Vol. 46, No. 2, pp 218-224, 2018

Indian Journal of Soil Conservation

Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Design of gravity flow underground pipe distribution network in the canal command area

R. Raghuwanshi, Dhiraj Khalkho[1], P. Katre, M.P. Tripathi and N.S. Raghuwanshi[2]

Department of Soil and Water Engineering, SVCAET and RS, FAE, Indira Gandhi Krishi Vishwavidayalaya, Raipur-492012, Chhatisgarh;
[2]Department of Agriculture and Food Engineering, IIT, Kharagpur-721302, West Bengal.

[1]E-mail: dkhalkho@rediffmail.com

ARTICLE INFO

Article history:
Received : March, 2017
Revised : June, 2018
Accepted : July, 2018

Key words:
Pipe distribution network,
Canal distribution network,
Irrigation,
Conveyance losses

ABSTRACT

The average water use efficiency (WUE) of irrigation projects is assessed to be only of the order of 30-35%. There is a gap between irrigation potential created and utilized, and it is of up-most important to minimize the gap. This can be achieved by use of pipe distribution network (PDN). The objective of this study is to emphasis on the use of underground PDN instead of canal distribution network (CDN) in the command area of irrigation project to improve WUE and to save land taken up by canals. Adoption of buried pipeline distributary systems had lead to the reduction in water conveyance and distribution losses, reduction in the land area taken up by the distribution system and reduction in the maintenance and operating costs of the irrigation system. A cluster of fields (*chak)* of 12 ha having 640 m length was selected for design of underground PDN alongwith controllable turnout structures. The inlet structure of rectangular shape having 1 m^2 area and 2.7 m height was designed just below the canal bank to trap silt. A screen was fixed at the inlet, through which the water enters into underground pipeline by forcing the thrash out of the system. A 20 cm diameter pipe was found suitable for delivering water till the end of PDN which was 560 m away from the inlet, when laid at bed slope of 0.8%. The head loss calculated from Darcy-Weisbach equation was 2.63 m and found to be less than that of available head of 4.77 m. Air vents of 5 cm diameter were also provided at appropriate points to release entrapped air. Eight numbers of outlets were proposed in the design of the underground pipeline system. The outlets deliver water to a diversion box of 45 × 45 × 45 cm. Two outlets of 20 cm diameter were proposed in each diversion box, one for right hand side of fields and other for left side fields for delivering irrigation water directly to the farmer's fields.

1. INTRODUCTION

Water is life for existence of all living beings on the earth. Presently the annual agricultural output is marginally sufficient to sustain our food grain requirement. To meet our ever expanding challenge of population, both the water and land use efficiency has to be increased as both land and water are the major and vital elements to influence agricultural productivity (Panigrahi *et al.*, 1992). Supplying water to the crop at right time, right place and right quantity remains the main objective of good irrigation management. In case of surface water reservoirs, the irrigation water is conveyed to the farm with the conventional wide spread open channel water distribution network. In fact, the above system is not capable to meet time based crop water need due to depletion of WUE of the system with age. More than 80% of available water resources worldwide as well as in India are being presently utilized for irrigation purposes (Panigrahi *et al.*, 2001; Bhalagea *et al.*, 2015). However, in India, the average WUE of irrigation projects is assessed to be only of the order of 30-35%

(Mahto, 2013). It is observed that the losses due to evaporation, infiltration, percolation and water thefts in open canal reduce the efficiency and yield of irrigation. Therefore, it is necessary to check these conveyance losses in case of irrigation canal (Gadekar *et al.*, 2015). The objective of this study is to emphasis on the use of PDN instead of CDN in command area of irrigation project to improve WUE. Low-pressure pipelines on surface irrigation distribution systems serve about 4-5% of the world irrigation area. The main benefits compared with open channels are reduced leakage rates and land take requirements, and flexibility in irrigation timing which is important for diversified cropping systems (Satpute *et al*., 2015; Kumar *et al.*, 2017). By virtue of PDN the WUE can be improved to 70 to 80% from existing efficiency of 25 to 40 %. Thus there is about two to three times increase in the WUE for irrigation, which means that there will be 55 to 65% improvement in overall WUE as irrigation itself is 80% shareholder in water use (Kolhe, 2012).

2. MATERIALS AND METHODS

The study area lies at *Munrethi* village in Raipur district of Chhattisgarh, India. The area comes under canal command of *Kurud* irrigation tank. Raipur district experiences sub-tropical climate, characterized by extreme summer from March to May and rainy season extends from June to September with well distributed rainfall. The number of rainy days in this area is 60-65 days. The district receives 89% of the total rainfall during June to September. Detailed methodology adopted in designing gravity flow buried PDN is discussed below. The buried pipe distributary system was designed based on the rate of water discharge in the pipe system for cluster of plots, crop water demand of the command area and cropping pattern. An agricultural land of 12 ha having 640 m length was chosen for design of underground PDN and controllable turnout structures.

Survey of the Study Area

The reconnaissance survey of the study area with the farmers was made first by moving around the area. The Bunds are boundaries and used to demarcate the study area from the surrounding area. After mapping the study area the next step taken was to conduct topographic survey in order to depict the average slope of the study area.

Selection of Type of System

Buried pipeline systems may be classified depending on the working pressure as, Low pressure systems (less than 10 m), Medium pressure systems (10 to 20 m) and high pressure system (more than 20 m). Low pressure pipeline systems can be classified on the method of pressure control into closed, semi-closed and open systems and on the method of providing head into gravity, pumped or mixed systems.

Pipe Material of the Pipeline

Concrete, verified clay, rigid PVC pipes and mild steel pipes are materials used for underground pipelines. Among these concrete and PVC are most commonly used (Campbell, 1984).

Design Velocity

Recommended maximum velocities in low pressure pipelines are in the range of 1.3 to 1.5 ms^{-1}. Minimum flow velocities should be around 0.5 ms^{-1} in order to prevent sedimentation of fine sand. The discharge is calculated as:

$$Q = A \times V \qquad ...(1)$$

Where, Q = Discharge from outlet (m^3s^{-1}), A = Area of cross-section of pipe (m^2), V = Velocity of flow through pipe (ms^{-1}).

Diameter of Pipeline and Frictional Head Losses

The diameter of pipeline is determined taking into consideration of rate of flow and the frictional losses in the pipeline. These losses depend on the mean flow velocity through the pipe, internal diameter of the pipe, roughness of internal pipe surface. Accurate estimation of friction losses in pipes is an important task. The most widely used empirical equations for calculation of pressure drops in pipes is Darcy-Weisbach equation (Yousef and Faisel, 2007).

Darcy-Weisbach Equation

It is widely accepted that the Darcy-Weisbach equation for calculating head loss is a highly accurate pipe flow resistance equation. The Darcy-Weisbach equation is rational, dimensionally homogeneous, and applicable to other fluids as well as to water (Liou, 1998).

$$H_l = f\,\frac{L \times V^2}{2 \times G \times D} \qquad ...(2)$$

Where, f = Friction factor, H_l = Head loss due to wall friction (m), L = Length of pipe (m), V = Mean Velocity (ms^{-1}), D = Internal diameter of pipe (m), G = Acceleration due to gravity (ms^{-2}).

In estimating the friction factor, f, Reynolds number (R_e) and the relative roughness of the pipe (e/D) were determined.

Colebrook-White Equation

The average value of roughness (e) was obtained from literature. These values of D, R_e, and e were used in determining the friction factor, f. For all pipes, many engineers consider the Colebrook-White equation (Barr, 1981) more reliable in evaluating f. The equation is:

$$\frac{1}{\sqrt{f}} = 1.14 - 2 \log \frac{e}{D} + \frac{9.35}{R_e \times f} \quad ...(3)$$

Where, f = Friction factor, e = Roughness of pipe (mm), D = Internal diameter (m), R_e = Reynolds number.

Minor Losses

In general for pipe system, head losses due to bends and valves comprises only 5 to 10% of total pipe friction losses and are frequently referred to as minor head loss.

$$H_m = \frac{K_m V^2}{2G} \quad ...(4)$$

Where, H_m = minor head loss (m), K_m = minor head loss coefficient, V = velocity before feature causing friction losses (ms^{-1}). A diameter for the pipeline be selected and the frictional losses calculated.

Design of Ancillary Structures

Gravity inlet

When water enters the pipe line from an open channel a gravity inlet is used. A screen is fixed to the inlet to keep the thrash out of pipeline. The top of the structure is provided with cover to prevent accident and to keep the thrash out from blown into it. It is larger than the size of pipeline. The larger capacity of stand permits dissipation of the velocity stream and release of entrapped air before the water enters the pipeline. If the irrigation water contains appreciable quantities of sand, a trap can be built into the inlet structure to remove most of the suspended material. When the stand functions as a sand trap also, it has an extra large diameter to ensure low velocity of water and its bottom is set about 60 cm below the bottom of the pipeline. When the channel water contains considerable quantities of debris and weed seed, a debris screen is provided at the inlet to clean the water before it enters the pipeline. Commonly, the stream is allowed to fall through a fine screen into a gravity inlet. The screen will need frequent cleaning. In small scale installations, inlet consists of simple masonry tanks of required height and about one meter square. The concrete bed is made at the bottom of 10 cm thickness for stands up to 3 m height.

Total height of inlet stand = 0.60 m below the bottom of pipe + Diameter of pipe + Depth of pipeline below the ground + Max. Depth of flow in the canal + freeboard.

Air vent

Air vent are vertical pipe structure to release air entrapped in the pipe line and to prevent vacuums. They are installed at all high points in the line including sharp turns and at those sections where there is a downward deflection of more than 10 degrees. Air vents to be provided directly down stream of any structure that may entrap air along with at the end of the designed pipeline. Vents are to be installed at every 150 m when the designed pipe system is laid on a level slope.

Outlets

These are needed to deliver the water from the pipeline system to the fields. The outlet consists of riser pipe jointed to the main pipe line vertically. At the end of the riser pipe near ground level a valve is fitted. Opening and closing of the valve control the flow of water. The diameter of the riser pipe is kept the same as the pipeline system where the entire flow of the pipeline is to be released through the valve. A field block of 1 ha provided with a separate outlet of 1 cu sec (27 lps) capacity, with the valve located about 15 cm above the field level with a division box (protection against scouring would be convenient.

3. RESULTS AND DISCUSSION

Topographic survey of the study area is conducted and average ground slope was calculated as 0.7%, and it is found that topography is relatively flat. The closed pipe system does not require dissipation of excess energy head and the entire pipeline is hydraulically connected. These are the systems which are widely adopted now in flat agricultural land. Hence closed pipe system is selected and designed for the study area. Design depth of flow in canal is 1.05 m so it is the head available at inlet of buried pipeline. The last outlet is proposed at 560 m head gain due to 0.7% slope is 4.32 m. A 160 mm diameter outlet is fixed with design discharge of 27 lps and 15 cm above the bed. Hence total available head at last point is 5.22 m. Fig. 1 shows cross sectional view of topographical elevations with respect to length of the field. The red line shows elevated middle bund present along the fields.

Trial -1

The major effort in the application of Darcy-Weisbach equation is the determination of the pipe friction coefficient which is a function of the Reynolds number *Re*. In estimating the friction factor, *f*, Reynolds number (*Re*) and the relative roughness of the pipe (*e*/*D*) were determined first. The mean pipeline flow velocity is calculated by assuming pipe diameter.

In first trial diameter of pipe is assumed is, 160 mm. Design discharge of outlet is 27 lps.. The mean velocity of flow is calculated by Continuity equation. The mean velocity of flow from 160 mm is equal to 1.34 ms^{-1}. To get the *Re*, the kinematic viscosity of the irrigation water (*i.e.*, v =1.12×10^{-6} m^2s^{-1}), the flow velocity (*i.e.*, V =1.34 ms^{-1}) and its internal diameter (*i.e.*, D = 0.160 m) were used. A value of 191428 for Reynolds number was calculated.

Then an average value (*i.e.*, e = 0.0165 mm) of its roughness was obtained from literature. These values of *D*, *Re*, and *e* were used in determining the friction factor, *f*, using the semi-empirical equation. The value of *f* was found to be 0.0239, which was then used with the Darcy-Weisbach formula used to calculate the head loss of turbulent flow in the pipeline on a rational basis.

Head loss due to friction in pipe only found as 7.62 m for the length of 560 m, which greater then available head of 5.22 m. Hence, gravity flow is not possible with this diameter up to desired length of 560 m. It is clear from Fig. 2 energy line is not above the ground up to desired length of 560 m.

Trial-2

Now when proposing pipe diameter as 200 mm and again repeating the analytical calculations. The mean velocity of flow from 200 mm is equal to 0.86 $m\ s^{-1}$. To get the desired *Re*, the kinematic viscosity of the irrigation water (*i.e.*, v =1.12×10^{-6} $m^2\ s^{-1}$), the flow velocity (*i.e.*, V = 0.86 $m\ s^{-1}$) and its internal diameter (*i.e.*, D = 200 mm) were used. A value of 153571 for Reynolds number was calculated.

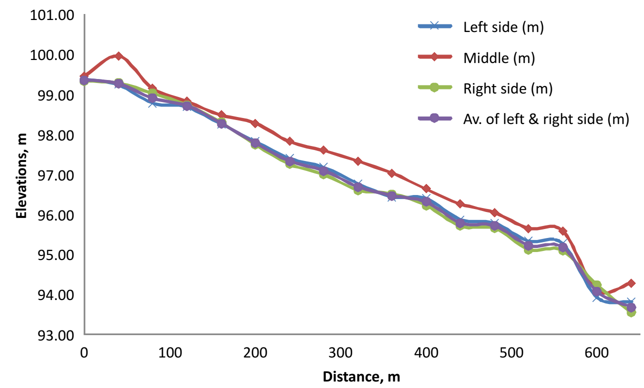

Fig. 1. Topographical elevation of the study area

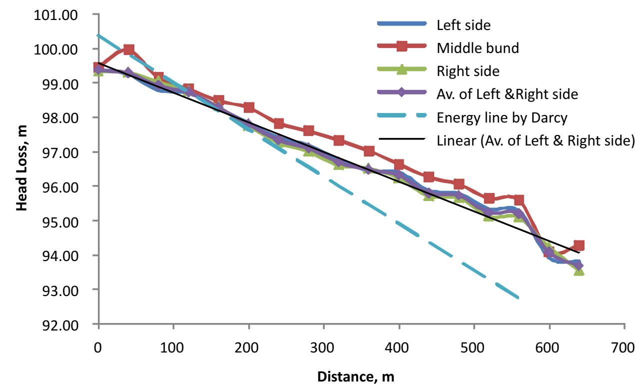

Fig. 2. Head loss by Darcy's-Weisbach equation with pipe diameter 160 mm

Then an average value (*i.e.* e = 0.0165 mm) of its roughness was obtained from literature. These values of *D*, *Re* , and *e* were used in determining the friction factor, *f*, using the semi-empirical equation. The value of *f* was found to be 0.0249, which was then used with the Darcy-Weisbach formula used to calculate the head loss of turbulent flow in the pipeline on a rational basis. Head loss due to friction in pipe only found as 2.63 m for the length of 560 m, which less then available head of 5.22 m. Fig. 3 shows with this diameter energy line is sufficiently above to discharge water on the ground though gravity.

Head loss due to valves and fittings

All outlets are assumed to be opened at the same time, therefore, their energy losses were considered in the friction head losses of the pipeline. Eight no of each 90^o bend and gate valve are fixed. Value of k for bends and valve is 0.3 and 0.1, respectively. Total value of minor head loss is obtained as 0.13 m.

Bed Slope of Pipeline

Bed slope of pipeline is equal to existing ground slope and minimum depth of pipeline below ground level is 0.50 m. While selecting the bed slope both of

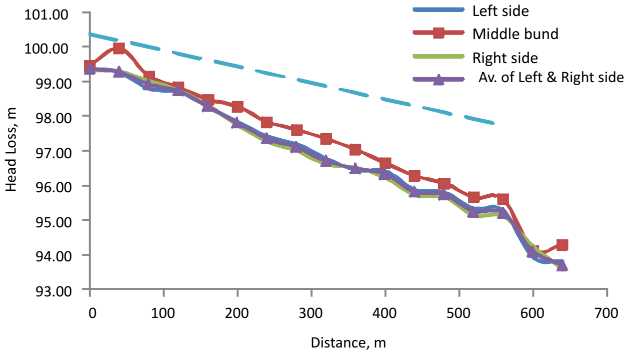

Fig. 3. Head loss by Darcy's-Weisbach equation with diameter 200 mm

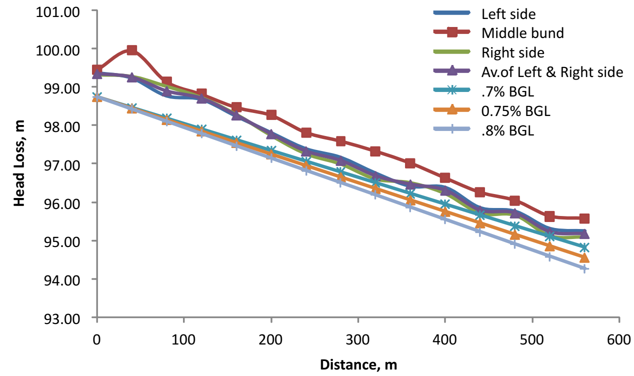

Fig. 4. Bed slope for underground pipeline

these factors are considered. Fig. 4 shows different bed slope grades with natural topography of study area. Bed slope of pipe line is selected as 0.8% as pipe line gradient of 0.7% and 0.75% slopes does not confirm the depth below ground level requirement without any auxiliary structure.

Energy Line and Outlets

The head loss due to friction up to distance of 560 m is 2.63 m and minor losses are 0.13 m. Hence the total head loss is 2.76 m. Height of water in the inlet structure is 0.90 m and gain of head due to slope is 4.32 m. Total head available is 5.22 m. Average height from underground pipeline to middle bund is 1.0 m. 1 m height from the pipeline sufficient for all outlets.

Design of Ancillary Structures

Gravity inlet

The length and width of structure is 1 m each. Depth of pipeline below the ground level is 0.60 m, diameter of pipe line is 0.20 m and another 0.60 m depth is provided to trap the silt. Total Depth of structure below the ground level is 1.20 m. Maximum depth of flow of water in canal is 1.05 m and freeboard of 0.25 m also provided. So height of structure above the ground level is 1.30 m and below ground level is 1.4 m. Total height of structure is 2.7 m. Schematic representation is shown in Fig. 5.

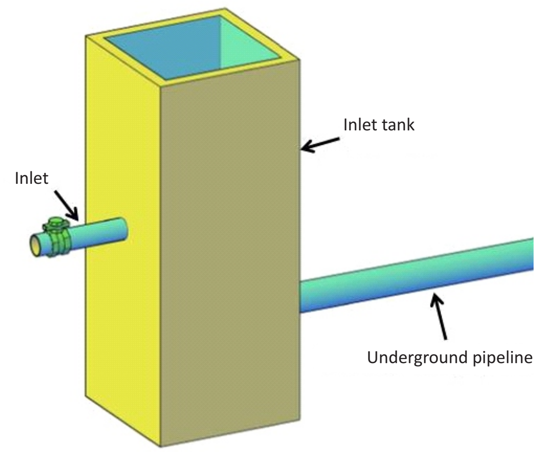

Fig. 5. Inlet tank

Outlets of the System

The entire command area of 12 ha was divided into 16 sections for delivering water directly into farmer's field. Eight sections are left side of the middle bund and 8 sections are right side of the middle bund. Eight outlets were proposed in the underground pipeline system as shown in Fig. 6. The outlets deliver water to a diversion box of 45 × 45 × 45 cm. Two outlets of 200 mm diameter were proposed in each diversion box, one for right side fields and other for left side fields. 200 mm diameter pipe will be fixed in the diversion of suitable length extended outside of box which should be closed by end plugs when water is not required. The diameter of all outlets *i.e.,* from underground pipeline to surface diversion boxes and diversion boxes to the each side field will be same and equal to 200 mm due to reason that full flow will be diverted into any of the section. The distance between two outlets is selected as 80 m. Schematic representation is shown in Fig. 7.

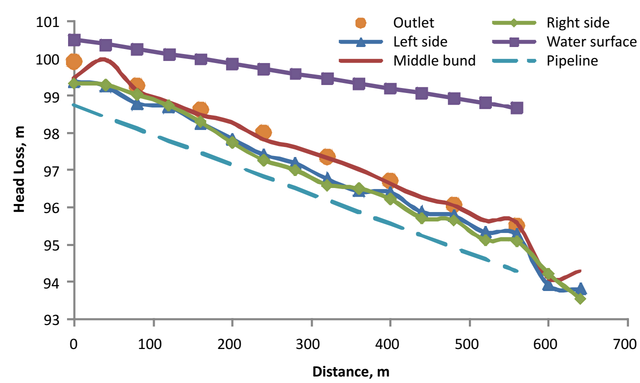

Fig. 6. Outlets of the system

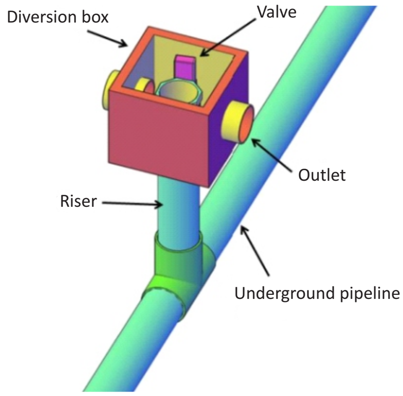

Fig. 7. Diversion box

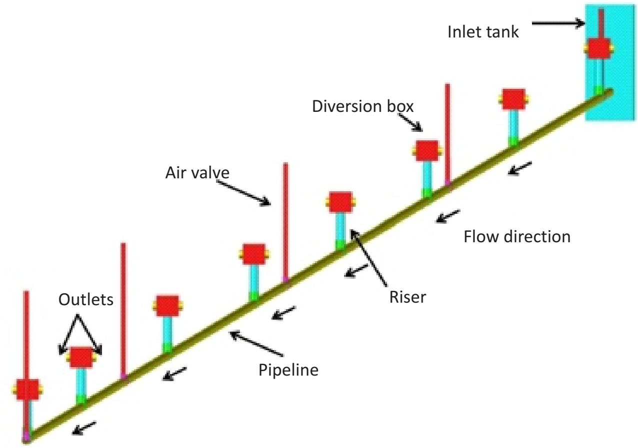

Fig. 8. Layout of underground pipe distribution network

Air vents

5 cm diameter PVC pipe is selected for air vent. First air vent is installed at 80 cm below the inlet tank. Last air vent is installed at the end of pipeline. Three air vents are installed at 150 m, 300 m and 450 m, respectively. The height of air vent is 0.25 cm (free board) above energy line.

Operation of the System

When the valve opened, water will enter from main canal into inlet tank. The head in the Inlet tank will be the same as that of the canal. Keeping only last valve open and remaining valve closed full flow of 27 lps can be diverted to either side of field as diameter of pipeline, riser and outlet is same. Similarly, one by one outlet valve will be opened from downstream to upstream and keeping all other outlet valves closed area will we irrigated from downstream to upstream. The layout of the system is shown in Fig. 8. By this system whole command area of outlet is irrigated from downstream to upstream. This system reduces conveyance losses and reserve water rights of downstream farmers. As pipelines are underground, arable land taken up by CDN can also be saved. The system was designed and proposed for paddy crop in the canal command area.

4. CONCLUSIONS

The entire command area of 12 ha was divided into 16 sections for delivering water directly into farmer's field which are away from canal outlet. 8 sections are left side of the middle bund and 8 sections are right side of the middle bund. Eight outlets were proposed in the underground pipeline system. The outlets deliver water to a diversion box of 45 × 45 × 45 cm. Two outlets of 200 mm diameter were proposed in each diversion box, one for right side fields and other for left side fields. 200 mm diameter pipe will be fixed in the diversion of suitable length extended outside of box which should be closed by end plugs when water is not required. The diameter of all outlets *i.e.*, from underground pipeline to surface diversion boxes and diversion boxes to the each side field will be same and equal to 200 mm due to reason that full flow will be diverted into any of the section. The distance between two outlets is selected as 80 m. In this study optimal crop plan is proposed which covers all crops such as cereals, pulses, oilseed and vegetable. In the existing pattern total profit from same crop (paddy) in two seasons was ₹ 8,20,944/-.

REFERENCES

Bhalagea, P., Jadiab, B.B. and Sangale, S.T. 2015. Case studies of innovative irrigation management techniques. *International Conference on Water Resources, Coastal and Ocean Engineering. Aquatic Procedia*, 4: 1197-1202.

Barr, D.I.H. 1981. Solutions of the colebrook-white function for resistance to uniform turbulent flow. *Proc. of the Institution of Civil Engineers*, 71(2):529-535.

Campbell, D.E. 1984. Pipe distribution systems in groundwater development. *Agric. Administration*, 16: 209-227.

Gadekar, R.G., Kute, S. and Sathe, N.J. 2015. Optimal utilization of irrigation water: a case study on Nashik left bank canal. *Indian J. Appl. Res.*, 5(1): 15-17.

Kolhe, P.S. 2012. Optimal utilization of irrigation water by use of pipe distribution network (PDN) instead of canal distribution network (CDN) in command area. *India Water Week*, New Delhi.

Kumar, A., Dhyani, B.L., Bankey, B., Mandal, D., Singh, C., Desai, S., Sharma S.K. and Garg, S. 2017. Design and development of gravity flow water conveyance system for irrigation in Himalayan foothills. *Indian J. Soil Cons.*, 45(1): 40-44.

Liou, C.P. 1998. Limitations and proper use of Hazen-Williams equations. *J. Hydra. Eng.*, 124(9):951-954.

Mahto, S. 2013. Present status of water use efficiency on irrigation projects in India and action taken for its improvement including role of role of farmers. *Training program on increasing water use efficiency (WUE) in irrigation sector. NWA, Pune*, 21 January – 1 February 2013, pp 09-19.

Panigrahi, B., Panda, S.N. and Raghuwanshi, N.S. 2001. Potato yield and water-use-efficiency under furrow irrigation. *Irrig. Sci.*, 20(4): 155-163.

Panigrahi, B., Sharma, S.D. and Behera, B.P. 1992. Irrigation water requirement models of some major crops. *Water Resour. Manag.*, 6(1): 69-77.

Satpute, M.M., Khandve, P.V. and Gulhane, M.L. 2015. Pipe distribution network for irrigation – an alternative to flow irrigation, Section VII: Environmental Sciences, *Proc. 99th Indian Science Congress, Part-II:* Abstracts of Poster Presentation, pp 72-81.

Yousef, A. and Faisel, Z. 2007. Improving conveyance and distribution efficiency through conversion of an open channel lateral canal to a low pressure pipeline at Al-Hassa irrigation project, Saudi Arabia. *Arabian J. Sci. Engg.*, 32(1): 77-86.