent, x(NPCD)	0.5
Conversion constant, K (For Q_s)	2.778
No. of Operating Stations, N_s (qty.)	1
Water holding capacity (Medium textured soil), (mm/m)	150
Plant root depth, Z (m)	0.65
Irrigation frequency, f ′ (day)	3
Average emitter discharge, q_a (lit/s)	.00111
Net depth per Irrigation, d_n (mm)	2
Electrical conductivity of Irrigation water EC_w (dS/m)	0.1
Electrical conductivity of saturated soil extract, EC_{em} (dS/m)	0.2
Electrical conductivity of drainage water, EC_{dw} (dS/m)	.05
Conversion constant used in calculation of G, K	1
Area of field, A (ha)	4
For Lateral Design	
Inner Diameter, ID (mm)	12,16
Ground slope, S (%)	1
Difference in elevation, ΔEI (m)	.01
Friction co-efficient, C	140
Conversion co-efficient, K	1.12×10^{12}
For Submain Design	
Inner Diameter, ID (mm)	50
No. of terraces, N (qty)	10
Riser Height.h_r (m)	1.5
Resistance Co-efficient, Kr	0.75
CO-Efficient of bend, Kb	82600

Lateral design parameters (outputs) for one and two emitters per plant and terraced rectangular submain design inputs and output parameters were obtained by using developed software. Terraced trapezoidal submain design parameters (input and outputs) were also obtained (Table 2 and 3).

It was observed that the difference between minimum and maximum pressure head along all the laterals, Δh_l is less than 20% of average emitter pressure head ($0.2H_a = 2$m) and fulfill the condition $\Delta h_l \le 0.2H_a$**.** **I**t was also recorded that only at first terrace, the condition $\Delta H \le 0.2H_a$ is satisfied for terraced rectangular submain design. It is shown that only at first terrace the condition $\Delta H \le 0.2H_a$ is satisfied for the design of terraced trapezoidal submain design. All the terrace the condition $\Delta H \le 0.2H_a$ is satisfied for sloping rectangular submain design. First to six**th** terrace, the condition $\Delta H \le 0.2H_a$ is satisfied and from seventh to ten**th** terrace the condition $\Delta H \le 0.2H_a$ is not satisfied for sloping trapezoidal submain design.

Table 2 Single design parameters (input) obtained by using developed software

Parameters →	fe (m)	Ni (qty)	Np (qty)	ΔE (m)	Q (lit/s)	F
Lateral length (m) ↓	For ID =16mm					
44	0.076	9	1,2	0.44	0.009	0.41
52	0.076	10	1,2	0.52	0.011	0.40
60	0.076	12	1,2	0.60	0.013	0.39
68	0.076	14	1,2	0.68	0.015	0.39
76	0.076	15	1,2	0.76	0.016	0.39
84	0.076	17	1,2	0.84	0.018	0.38
92	0.076	18	1,2	0.92	0.020	0.38
100	0.076	20	1,2	1.00	0.022	0.38
108	0.076	21	1,2	1.08	0.023	0.37
116	0.076	23	1,2	1.16	0.025	0.37

Table 3 Lateral Design parameters (Outputs) obtained by using developed software (One emitter per plant)

L (m)	J (m/100m)	J′ (m/100m)	h_f (m)	β′	H_l (m)	H'_n (m)	ΔH_l (m)	H_l (m)	H'_n (m)	ΔH_l (m)	ΔH_c (m)
					Uphill Lateral			Downhill lateral			
44	0.030	0.031	0.005	18.7	10.02	9.55	1.87	10.01	9.57	1.87	1.87
52	0.041	0.042	0.008	9.6	10.03	9.47	1.88	10.02	9.66	1.88	1.88
60	0.054	0.055	0.0112	5.2	10.04	9.39	1.90	10.03	9.74	1.90	1.99
68	0.068	0.069	0.018	3.2	10.06	9.30	1.89	10.05	9.80	1.89	1.89
76	0.084	0.085	0.025	1.8	10.08	9.21	1.87	10.07	9.88	1.87	1.87
84	0.101	0.103	0.032	1.1	10.10	9.13	1.89	10.09	9.94	1.89	1.89
92	0.120	0.122	0.042	0.6	10.13	9.04	1.89	10.12	10.01	1.89	1.89
100	0.140	0.142	0.054	0.3	10.17	8.94	1.88	10.16	10.09	1.88	1.88
108	0.162	0.164	0.065	0.1	10.20	8.85	1.91	10.19	10.15	1.91	1.91
116	0.185	0.187	0.080	.07	10.25	8.76	1.89	10.24	10.21	1.89	1.89

Development of Design Charts for Designing Submain of Drip Irrigation in Hilly Terraced Land

The design chart was developed based on the data generated using the developed computer software. The generated data from the equations used were plotted using the software with the help of these design charts the manifolds, feeding the lateral laid on rectangular and trapezoidal shapes of land with ground slope up to 40 percent and the number of terraces up to 10, can be designed easily for both the locations of the water sources. The design chart was developed for the subunits having ground slope 10, 30 and 40 percent. These three slopes cover almost all the hilly horticultural lands in India. The 25 percent slope was not considered in the development of design chart because in India, people commonly adopt the vegetable or cereals farming even up to 35 percent slopes and generally do not take horticultural crops in such low sloped lands. Manifold design chart for a trapezoidal shaped (S_f = 0.5), rectangular shaped (S_f =1.0) and trapezoidal shaped (S_f =1.5) subunit having 10 terraces were developed for 10, 30 and 40% ground slopes (Fig. 3).

Table 4 Average unit cost of drip irrigation system components

Sl. No.	Name of components	Unit cost, Rs
1.	Pumping unit (3 HP)	75000.00
2.	Sand filter (10m³/hr. capacity)	10000.00
3.	Screen filter (10m³/hr capacity)	2500.00
4.	PVC/HDPE pipes	
	63 mm x 4kg/m²	89.00
	50 mm x 4kg/m²	58.00
	40 mm x 4kg/m²	37.00
5.	By pass assembly	1345.00
6.	PVC valve	589.00
7.	Fustigation system	2500.00
8.	LLDPE lateral pipe	
	12mm	5.50
	16mm	6.50
9.	Emitter	3.50
	8lph	3.10
	4lph	2.50
10.	GTO	110.0
11.	Flush valve Accessories	Lump sum

Determination of Cost of Installation of Drip Irrigation System in Hilly Terraced Land

Various cost components of irrigation system, operational cost of the system and cost of production of mango have been worked out for each year after transplanting of mango in 1996.The yield of mango under different irrigation and mulching treatments was covered in per hectare basis. Income from the produce was computed by multiplying the yield with the prevailing average selling price of mango collected from the local mango mandi at Haldwani. It s evident from the Table 4 that the initial cost of the drip irrigation system including pumping unit is Rs. 28600, 32100, 37300, 44800 and Rs. 66600 for the mango crop planted at 10m × 10m, 8m × 8m, 6m × 6m, 5m × 4m and 3m × 2.5m spacing, respectively. If the water is not clean and it contains biological impurities, use of a media filter is essential under drip irrigation system. In such case the cost of drip irrigation system including pumping unit and media filter increases to Rs 38600, 42100, 47300, 54800 and Rs 76600 per hectare for the same sequence of plant spacing. The cost of drip irrigation system further increases to Rs 41100, 45600, 49800, 57300 and Rs 79100 per hectare with the integration of fertigation unit in the system. The cost of drip irrigation system is higher for the mango crop planted at closure spacing which is mainly due to the increase in the length of laterals and number of drippers required for the more number of plants per hectare. Bill of Quantities (BOQ) i.e. components requirement Drip Irrigation System 4000 m² area is demonstrated in Table 5.

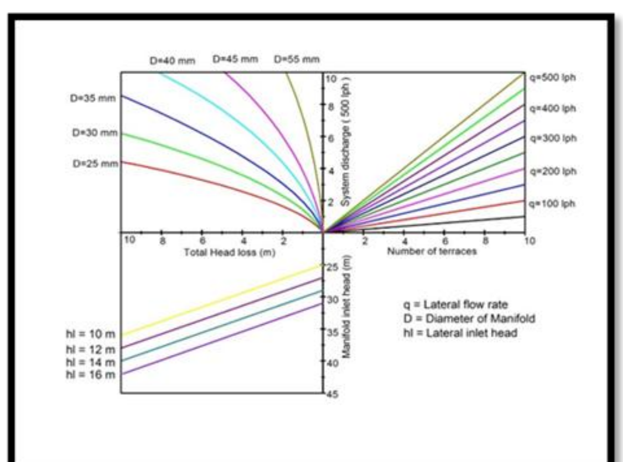


Fig. 3 Manifold design chart for a trapezoidal shaped (S_f = 0.5) subunit having 10 terraces on 10 % ground slope

Table 5 Bill of Quantities (BOQ) i.e. components requirement Drip Irrigation System 4000 m² area

Area : 200 m²				
SN	**Components**	**Unit**	**Close growing vegetable (row Crops) 0.3 × 1.0 m**	**Fruit Crop 5m × 5m**
1.	1000 litre Tank with connector for connecting Non-return valve / gate valve and Screen filter with HDPE Main line (Good Quality standard make-durable Plastic of life 10 years	No	1	1
2.	Screen Filter 10 m³/hr	No	1	1
3.	HDPE pipe 40/32 mm 4kgm-2	m		
4.	Lateral 12 mm,ClassII;2.5kg/cm2	m		800
5.	Emitting Pipe16 mm; ClassII: emitter spaced at 20 cm of 4 lph capacity	m	4000	-
6.	Pressure regulating Emitter/ Dripper 4 lph (2 drippers per plant)	No	-	
7.	Control Valve 40/32 mm	No		1
8.	Flush Valve 40/32 mm	No	1	1
9.	Fittings & Accessories @10%	Lump sum	As required	As required
10	Installation cost @ 10%			

Conclusions

A user-friendly computer software package was developed for the design of drip irrigation systems in hilly terraced land using Visual Basic (Version 6.0). The software facilitates the design of both single-lateral and paired-lateral configurations, as well as submain units, for different terraced field geometries including terraced rectangular subunits, terraced trapezoidal subunits, sloping rectangular subunits, and sloping trapezoidal subunits. The tool computes essential design parameters such as total number of emitters per plant, tree spacing, wetted area percentage, total number of plants, average daily transpiration rate, net irrigation depth, emission uniformity, leaching requirement, gross irrigation depth, gross volume of water required per plant per day, application time, average emitter pressure head, total number of emitters, and total system capacity. It also assists in selecting the appropriate emitter type (pressure-compensating or non-pressure-compensating).

The software was tested and validated using real-time field data and performed satisfactorily. Design charts for three land slopes (10%, 30%, and 40%) were generated using the model outputs.

These charts cover three quadrants of a design plan:
(i) terrace number vs. lateral flow rate to determine system discharge.
(ii) system discharge vs. manifold diameter and total head loss.
(iii) total head loss vs. manifold inlet heads for different lateral inlet heads.

Based on the generated design charts and software outputs, material requirements were estimated for terraced fields ranging from 0.2 to 5 ha. Using prevailing market prices of drip irrigation system components, the total installation cost for various field sizes was also derived. The developed software thus provides a practical decision-support tool for efficient design and optimization of drip irrigation systems in hilly terraced agro-ecosystems. It requires minimal user input and generates comprehensive design outputs for both small and large land areas. Additionally, it supports economic analysis, making it highly suitable for planning and evaluating drip irrigation adoption in hilly regions.

Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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