Methodological approach for techno-economic study towards adoption of Microirrigation Methods in Canal Command Area - A Case

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ABSTRACT:
A mathematical approach is developed for techno-economic feasibility study towards adoption of microirrigation methods in areas bestowed with good quality surface water under rotational distribution of canal network. The methodology includes integration of different modules in the form of a computer model. The approach involves water requirement scheduling of crops using FAO Penman-Monteith method and optimal allocation of available resources i.e. land and water using linear programming technique (Optimal Crop Allocation Model) among the crops selected on the basis of farmers preference and productivity in the area. The another module determines the minimum reservoir capacity and design a dug out type surface storage reservoir using linear programming technique (Storage Reservoir Design Model) to store water for use during the “OFF” time period of the canal operation. The Microirrigation Layout & Design Module designs a microirrigation system for an individual field and selects the optimal field layout for the most economical arrangement of lateral, submain and mainline on the field. The minimal spanning tree approach is proposed to estimate the minimum length of branched pipe network connecting the individual field to the internal storage reservoir of the command area. The Pipe Network Design Model gives optimal design of conveyance piping system based on the optimization technique with an objective of minimum total cost. The methodology facilitates comparison of options of having a single common reservoir and pumping unit for all fields in the study area and the field reservoir and pump for an individual field.
The application of developed methodology to command area of Direct minor no. 3 of the Mula Irrigation Project, Ahmednagar, Maharashtra indicated 3.5 times higher net benefits due to adoption of microirrigation methods using field reservoir and pump for an individual field and 2.8 times higher net benefits due to microirrigation methods using single common reservoir and pumping unit as compared to the surface irrigation method. The reutilization of the microirrigation systems among the seasonal crops having growth periods less than six months showed approximately 6% increase in the net benefits.
Thus, indicating replacement of surface irrigation methods by microirrigation methods in a command area of an irrigation project under the rotational water supply system to be beneficial. The developed methodology can be useful to the policy makers for planning large scale adoption of microirrigation methods in canal command area with rotational water supply. The methodology can also be adopted to individual outlet of the command area or group of outlets with common water inlet where water user association are in existence.

INTRODUCTION

It is established fact that the micro-irrigation methods can save about 30-50 % of water and increase yield to the extent of 10-20 per cent over the conventional surface irrigation methods for most of the crops. Hence, these systems are becoming popular and farmers are adopting them to great extent. However, the adoption of these systems is limited to the well-irrigated area, where the individual farmer mostly owns the source. These systems are not still adopted to canal command area mainly due to the irrigation rotation feature of the canals, wherein the water is delivered by gravity and long off periods of canal are often encountered.
Almost 50 per cent area in the semi-arid regions of India, which are water scarce regions, is under canal irrigation. The efficiency of the surface irrigation methods in canal command area is just around 30-35 per cent and if the net irrigated area is to be increased beyond the present 16-20 per cent, it

shall be possible with the introduction of more efficient methods. The adoption of micro-irrigation methods to canal command area may prove to be the formidable option. Thus it is necessary to explore the possibility of adopting the micro-irrigation methods on canal command area and develop a methodology for its adoption. Moreover, it will also be necessary to check the technical and economical feasibility of their adoption to canal command area. Hence, the present investigation is proposed with the aim to develop the complete methodology for adopting micro-irrigation methods to the command area of irrigation project under rotational water supply.

METHODOLOGY

In surface irrigation methods, the minimum depth of water to be applied for each irrigation is usually large and the water distribution system in the outlet command area of irrigation project is designed in such a way that the particular field gets water only once during the irrigation period.
However, if microirrigation methods are to be adopted in command area of irrigation projects, the irrigations need to be scheduled daily or at an alternate day. Under such cases, it is necessary to store the water available to the command area in a storage structure (reservoir or pond) and make it available to crop as per the requirement (i.e. depth and frequency). The size and number of storage structures may vary according to the volume of water that needs to be stored, maximum permissible depth available for the storage, area available for storage etc. The water stored in the reservoirs then needs to be carried to an individual farm through the network of pipes. Therefore, development of a methodology for adoption of micro irrigation system in command area must include the design of the storage structures, design of pipes network and microirrigation system for the fields with in the command area.
The microirrigation methods though produce more per unit volume of water, involve heavy initial investment. Therefore, while adopting the microirrigation methods in the command area of irrigation project, it is necessary to develop a suitable optimal crop plan to suit the local conditions and ensure the maximum returns.
The present study is aimed to develop a methodology for the adoption of microirrigation methods to the command area in which the surface irrigation methods are currently practiced. The methodology involves developing the procedures for obtaining the optimum crop allocation plans under the microirrigation methods, optimally designing the storage reservoir volume, dimensions of the storage structure for storing the water during off period of canal rotation and dimensions of pipe network for conveying water at requisite pressure from the reservoir to each field. The developed methodology can also be applied to the command area of Water Users Association that usually consists of command area of a minor or more than one minor.

DEVELOPMENT OF A MODEL

Optimal Crop Allocation Model

The Optimal Crop Allocation Model (OCAM) is developed using a linear programming technique.

Objective function

The objective of the optimum allocation of land and water resources to different crops is to obtain the maximum net benefits from the irrigation. Hence, the objective function is represented as:

$$Max \quad Z = \sum_{n=1}^{N} B_n X_n \qquad (1)$$

where,

Z = total net benefits, Rs
X_n = area to be irrigated under n^{th} crop, ha
B_n = net benefit estimated from irrigation of n^{th} crop, Rs/ha
N = total number of crops
n = subscript for crop

In case the net benefits need to be estimated with costs of the common pumping units the objective function is represented as under:

$$Max \quad Z = \sum_{n=1}^{N} B_n X_n \quad - \quad C \tag{2}$$

Where,

C = the cost of the pumping unit at common point.

B_n = net benefit estimated from irrigation of n^{th} crop without considering the cost of pumping unit for individual field, Rs/ha

Constraints

Area

These constraints state that the area to be brought under irrigation of different crops during particular irrigation period should not exceed the total available cultivable area, and is represented as:

$$\left(\sum_{n=1}^{N} X_n \quad \leq \quad A \right)_i \qquad \text{for i =1, I} \tag{3}$$

where,

A = total available cultivable area, ha

i = index for irrigation period

I = total number of irrigation periods.

Water availability

These constraints states that the total water required for irrigating different crops in particular irrigation period should not exceed the total water available for irrigation in that irrigation period. Generally, in surface irrigation methods, the water is delivered through the outlet for few days (“ON” period) and no water is delivered during the remaining few days (“OFF” period). For example if the irrigation interval is 14 days, for a period of one year, the corresponding irrigation index becomes 26.

However, for adoption of micro irrigation it is proposed to store water in the reservoir. The “OFF” period water requirement is to be met by this storage reservoir. Further, the surplus water available in particular irrigation period can be used for the irrigation periods succeeding this irrigation period or surplus water from the preceding irrigation periods can be used for irrigation period of deficit. Hence, to workout the optimal storage capacity of the reservoir the index period needs to be decided based on ‘OFF’ days of the canal operations. Thus, for example, if a water delivery period is 7 days in a 14 days irrigation interval period, design of reservoir capacity shall have 52 irrigation indices during the period of one year.

The water availability constraints are formulated on the basis that the total water to be released or the irrigation requirement of all the crops during the particular period should be equal to or less than the summation of water available in the reservoir at the beginning of that period and inflow during that period less any losses due to evaporation during that period. Since it is proposed to provide the lining to reservoir, the seepage losses are neglected. These constraints are represented as:

$$\sum_{n=1}^{N} w_{in} X_n \quad \leq \quad W_{i-1} + Inf_i \qquad \text{for i = 1, I} \tag{4}$$

where,

$$W_{i-1} \quad = \quad W_{i-2} + Inf_{i-1} - \left(\sum_{n=1}^{N} w_{in-1} \right) X_n \qquad \text{for i=2, I} \tag{5}$$

$$W_{i-1} \quad = \quad ISt \qquad \text{for i=1} \tag{6}$$

where,

w_{in} = the irrigation requirement of n^{th} crop during i^{th} irrigation period, ha-m

Inf_i = the inflow of water into reservoir from the outlet during i^{th} irrigation period, ha-m

ISt = initial storage in the reservoir, ha-m

W_i = water storage in the reservoir at the beginning of i^{th} irrigation period, ha-m.

For surface irrigation method, this constraint states that the total water required for irrigating different crops should not exceed the total water available for irrigation during a particular period. This constraint is represented as:

$$\sum_{n=1}^{N} w_{in} X_n \quad \leq \quad Inf_i \qquad \text{for i = 1,I} \tag{7}$$

where,

w_{in} = the irrigation requirement of n^{th} crop during i^{th} irrigation period, ha-m
Inf_i = the inflow of water through the outlet during i^{th} irrigation period, ha-m

Crop area restriction

These are the constraints required to put certain restrictions on the resources to be allocated (land or water) to different crops grown in the outlet command area according to certain predetermined criteria. These constraints are represented as:

$$\sum_{c}^{C} X_c \leq A\max$$
$$\sum_{c}^{C} X_c = Aeq \qquad (8)$$
$$\sum_{c}^{C} X_c \geq A\min$$

where,

c = the index for those crops for which the total area need to be restricted
C = the total number of crops for which the area needs to be restricted
Amax = the maximum area which need to be restricted for 'c' crops (ha)
Aeq = the area which need to be irrigated for 'c' crops (ha)
Amin = the minimum area which need to be restricted for 'c' crops (ha)

No **overlap constraints**

It is possible to use the microirrigation system installed for the seasonal crops for the other seasonal crops during the remaining part of the year. The crop season of such crops should not match with each other. The system requirements like emitters spacing and lateral spacing should also be similar. Using the same set of microirrigation system for different crops in different seasons may be economically feasible, as the initial cost of the microirrigation unit is high. The constraints for using the same set of microirrigation system for different crops in different seasons are represented as:

$$\sum_{j_1}^{J_1} Xj_1 \leq \sum_{j_2}^{J_2} Xj_2 \qquad (9)$$

where,

j_1 = index for those crops, the crop season of which does not match with crop season of crops having index 'j_2'and have similar system requirement .
j_2 = index for those crops, the crop season of which does not match with crop season of crops having index 'j_1' but have similar system requirement. The net benefits are estimated without considering the cost of the set of microirrigation system.
J_1 = total number of crops with index 'j_1'
J_2 = total number of crops with index 'j_2'

Estimation of Irrigation Requirement

The irrigation requirement of the crop for the particular irrigation period is the sum of the daily irrigation requirement during this irrigation period.

Reference crop evapotranspiration

In this study FAO Penman-Monteith method (Allen *et al*., 1998) is used. The maximum crop evapotranspiration is estimated as follows:

Etc = Etr Kc (10)

where,

Etc = daily maximum crop evapotranspiration, mm
Etr = daily reference crop evapotranspiration, mm
Kc = daily crop coefficient

Crop coefficient

In literature, the crop coefficient values are available stage wise. These values are generally adopted from Doorenbos *et al*., 1979 / Allen *et al*., 1998 or developed locally. However, for planning, management and operation purposes the daily values of crop coefficients are required. Therefore, the equations of crop coefficients as function of number of days since sowing/planting or crop coefficient curves are required. This type of formulation helps to use the equation for different lengths of crop growing season. Such equations for crop coefficient are also useful for computer programmes.

$$Kc_t = a_1\left(\frac{t}{T}\right)^1 + a_2\left(\frac{t}{T}\right)^2 + a_3\left(\frac{t}{T}\right)^3 + a_4\left(\frac{t}{T}\right)^4 + a_5\left(\frac{t}{T}\right)^5 \qquad (11)$$

Where,

Kc_t = crop coefficient of t^{th} day.
t = day considered.
T = total period of crop growth from sowing to harvesting, days.
a_1, a_2 … constants of equations.

Water requirement

The daily water requirement is estimated as follows:

WR = Etc x Wa (12)

where,

WR = daily water requirement, mm
Wa = the area wetted as the percentage of the total area, fraction

However, the effective rainfall at appropriate probability level needs to be deducted from the daily water requirement to workout the actual requirement in case of rainfall.

Irrigation requirement

The irrigation requirement is estimated as follows:

IR = WR/Eff (13)

where,

IR = daily irrigation requirement, mm
Eff = distribution uniformity of the microirrigation system, fraction

Estimation of reservoir storage capacity

The optimization analysis (Loucks *et al*., 1981) is used in this study for estimating the reservoir storage capacity. The optimization analysis is based on mass-balance equations for routing flows through the reservoir. The mass-balance or continuity equations explicitly define storage volumes at the beginning of each period 'i'. A knowledge of reservoir storage volumes is required to compute evaporation loss as well as to analyze reservoir based recreation and other development alternatives. A model based on linear programming is developed to work out the minimum required farm reservoir capacity.

Objective function

The objective of the formulation is to decide the minimum reservoir storage capacity required to meet the crop water demand and the evaporation losses from the reservoir.

Minimize K (14)

where,

K= design storage capacity of the reservoir, m^3.

Constraints

Continuity equation

Continuity or conservation of flows requires that the initial storage volumes plus any inflow less the release and losses during any period must equal the final storage volume in that period. This final storage volume is equal to the initial reservoir storage volume in the next period. This continuity equation is represented as:

$S_i (1-a_i) + Q_i - L_i - D_i \geq S_{i+1}(1+a_i)$ for all i (15)

where,

i = index for the period

S_i = the storage volume in the reservoir at the beginning of period i, ha-m

Q_i = the inflow in the reservoir due from canal during period i, ha-m

D_i = demand of water for irrigation during period i, ha-m

L_i = losses in the reservoir during period i, ha-m

S_{i+1} = the final storage volume in the reservoir at the end of the period i, ha-m.

a_i = factor for evaporation losses $= a \times \frac{e_i}{2}$

a= surface area per unit active storage or slope of the straight line segment with water surface area (y- axis) plotted against reservoir storage (x-axis)

e_i = evaporation rate during the period i, mm.

This form of specifying the constraints has built in flexibility to take care of spills, where necessary.

The spill in the period i, $spill_i$, in this formulation is given by equations (16) and (17).

$Spill_i = S_i (1-a_i) + Q_i - L_i - D_i - S_{i+1}(a_i) - K$, if positive (16)

$= 0$, otherwise (17)

Further, the inflow is assumed to be repetitive i.e. to occur over a period of years. Hence, it is necessary to ensure that the storage at the end of the last period in the year is same as the storage at the beginning of the first period. This is introduced through equation (18).

$$S_{T_{1j}} = S_{1_{j+1}} \qquad (18)$$

Where, T is the last period in the sequence.

j = index for the year.

Storage capacity

The storage in a reservoir during any period cannot exceed its capacity. This constraint is represented by equation (19).

$S_i \leq K$ for all i (19)

where,

K = design storage capacity of the reservoir, m^3.

Non negative constraint

The storage cannot be negative. This constraint is expressed as under.

$S_i \geq 0$ for all i (20)

Design of microirrigation system

The various input parameters required for design includes field data such as area and dimension of the field, soil type; crop data viz spacing, no. of emitters per plant etc. and system data such as lateral spacing, emitter type, its discharge and operating pressure.

The microirrigation system design essentially includes design of main, sub main and laterals pipe for the field. The selected size must fulfill the design criteria of head loss, velocity and capacity. The proper layout of these pipes (lateral, submain and lateral) on the field is also equally important for reducing the expenditure on the pipe network.

This methodology ensures the selection of layout with minimum fixed cost of the submain and lateral with allowable variation in pressure/ discharge and also minimum total cost for the mainline.

Design of Conveyance Pipe Network and Pumping System

Network technique for pressurized distribution pipe -Minimum Spanning Tree (MST)

Objective function

The costs of pipe, energy and power requirement for each link should be minimum

$$Min \quad Z_{op} = Min\begin{bmatrix} \{C(D_{op}) + E(D_{op}) + P(D_{op})\}_1, \{C(D_{op}) + E(D_{op}) + P(D_{op})\}_2, \\ \ldots\ldots\ldots\ldots, \{C(D_{op}) + E(D_{op}) + P(D_{op})\}_n \end{bmatrix} \qquad (21)$$

where,

$C(D_{op})$ = annual fixed cost on pipe and accessories and operating cost including maintenance, repairs, taxes and insurance costs, Rs.

$E(D_{op})$ = annual energy costs, Rs.

$P(D_{op})$ = contribution towards annual fixed cost on pumping unit, Rs.

D_{op} = pipe diameter of a link.

Annual fixed costs

The life of all the components of the pipe network is considered same. The depreciation values are assumed as negligible. The annual fixed costs are computed as:

$$C(D_{op}) = PWc(D_{op})crf \tag{22}$$

$$crf = \frac{w(1+w)^y}{(1+w)^y - 1}$$

where,

$PWc(D_{op})$	=	present worth of pipe and accessories, Rs.
crf	=	capital recovery factor
w	=	interest rate and
y	=	the number of years the cost will be incurred in future

Annual energy costs

The annual energy cost is estimated as:

$$E(D_{op}) = \frac{0.735 Q_{op} H_{op}}{75\eta_p} Ta_{op} Rp\, cef \tag{23}$$

$$cef = \left[\frac{(1+r)^y - (1+w)^y}{(1+r)-(1+w)}\right]\left[\frac{w}{(1+w)^y - 1}\right]$$

where,

cef	=	cost escalation factor
Q_{op}	=	discharge through the link, lps
H_{op}	=	total pressure requirement, m
r	=	annual rate of escalation
Ta_{op}	=	annual hours of operation
Rp	=	cost of power, Rs/KWh
ηp	=	pump efficiency

Contribution towards annual fixed cost on pumping unit

It is computed as:

$$P(D_{op}) = \left(B + \frac{Q_{op} H_{op}}{75\eta_p} Rpu\right) crf \tag{24}$$

where,

B	=	minimum cost of the pumping unit, Rs
Rpu	=	cost of the pumping units, Rs/HP

Constraints

Conservation of mass

The total amount of water flow into junction node should be equal to total amount of water flow out from this junction node. There will be continuity equation for each node of the form given as:

$$Q_{op} = \sum_{k=1}^{K} Q_{ko} \quad (25)$$

where,

Q_{op} = discharge requirement of the link op

k = subscript for all the links joining to the junction o

K = total number of links joining to the junction o

Conservation *of energy*

The energy requirement at the end of particular link should be equal to the energy requirement at the beginning of this link and all the losses in that link. This is given as:

$$H_{op} = Max\{H_{1o}, H_{2o}, \ldots\ldots, H_{K,o}\} + Hl_{op} \quad \text{for communicating links (26)}$$

$$H_{op} = HF_o \quad \text{for primary links}$$

where,

H_{op} = requirement of head at the end of link op

Hl_{op} = head loss due to friction and other losses for the link op.

HF_o = head requirement at sink/field o

Design of the network mainline pipe size and the raising main pipe size

High velocity in a link shall increase the chances of pipe failure due to surge pressure and hammering action. Hence a velocity limit up to 1.5 m/sec is often recommended in the design. The velocity in a network mainline link is estimated using equation (27).

$$Vnl = \frac{Qnl}{Anl} \quad (27)$$

Where,

Qnl= discharge in network mainline link, L/s.

Anl = cross sectional area of network pipe, m^2.

Vnl= velocity in network mainline link, m/s.

The headloss in the network mainline link is estimated using equation (28).

$$J = 1.212 \times 10^{12} \times \left(\frac{Qnl}{C}\right)^{1.852} \times (Dnl)^{-4.871} \times Lnl \quad (28)$$

Where,

Qnl = discharge in network main line link, L /s

Dnl = Inside diameter of network main pipe, mm

Lnl = length of network main line link, m

Total Net Benefit

Total Annual Costs

The total annual costs are the annual costs on

1. Crop production
2. Pipe network
3. Energy
4. Reservoir

Crop production cost

Cost 'A': These are the paid out costs (pocket expenses) consisting of the costs incurred on following items:

1) Hired human labour
2) Attached labour
3) Bullock labour (Owned + Hired)
4) Machine labour (Owned + Hired)
5) Seed (Home produced + Purchased)

6) Manures (Owned + Purchased)
7) Fertilizers
8) Irrigation charges
9) Insecticides, pesticides, weedicides and bio-fertilizers
10) Incidental charges (eg. acquisition of inputs)
11) Expenditure on repairs of implements, machinery, farm buildings during the year.
12) Interest on working capital (sum up of item 1 to 11)
13) Land revenue, cess and other taxes.
14) Depreciation on implements, machinery and farm buildings.
Therefore,

1. Cost A **=** Paid out costs + interest on working capital + land revenue + depreciation.
2. Cost 'B'= Cost A+ rental value of owned land (less land revenue) + interest on fixed capital + annual amortization cost (in the case of fruit crops)
   Cost 'C' =Cost 'B' + Family labour charges.

Cost of microirrigation system

Depreciation

The depreciation to farm buildings, irrigation structures, implements, machinery, hand tools etc. are estimated as under:

$$Depreciation = \frac{Present\ value - 10\ per\ cent\ of\ present\ value}{Remaining\ life\ in\ years} \quad (29)$$

Interest on fixed capital

The interest rate of fixed investment on different farm assets needs to be calculated at a prevailing interest rate per annum, say for example10 per cent for the year.

Irrigation charges

The actual charges paid for irrigation needs to be considered.

Land revenue and other cess

It includes land revenue, education cess and other special taxes on certain crop(s) paid to the Government. All those taxes are considered for the farm as a whole.

Rental value of land

For high paying crops (i.e. fruits, vegetables and all other cash crops) the rental value of 1/6 values of gross produce or 10 % of government value of land whichever is less is to be considered. For other crops it is computed at the rate of $1/6^{th}$ of the gross value of produce less land revenue and other taxes.
Since the microirrigation system involves heavy investment, generally these systems are installed on crops with higher returns. Therefore, in this study, for the economic analysis, it is proposed to consider the land rental value that is applicable to the high paying crops.
Further, per hectare cost of cultivation is estimated as per the equation (30)

$$\text{Per hectare cost of cultivation} = \frac{\text{Net cost "C"}}{Area\ (ha.)} \quad (30)$$

Where,
Net cost “C”= Cost “C”- value of by produce
In case of fruit crops, the Net cost “C” is calculated by deducting the income received from the inter crops from cost “C”.The net income from the crop can be estimated using equation (31). The gross produce is the production obtained (main plus by product) from the field multiplied by the prevailing market rate of the produce.

$$Net\ Income = Value\ of\ gross\ produce - Cost\ "C" \quad (31)$$

Pipe network costs

These costs include the costs of pipes and accessories, pumping units, installation and operation and maintenance.

Energy cost

These costs include the costs for operating the different pumping units. These are based on the annual hours of operation of each pumping unit for the optimum crop plan.

Reservoir cost

These are the costs, which are required for the construction of each reservoir and their maintenance.

Total annual benefits (Gross produced)

Total annual benefits are computed by multiplying the total crop production and unit selling rate of crop produce and bi-produce for each crop.

Study area

Direct Minor no. 3 of Mula Right Bank Canal (MRBC), Mula Irrigation Project, Ahmednagar district, Maharashtra is selected as the study area. The command area of Mula Irrigation Project lies in between latitudes 19°15'00" N and 19°45'00" N and 74°30'00" E and 75°15'00" E longitudes. The mean annual rainfall of the area is 550 mm. The climate of the area is semi-arid and the average annual temperature varies from 32 ^{O}C to 17 ^{O}C.

The Rotational Water Supply system is followed in the canal command area of Mula Irrigation Project. The rotation is based on 7 days "ON" and 7 days "OFF" period. Presently, water users associations are formed in the command and water charges on volumetric basis is proposed. The total cultural command area encompassed by the minor is 431.75 ha. The discharge of this minor at the head regulator is 10 cusec.

The majority of the farmers (52 %) in the study area are marginal farmers. Small farmers constitute for about 33% of the total farming community of the command area. 12 % of the total land holders are in semi- medium category and only 1 % farmers have medium size land holding. The maximum land holding in the command area is 6.35 hectare, where as the minimum land holding in the command is merely 0.02 hectare. The total command area consists of 431.73 hectares are shared among 346 land holders.

Formulation of Optimization Models for Case Study

Optimal Crop Allocation Model

Decision variables

Decision variables are the area to be irrigated under different crops. Twenty one crops have been considered for the analysis, out of which six crops (Papaya, Pomegranate, Lime, Sugarcane, grapes and Banana) are annual or perennial and remaining crops (*Kharif* Soybean, *Rabi* Tomato, *Kharif* Groundnut, *Rabi* Onion, Cotton, Gram, Potato, *Kharif* Brinjal, Cabbage, Summer Brinjal, Summer Cucumber, Summer Onion, Summer Okra, Summer Groundnut, Summer Chilli) are seasonal (having crop period less than six months). These seasonal crops can have specially designed microirrigation system or may use the system designed for some other crop grown during some other season but requiring similar emitter spacing, lateral spacing and emitter discharge. Thus, each of these seasonal crops has two decision variables.

Therefore, the total decision variables for seasonal crop are thirty and six decision variables for perennial crop. Thus there are thirty-six decision variables for seasonal and perennial crops together.

Period

In the present study, the availability and requirement of different resources need to be checked over a certain period. The convenient period here is the water delivery interval or rotation period. The water delivery period for the surface irrigation project is 14 days. Therefore, the total numbers of index periods in a year are 26.

Constraints

Area constraints

The existence of a particular crop during any index period depends on the crop planting date and its growth period. The existence of a crop during any index period is indicated by the coefficient to basic variable as ‘1’ and non-existence as ‘0’.

Crop area restriction

These restrictions are based on the general cropping pattern in the region.

1. The maximum area under Sugarcane should be 10% of the total minor command area.
2. The maximum area under all fruit crops together (Papaya, Banana, Pomegranate and Lime) should be 10% of the total minor command area.
3. The maximum area under all *Kharif* crops (*Kharif* Soybean, *Kharif* Groundnut, Cotton and *Kharif* Brinjal) should be 20% of the total minor command area.
4. The maximum area under all *Rabi* crops (*Rabi* Tomato, *Rabi* Onion, Gram, Potato and Cabbage) should be 40% of the total minor command area.
5. The maximum area under all summer crops (Summer Brinjal, Summer Cucumber, Summer onion, Summer Okra, Summer Groundnut and Summer Chilli) should be 20% of the total minor command area.

The maximum area available for cultivation during any period cannot exceed the total command area of the minor i.e. 431.73 hectare.

Water availability constraint

The daily flow at the inlet of the minor during the “ON” period of the canal is 0.283 cumec (10 cusec). Hence, the total water available to the command during the “ON” period(7 days) of the water supply is 171279.4 m^3. This water availability is considered as the maximum inflow for all irrigation indices (26 nos.) of a year under surface irrigation method. The irrigation requirement for any index period must be less than or equal to this maximum water availability. However, for microirrigation methods, it is proposed to construct a storage reservoir to store water to meet the ‘OFF’ period demand of the crops growing in the command area. Hence, the maximum water available during any index includes the balance water available in the reservoir at the beginning of the index period plus inflow during the index period.

No overlap constraints

In order to effectively utilize the investment made on microirrigation system, it is proposed to use the microirrigation system installed for a particular seasonal crop, for the other seasonal crops during the remaining part of the year. However, for reutilization of the system, the system requirement such as emitter spacing, lateral spacing, emitter discharge etc. among those crops must be similar, but the crop season for such crop should not match with each other. The no overlap constraint takes care of this. Considering the different seasonal crops, having similar system requirements (*Kharif* Soybean, *Kharif* Groundnut, *Kharif* Brinjal, *Rabi* Onion, Gram, Potato, Cabbage, summer Brinjal, summer onion, summer Okra and summer Groundnut) and their growth periods, fifteen different constraints are imposed. These are considered as constraints in the linear programme.

Storage Reservoir Design Model

The SRDM model is developed using a linear programming technique.

Period

For a water delivery period of 7 days in a 14 days irrigation interval period, the design of reservoir capacity shall have 52 irrigation indices.
For the rated inflow, the available water at the inlet of the command area during the “ON” period of the water supply is 171279.4 m^3.The inflow during the “OFF” period is considered to be zero.

Decision variables

The SRDM model consists of 52 decision variables, one for each reservoir storage capacity during the individual irrigation index and one for the objective function. Thus, the total decision variable for the SRDM module consists of 53 decision variables.

Constraints

The model has two sets of constraints to be satisfied. One relates to storage continuity and other to the reservoir capacity.

Storage continuity equation

The storage reservoir is considered to be located at the inlet of the minor. A dugout trapezoidal shape reservoir is considered for storage of water to meet the “OFF” period demand of the crop.
There are 52 irrigation indices. The water available at the inlet of the command area during the “ON” period of the water supply is 171279 m^3. The inflow during the “OFF” period is considered to be zero. Also, the volume of water initially present in the reservoir is considered to be zero.
The total irrigation requirement of crops in a command depends on the climatological data of the command. The evaporation during the index period is governed by the evaporation rate during the index period and the active water surface area of the reservoir which is a function of climatological data and the reservoir storage. The seepage loss from the reservoir is considered to be nil on account of the proposed reservoir lining.

Storage capacity

There are 52 storage capacities required for 52 irrigation indices. The minimum design capacity of the reservoir should be sufficient to accommodate the storage capacity for any index.

Pipe network design model

The pipe network design model estimates the diameter of different links connecting the reservoir and an individual field of the command area.
Taking into the consideration the village boundaries and the existing outlets in the command area of the minor under study, the area is divided into eight blocks. The rising main conveys water from the storage reservoir to an individual block through a hydrant at the inlet of the block. Thus, the study area has a single rising main connecting eight block hydrants.
The pipe line joining individual field of the block to a common water supply point (block hydrant) constitutes the network main line of the block. The cost of the network main line depends on the length and the diameter of the links in a pipe line. Hence, to select the optimal pipe line layout connecting all individual fields of the block, a minimal spanning technique is used. The actual length of the links required to connect the adjoining fields were measured from the command area map. These distances were used as an input to the minimal spanning tree software (TORA) to decide the minimum length of the pipe line connecting all the fields to the block hydrant.
The output from the TORA is a minimal spanning tree that gives the shortest possible length of the pipe links connecting the fields to the block hydrant.The individual link of this network is then subjected to design that includes selection of an optimal diameter from the available range of the pipe diameters using the optimization technique. The head and discharge requirement of the individual field is obtained from the MILDM module. The design of the individual link starts with the selection of the most remote link in the minimal spanning tree. The head and discharge requirement of this link is the head and pressure requirement of the field connected at its end. After designing of the first link, the next link of the minimal spanning tree is considered, till all the links in the tree are completed. The velocity limit of 1.5 m/s is considered for selection of a feasible diameter among the available pipe diameter ranges. The optimal diameter is selected based on the minimum total cost for the link. If none of the available diameter range meets the velocity criteria, the flow in the link is reduced by addition of pipe in parallel to this link. The flow through this link thus reduces to half and the optimal design is then carried out for selection of the optimal diameter of the pipe.
The pipe line joining the different block hydrants to the water reservoir constitutes a rising main. The design of the rising main also starts with the most remote link of the rising main. The length of the links joining the different hydrants is measured from the command area map.

Microirrigation Layout and Design Model

This model selects and designs the optimal layout consisting of lateral, submain and main for an individual field. The field size of the individual field is measured from the command area map. The 12 mm and 16 mm lateral size are considered for different crops under the study. The available pipe range from 32 mm to 110 mm in diameter is considered in this study for the submain and main line pipes of the microirrigation system. The average rated discharge of the emitter considered in this study is 4 Lph. The standard procedure and the design criteria for the design of lateral, submain and main line have been adopted.

Results and Discussions

The optimum crop plans

Microirrigation method

The optimal crop plan that yields maximum return(186 Million Rupees) showed area allocation of 6% to Papaya crop, 6% to Sugarcane, 11 % to *Kharif* Brinjal, 33% to Cabbage, 11% to summer Onion and 33% of the total command area to the summer Brinjal under microirrigation methods.

Surface irrigation method

The available rated flow at the inlet of the minor was insufficient to irrigate the entire command area under surface irrigation method. For the rated inflow at the minor inlet under surface irrigation method, the maximum net benefit (50.0 Million Rupees) was observed when 60% of the minor command area is brought under irrigation (available water is 171280 m^3). The crop plan for rated inflow that yielded maximum net benefit had area allocation of 25.90 ha for papaya, 25.90 ha to sugarcane, 96.40 ha to Rabi tomato, 6.17 ha to *Rabi* onion, 78.35 ha to *Kharif* brinjal and 2.98 ha to cabbage crop.

Intermediate storages

The minimum storage capacity of a common reservoir was observed to be 139147 m^3. This designed capacity was sufficient to yield the maximum return from the command area and satisfy the crop water requirement under the rated inflow situation.
It is more economical to have a single large reservoir than many small reservoirs to store water in a command area.
The mathematical relationship developed between the capacity of an individual field reservoir and its cost is as under:
$Y = 123.3X + 5942$
Where,
Y= cost of the reservoir, Rs
X = reservoir storage capacity, m^3.
The estimated total cost for construction of an individual field reservoir was higher (2.37 Million Rupees) as compared to the total cost of a single common reservoir (1.88 Million Rupees) in the command area of a minor.

Design of pipe network

The minimal spanning tree technique yielded a shortest length branched network for connecting the individual fields in a block. The total length of the mainline pipe network was observed as 21405 m and the total length of the rising main pipe was observed to be 2433 m. The total annual cost of the pipeline network including the fixed cost of pipe, pumping unit and the operating cost was observed to be Rs 38.23 Million Rupees.

Total Annual Net Benefits

The total annual net benefits estimated for an optimum crop plan under different strategies are presented in Table 1.

Table 1 Net benefits obtained from adoption of different irrigation systems.

Sr. No.	System details	benefit from crop	Total annual	Net benefit from adoption of

		production, Million Rupees	cost, Million Rupees	irrigation system, Rs
	1	2	3	(2-3)
1	Microirrigation system + common reservoir and pump	185.8	40.1	145.2
2	Microirrigation system with individual pump and field reservoir	184.7	2.4	182.3
3	Surface method	50.7	0	50.7

It is seen from Table 1 that the different strategies influence the total annual net benefits. The benefit obtained from the crop production for microirrigation methods with common reservoir and pumping unit is higher than the benefit obtained from the crop production for microirrigation methods with individual reservoir and pumping unit. This is due to the fact that the benefit estimated for microirrigation methods with common reservoir and pumping unit does not include the cost of pumping unit. However, the cost of such common pumping unit has been considered separately and hence the total annual cost for the microirrigation system with common reservoir and pumping unit is high.

The total net benefit is higher for microirrigation with an individual field reservoir facility. This higher benefit is due to saving in the expenditure on the pipe network. The surface method does not require any reservoir or the pipe distribution network and hence the annual costs of these items are considered as nil.

The total net benefits estimated due to adoption of microirrigation methods are compared with the total net benefits estimated for surface irrigation methods. The total net benefits obtained due to adoption of different irrigation methods are presented in Fig. 1.

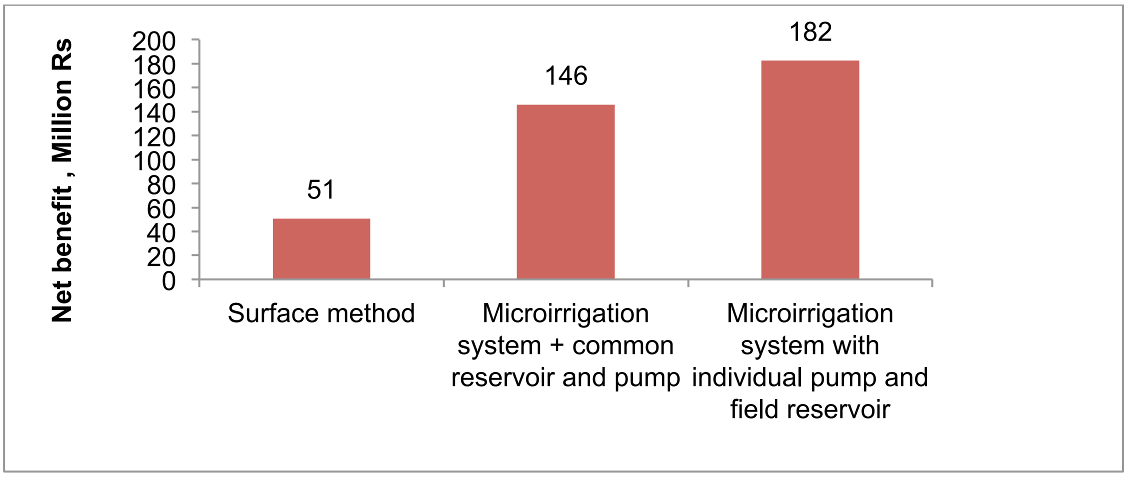

Fig.1 Net benefit obtained due to adoption of different irrigation methods.

It is observed from Fig. 1 that the total net benefits due to microirrigation methods under different strategies are 188% and 260% higher than the total net benefit from the surface irrigation method. Further, adoption of microirrigation system with an individual field reservoir increases the total net benefits by 25% when compared to adoption of microirrigation system with common reservoir and pumping unit.

The results obtained indicate that replacing surface irrigation methods in the command area of irrigation project by microirrigation methods is beneficial. Adopting microirrigation system with individual pump and field reservoir is more beneficial than the microirrigation system with common storage reservoir and pumping unit.

Conclusions

The present study is aimed towards developing a methodology for adopting the microirrigation methods in the command area of irrigation projects, wherein the surface irrigation methods are in existence. Testing of the computer model for the developed methodology with the help of a case study led to the following conclusions.

1. The adoption of microirrigation system using the field reservoir and pump for an individual field for the minor under case study having cultural command area of 431.75 ha increases the total net benefits by 25% when compared to adoption of microirrigation system with common reservoir and pumping unit. This indicates that the adoption of microirrigation methods using field reservoir is beneficial as compared to the adoption of microirrigation with a common storage and pumping unit.

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