International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
IJISAE
ISSN:2147-6799 www.ijisae.org Original Research Paper

Design and Analysis of Optimal Piped Irrigation Network using CROPWAT, EPANET and Genetic Algorithm

Pooja Somani[1], Shrikant Charhate[2], Avinash Garudkar[3]

Submitted: 10/03/2024 **Revised**: 25/04/2024 **Accepted**: 02/05/2024

Abstract: Conventionally irrigation water is supplied to the command area through open canals. However, these open channels are subjected to high conveyance losses like evaporation, seepage, and percolation. To reduce these losses Piped Irrigation Network (PIN) is the feasible alternative to Canal Distribution Network (CDN) in the command area. PIN reduces conveyance losses substantially and thereby improves water use efficiency. In this paper, an attempt has been made to design a cost-effective PIN with micro irrigation using CROPWAT, EPANET, and Genetic Algorithm for the Pawale irrigation project, Thane, Maharashtra, India. Environmental Protection Agency Network Evaluation Tool (EPANET) is used to analyze the system, with the required minimum pressure head at demand nodes and velocity as a constraint. Discharge requirement at each demand node is calculated by using CROPWAT. The total cost of the network is the summation of the cost of all pipes in the network. The network with minimum cost is selected with the help of a Genetic Algorithm for the design. It is observed that coupling of CROPWAT model with the EPANET model and optimizing it with GA has the potential to maximize PIN in heterogeneous command areas. This study has indicated that the PIN cost with this approach is approximately 20% less than the conventional design cost.

Keywords: *CROPWAT, EPANET, Genetic Algorithm, Pawale Irrigation Project, Piped Irrigation Network.*

1. Introduction

Conventionally water is delivered to command areas from dams through the Canal Distribution Network (CDN), but it is inherently linked to losses due to evaporation, seepage, and percolation, resulting in reduction in irrigated area. By incorporating highly effective lining and an efficient canal design, it is possible to achieve an efficiency of up to 70% [1]. In comparison, the overall project efficiency for sprinkler irrigation stands at 47.25%, while for drip irrigation, it reaches 56.7% [2]. The implementation of optimally designed and executed piped irrigation network emerges as a viable alternative to the canal network, leading to substantial reduction in conveyance losses (Water Resource Department, 2017) [3]. Piped irrigation networks are essential for efficiently delivering water to agricultural fields through a network of pipes [4]. Unlike traditional surface irrigation methods, piped networks offer better control over water distribution, reducing water wastage and optimizing resource use. Piped systems ensure precise delivery of water to crops, leading to improved water use efficiency and crop yield [5-7]. It is observed that the overall project efficiency obtained using the Piped Irrigation Network (PIN) with sprinkler irrigation is 68% and with drip irrigation is 81.23% (World Bank, 2019) [8]. This indicates that at least 20% more efficient use of water could be achieved using a piped irrigation network compared the piped irrigation network with the conventional gravity irrigation network and concluded that the overall efficiency of the project increased by 13% with PIN [9]. The saved water could be used for irrigating additional land in the command area. In Piped Irrigation Network water is supplied under pressure to the irrigable command area at required pressure and velocity. Unlike open channels, pressurized pipes also facilitate the conveyance of water against normal slopes in the case of hills or ridges. Providing water on non-uniform slopes is also possible in the case of PIN [10-12]. Since crops may be grown on the fields above the pipes, buried pipe provides the most direct path from the water source to the fields. The use of a pumped irrigation system in the form of buried pipes, rather than open channels may significantly increase the irrigation command area [13]. Unlike CDN, the command area to be irrigated and the source of supply in terms of elevation and slope does not regulate the planning and layout of PIN [14]. The extent of seepage losses can be very high in CDN, as even in a small conventional earthen canal (200m) the conveyance efficiency was just 75.07 % mainly due to seepage losses [15]. This reduces the overall project efficiency to 41 to 48 % for open canals, whereas overall project efficiency in most of the irrigation projects is only 20 to 35 %, due to various constraints and operational reasons, making the need for PIN imperative used the Steiner idea to reduce the

[1]*Research Scholar Amity School of Engineering and Technology Amity University Maharashtra, India*
poojadsomani@gmail.com
ORCID ID: https://orcid.org/0000-0003-2083-5235
[2]*Professor Amity School of Engineering and Technology Amity University Maharashtra, India*
scharhate@mum.amity.edu
ORCID ID: 0000-0001-7052-2777
[3]*Professor. Faculty of Engineering, Water and Land Management Institute, Auranagabad, India*
as_garudkar@rediffmail.com

length of pipes, thus resulting in a reduction in the overall cost of PIN [16-22]. As velocity is more in PIN than open channel, transit time is less resulting in lower conveyance losses [23]. Therefore, the delivery of the water is more flexible in terms of duration and frequency of irrigation, as compared to CDN. The PIN coupled with the Micro Irrigation System (MIS) further improves the efficiency. Depending on the crop type, piped irrigation network may be used more effectively in combination with micro irrigation such as sprinklers or drippers [24]. The importance of micro irrigation for optimal water productivity is needed [25]. Optimizing piped irrigation networks is crucial for ensuring efficient water use, minimizing operational costs, and maximizing crop productivity [26]. Various models are available for the calculation of crop water requirements. CROPWAT, by the Food and Agriculture Organization (FAO), is widely used for the calculation of crop water requirements. It considers various factors such as climate, soil, and crop characteristics to estimate the irrigation needs of different crops [27-28]. CROPWAT has been used by many researchers for various objectives such as for computation of crop water requirements of major crops in various agro-ecological zones of the Palakkad district of Kerala and compared the same with available water resources of the district [29]. Researcher emphasized the necessity and efficacy of the CROPWAT model determining crop water requirement required for effective irrigation management [30]. Various computer software is available for pipe network design for urban water supply and PIN. EPANET is used in the design of the water distribution system. It is open-source software used for analysis of Irrigation networks, apart from its original framework different researchers have developed extensions for the tool to calculate leakage pressure, volume-driven demand, and nodal outflows which simulate future problems conveniently [31-34]. The data set used in EPANET includes elevation at nodes, roughness of pipe, and diameters of pipe. This leads to output in terms of pressure at every node, velocity, and head loss in each pipe. The basic assumptions used in EPANET about flow analysis are namely: Incompressible flow, turbulent flow, closed pipe e.g. contaminant injections are modelled as mass/time and full pipe. For constant reservoir levels/tank levels, and water needs, EPANET's hydraulic simulation model estimates junction heads and link flows over a period. Heads and flows at a given time may be calculated by solving the flow conservation equation at each junction and then the head loss relationship at each link in the network. Nonlinear equations must be solved using an iterative method known as hydraulically balancing of the network. To do this, EPANET uses the Gradient Algorithm. PIN was designed for the Left Bank Canal of Pench Irrigation Project at the distributary level using EPANET 2.0 for pipe diameter and compared to critical route approach and optimization using linear programming in India. EPANET is also used for the determination of the efficiency of pumps used in irrigation networks depending on their variable speed. Pressure is a key element in the irrigation network, a sufficient supply of water depends on good pressure as pressure deficiency can reduce the supply area of the whole network. The role of topography in irrigation is studied which shows how the distribution gets affected by changing topography. To understand the operation of the drip irrigation system EPANET software is highly efficient. The allocation of water according to the irrigation need is necessary for crop development while designing the irrigation network productivity and equity in the allocation process is important. EPANET, coupled with Genetic Algorithms, can be employed to optimize the layout, pipe sizing, and operational schedules of the piped irrigation network. Genetic Algorithms excel in handling the complex, non-linear nature of optimization problems. Genetic algorithms provide a powerful tool for tackling the optimization challenges inherent in irrigation networks. Various steps involved in GA are initialization, selection, crossover, mutation, and fitness function in the form of evaluation. By iteratively applying the steps of selection, crossover, and mutation, genetic algorithms can effectively explore the vast solution space of irrigation networks, finding near-optimal or optimal designs that balance system performance and cost. Piped irrigation networks often involve conflicting objectives, such as minimizing energy consumption, reducing conveyance losses, and maximizing water use efficiency. Genetic Algorithms have been successfully applied in multi-objective optimization studies to find Pareto-optimal solutions.

The present study provides an integrated approach by sequentially applying the CROPWAT model, which is used to calculate crop water requirements and then simulated by EPANET and Genetic Algorithms to optimize the piped irrigation network based on the crop water requirement. By minimizing water losses and ensuring efficient water delivery, piped irrigation networks contribute significantly to saving water. The input diameters of commercially available pipes are considered to meet the pressure and velocity requirements of the system. The cost of each possible network is calculated and the cheapest one is selected as the best one to be used in the design. The total cost of the network is the sum of the costs associated with each pipe.

2. Materials and Methods

2.1 Study Area

The developed methodology is applied to the Pawale Irrigation Project, in the Thane district of Maharashtra. This is a new irrigation project in which a dam is constructed, but considering the shortage of water and losses in the canal network, it is proposed to design a PIN considering a micro irrigation system, to save water. Salient features of the Pawale Minor Irrigation (MI) Project are presented in Table 1

Table 1. Salient Features of Pawale Irrigation Project

Description	Details	
Name of project	Pawale Minor Irrigation project	
Catchment area	2.087 Sqkm	
Average annual rainfall	246.08 cm	
Gross storage capacity	3167.48 Tcum	
Dead storage of project	44.463 Tcum	
Canal	LBC	RBC
Length of the canal	5.04 km	2.88 km
Discharge carrying capacity	0.173 cumecs	0.31 cumecs
Area under (irrigable) Command	90 ha	162.0 ha
Gross Command Area	424 ha	
Culturable command area	339 ha	
Irrigable command area	252 ha	
Cropping pattern	Kharif and Rabi	
Kharif	65 %	
Paddy	40 %	
Pulses	10 %	
Vegetables	15 %	
Rabi	100 %	
Paddy	30 %	
Groundnut	15 %	
Vegetable	20 %	
Pulses	25 %	
Milk production grass	10 %	

3. Methodology

The layout of PIN on the Pawale Irrigation Project consists of a rising main from the source, three direct minors, and various direct laterals on the main line of the project as shown in Fig. 1.

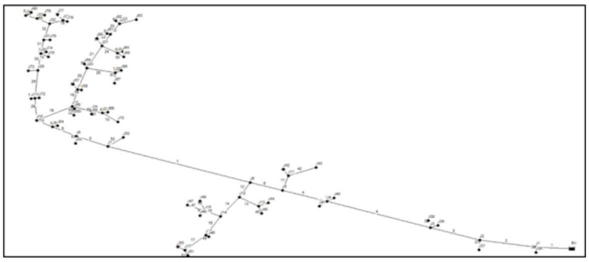

Fig. 1. The Network Layout of Pawale Irrigation Project

The network consists of 80 pipes with 80 nodes inclusive of 46 outlet nodes and one reservoir. The main line has 10 junctions and 11 outlets. Minor 1 has 6 junctions and 8 outlets, similarly, minor 2 has 10 junctions and 16 outlets and minor 3 has 8 junctions with 10 outlets.

3.1 CROPWAT 8.0 Model

The FAO has developed a decision-supporting computer application model CROPWAT 8.0. for calculating the Crop water requirement of irrigation projects. This model utilizes crop, soil, rainfall, and meteorological data for calculations of Reference Evapotranspiration (ETo), Crop Evapotranspiration (ETc), Net Irrigation Water Requirement (NIWR), Gross Irrigation Water Requirement (GIWR), and irrigation schedule using a various formula. The net irrigation water requirement for the crops is also calculated. For this purpose, climatic (maximum and minimum temperature, radiation, wind velocity, humidity, and sunshine hours) and rainfall data are obtained from the concerned authorities and analyzed. The CROPWAT 8.0 model requires crop soil and weather data viz. cropping pattern, soil types, and weather parameters including rainfall. Crop water requirement is calculated for eight major crops namely groundnut, pulses, small vegetables (Rabi and Kharif), pasture perennial, Pulses, and Rice (Rabi and Kharif) grown in the area. Region-specific appropriate dates for planting and harvesting are considered. Crop data like plant growth stage, lengths, and rooting depth is obtained from the Water Resource Department of the Government of Maharashtra, the Water Resources Department in Thane, and the Water and Land Management Institute Maharashtra in Aurangabad. The crop coefficients (Kc) for the early, middle, and late stages according to the season are considered for the study. The other input parameters were maximum and minimum temperatures (℃), relative humidity (%), wind velocity (km/hr.), sunshine hours, and rainfall were considered for 20-20-year periods.

3.2 EPANET Model

EPANET 2.0 was used to construct the pipe networks for main pipeline and three minors along with laterals on the main pipe and minors of the Pawale irrigation project. In EPANET there is the option of pipe status which means that if intermittent valves are not considered in pipe, then pipe status is kept open, else it is called closed or partially closed. For this study, as there are no intermittent valves considered, hence the pipe status is considered as open. The Input parameters of EPANET 2.0 are the elevation of the node, demand at outlet nodes, length of the pipe, and diameter of the pipe. Hazen Willaims equation is used for the calculation of head loss. Also, the pipe material is selected as PVC and/or HDPE and its roughness coefficient is considered accordingly. The PVC pipes are used for pipe sizes of 63 mm diameter to 140 mm diameter (with a roughness coefficient value of 150) and HDPE pipes are used for sizes having diameters greater than 140 mm (with a roughness value of 140) to reduce the total cost of network

3.3 Genetic Algorithm Model

Optimizing a piped irrigation network using a Genetic Algorithm (GA) involves finding the optimal diameter satisfying all constraints with minimum cost. GA provides an efficient and flexible approach to solving complex optimization problems in the domain of irrigation management. In GA initial population of potential diameter for the irrigation network is generated. The fitness of each configuration by calculating the cost function, by considering the total cost of pipe is assessed. Selection is to extract a subset of genes from an existing population mainly based on fitness value. In the present study, the Tournament selection operator is used. This selection has better or equivalent convergence and computational time properties as compared to any other reproduction operator. Similarly, the blend crossover and random mutation operator, as available in the MATLAB toolkit is used in this study. The termination criteria used in this study was number of the generations where there is no improvement in solution by 10 % in fitness function value over ten consecutive iterations, or two generations whichever is earlier. The objective function involves the summation of the total pipe cost corresponding to the predefined diameters. The constraints used are maintaining minimum pressure requirements at each node, pipe velocity constraints, apart from satisfying continuity at the nodes, and energy balance in a loop. By iteratively applying the Genetic Algorithm, the system evolves towards a set of irrigation network configurations that offer a balance between cost-effectiveness and irrigation efficiency. These configurations can then be evaluated and compared. The flowchart showing various operations for optimal cost design of piped irrigation network is shown in Fig 2.

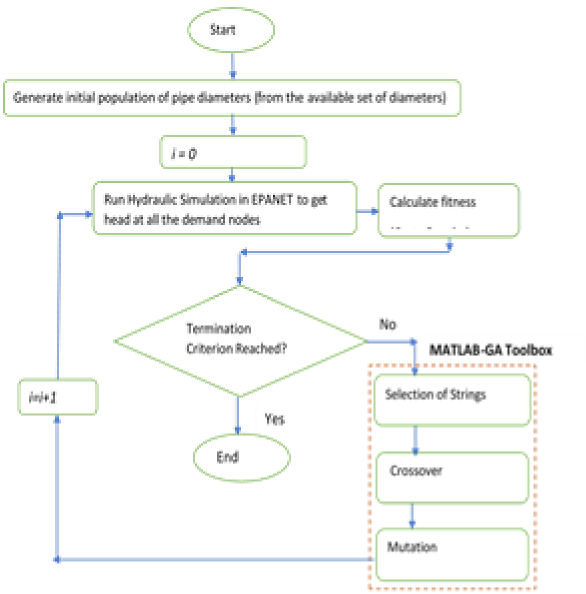

Fig 2. Flowchart showing various operations for optimal cost design of piped irrigation network

4. Results and Discussions

Required discharge considering physiographic and climatic aspects at each outlet node is calculated by the CROPWAT model. As discussed in an earlier section, to begin with, the initial set of pipes that are available in the market are considered. Only those networks fulfilling minimum pressure head criteria of 0.6 m for surface irrigation and 20 m to 40 m for micro irrigation at the outlet node and also a range of velocity in the pipeline between 0.6 m/s to 3 m/s as per Central Water Commission (CWC), Government of India, guidelines were selected as the feasible set of pipes for the network. The cost of each feasible network was worked out and the network having minimum cost is proposed as an optimal network for design. It is observed that the max pipe diameter is 560 mm and the minimum pipe diameter is 63 mm in the network. A total of sixteen types of pipe diameters are considered in the network. The whole pipe network for the command area is divided into four sections, viz. Pipe main, Minor 1, Minor 2, and Minor 3. Pipe Main has 10 intermediate junctions and 11 outlets which are connected by 21 pipes. The Intermediate junctions are represented by J and the outlet Junctions are represented by O. The input data (for nodes and junctions) like Elevation head (ground level) and water demand at every outlet node is represented in Fig. 3. It also shows obtained head at each node. Fig. 4 represents the diameter of various pipes and the corresponding velocity in all pipes of the pipe main.

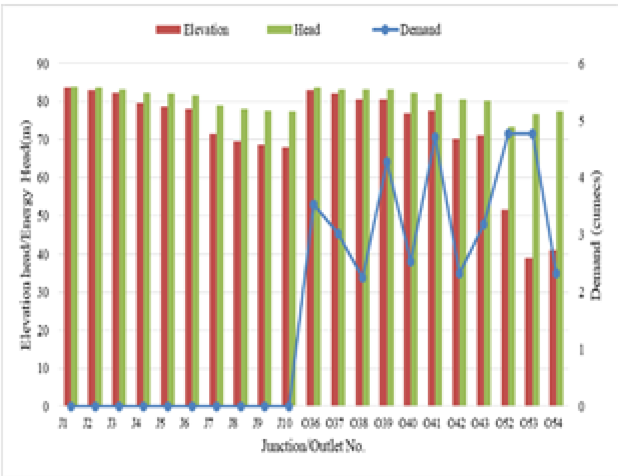

Figure 3 Elevation Head/ Energy Head and Demand Variation at nodes of Main Pipe

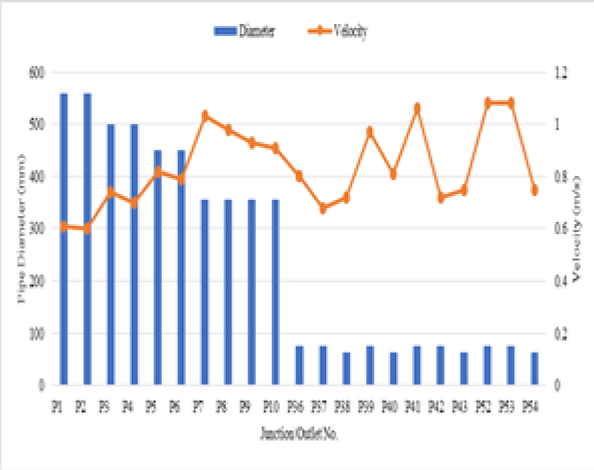

Figure 4: Pipe Diameter and Velocity Variation in all pipes of Main Pipeline

Minor 1 has 6 intermediate junctions and 8 outlet nodes connected by 14 pipes. Fig. 5 represents the elevation head (ground level) at all nodes and demand of water at all outlet nodes. It also shows the energy head available at all nodes of Minor 1. Fig. 6 represents diameters of all pies of Minor 1 and associated velocities.

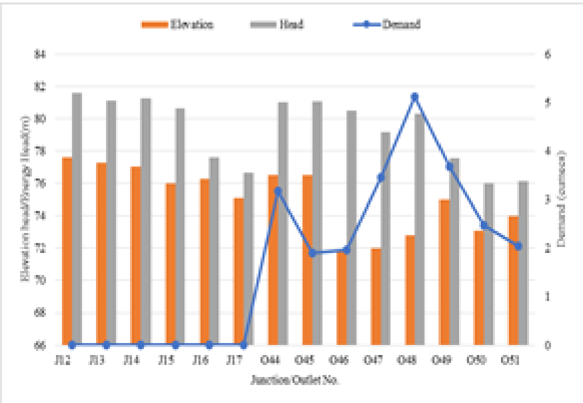

Figure 5: Elevation Head/ Demand Head and Demand Variation at nodes of Minor 1

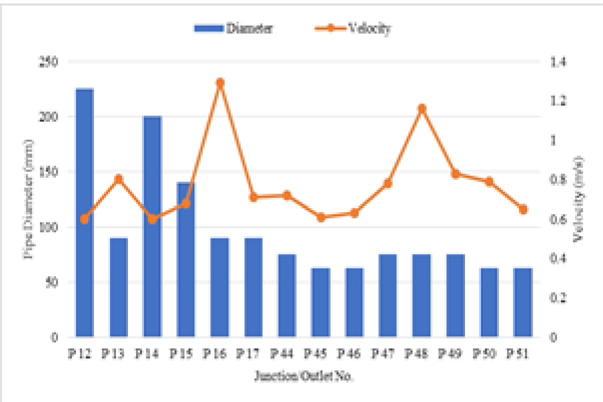

Figure 6: Pipe Diameter and Velocity Variation in all pipes of Minor 1

Minor 2 is the longest minor of the network, having 10 intermediate junctions and 16 outlet nodes connected by 26 pipes. Fig. 7 represents the elevation head (ground level) at all nodes and demand of water at all outlet nodes. It also shows the energy head obtained at all nodes of Minor 2. Fig. 8 represents diameters of all pies of Minor 2 and associated velocities.

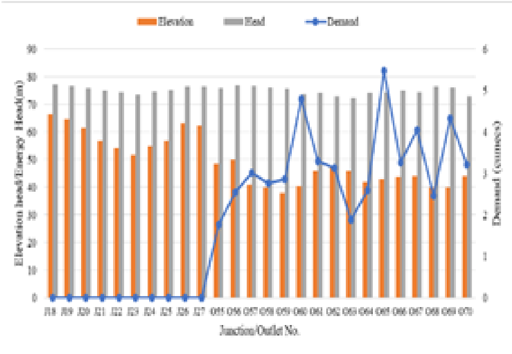

Figure 7: Elevation Head/ Demand Head and Demand Variation at nodes of Minor 2

Minor 3 has 8 intermediate junctions and 10 outlet nodes connected by 18 pipes. Fig. 9 represents the elevation head (ground level) at all nodes and demand of water at all outlet nodes. It also shows the energy head obtained at all nodes of Minor 3. Fig. 10 represents diameters of all pies of Minor 3 and associated velocities.

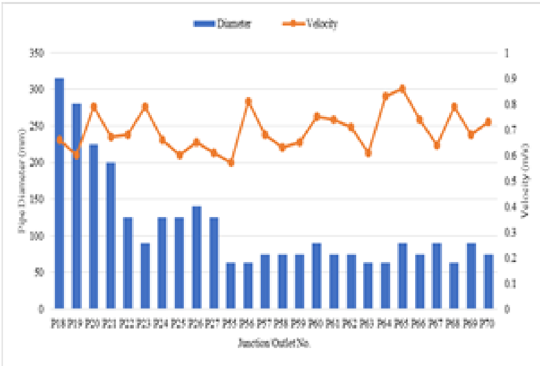

Figure 8: Pipe Diameter and Velocity Variation in all pipes of Minor 2

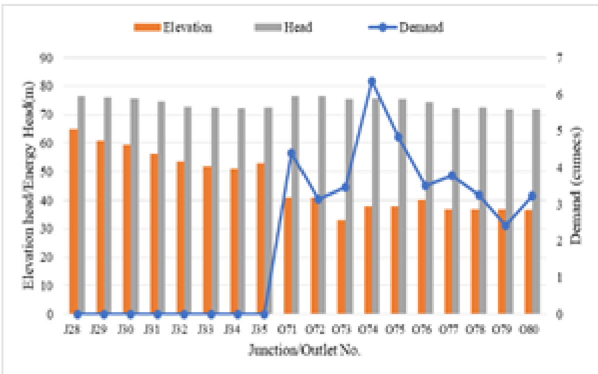

Figure 9: Elevation Head/ Demand Head and Demand Variation at nodes of Minor 3

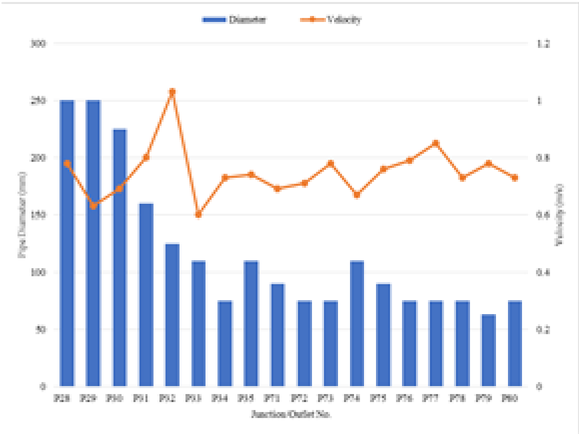

Figure 10: Pipe Diameter and Velocity Variation in all pipes of Minor 3

The variation of pressure head with respect to outlet node is presented in Figure 11. In the initial section of the command area (i.e. near the reservoir,) soil type is suitable for cereals like jawar, bajra. Hence these types of crops are taken in this area. So pressure requirement at the initial section is low, hence minimum pressure of 0.6 m is considered for this area. The pressure head at the outlet node in the results indicate that, outlet pressure varies from 0.71m to 10.33 m for outlet node 36 to 51, near the reservoir. Also, there is lesser difference between the elevation in the vicinity of the reservoir and main source of supply of water. This pressure difference is sufficient for flow irrigation. However, in the area having outlet no 52 to 80, soil type is better than the initial area. Vegetable and fruit trees are proposed in this area with micro irrigation, hence it is ensured to have minimum pressure of 20 m in this area, and results indicate that variation of pressure head is substantial from outlet node 52 to 80. This is also associated with the steep slope in these areas. This leads to pressure variation of 21.89 m to 38.52 m for all other remaining outlets, which is sufficient for micro irrigation in this area. It is observed that available pressure is increasing for the nodes which are away from reservoir, as the slope for the terrain is falling, going away from reservoir.

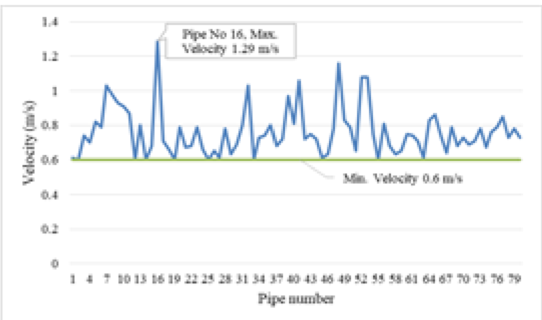

Figure 11. Variations in Pressure Head at Piped Irrigation Network Outlet Nodes

Government of India, Central Water Commission New Delhi has recommended that variation in the velocity of Piped irrigation network should be between 0.6 and 3 m/s hence fulfilment of this criteria is ensured in the study (Water Resource Department, 2017). It has been observed that velocity in all the pipes in the network ranges between 0.6 m/s to 1.29 m/s. It was 0.6 m/s for pipe no 55 to 1.29 m/s for pipe no 16. Variation in the velocities in all the pipes in the Piped Irrigation Network is shown in Fig. 12.

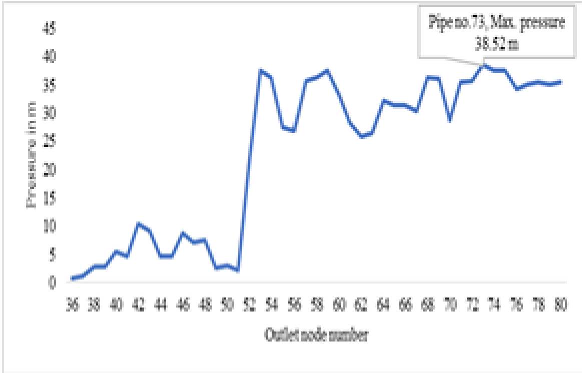

Figure 12. Variations of Velocities in the Pipe Network

3.1 Estimation of Cost for the Designed Network

The initial investment cost of PIN is more, as compared to CDN. However, economic feasibility of PIN is justified by considering the cost of land acquisition and more conveyance losses in CDN. The cost for the pipes for the optimum set of diameters is calculated and given in Table 2. The details of cost estimates by considering common schedule of rates of Maharashtra Jeevan Pradhikaran (CSR-MJP 2021-22), Government of Maharashtra, India are given in Table 2 (Maharashtra, 2021-22). The optimal cost of the network was found to be INR 26592930. This amount indicates approximately 19.75% reduction in the cost of pipe as compared to the cost of pipes with the conventional method.

Table 2: Cost of Optimal Design Network

Diameter (mm)	**Total Length (m)**	**Rate /meter (INR)**	**Cost (INR)**
560	750	7723	5792250
500	1437	6170	8866290
450	520	4990	2594800
355	1803	2891	5212473
315	246	2281	561126
280	271	1801	488071
250	669	1438	962022
225	506	1169	591514
200	662	908	601096
160	309	615	190035
140	376	314	118064
125	768	259	198912

110	145	189	27405
90	1206	138	166428
75	1843	96	176928
63	674	69	46506
Total Cost			26593920

5. Conclusion

In this study, the GA toolbox in MATLAB is linked for the optimization of PIN with EPANET as an evolution function that satisfies minimum pressure and required velocity constraints for finding out the optimum diameter of the pipe with minimum cost. The study demonstrates that this is the most flexible and practical decision-support system approach to obtain multiple feasible solutions. As it is established that conveyance losses are substantially reduced in PIN, the efficiency of the irrigation network can be enhanced by PIN coupled with micro-irrigation. In properly executed PIN, though the net irrigation requirement remains the same, irrigation water demand is reduced due to improvement in water use efficiency. Coupling the CROPWAT model with the EPANET model has potential to optimize irrigation networks for micro irrigation systems considering the entire command area which is complex and heterogeneous. The following conclusions can be drawn from the present study The irrigation system's efficiency is substantially improved with a pipe irrigation system coupled with micro-irrigation. The cost of an irrigation system can be significantly reduced as a nearly 20% reduction is observed in the cost of pipes using this model. In properly executed PIN, though the net irrigation requirement remains the same, irrigation water demand is reduced due to improvement in water use efficiency. Coupling the CROPWAT model with the EPANET model has potential to optimize irrigation networks for micro irrigation systems considering the entire command area which is complex and heterogeneous.

Acknowledgment

The authors are thankful to Pawale Irrigation project authorities at Shahapur, Thane, Maharashtra, (India) and Hydrology department, Nashik, Maharashtra, (India) for providing required data.

Author contributions

Pooja Somani: Conceptualization, experimentation, Methodology, Original draft preparation. **Shrikant Charhate:** Supervision, Editing of the manuscript **Avinash Garudkar:** Supervision, Editing of the manuscript.

Conflicts of interest

The authors declare no conflicts of interest.

References

[1] Arora, S., & Jaiswal, A. (2013). Optimal Cost of Irrigation Network using EPANET. International Journal of Computer Application, 68, 41-45. DOI:10.5120/11707-7404

[2] Bentum, R., Smout, I., & Ci, X. (1995). Use of pipelines to improve surface irrigation in Hebei province, China. Journal of Irrigation and Drainage Engineering, 121(6), 405-410. DOI:10.1016/S0378-3774(98)00089-4

[3] Water Resource Department. (2017). Guidelines for Pipe Distribution Network. Government of Maharashtra.

[4] Burt, C., Clemmens, A., Strelkoff, T., Solomon, K., & Bliesner, R. (1997). WAter Managemnet and Conservation in Irrigated Agriculture. CRC Press.

[5] David, E., Goldberg, & Kalyanmoy, D. (1991). A comparative analysis of selection schemes used in Denetic Algorithms. Foundations of Genetic Algorithm, 69-931. DOI: 10.1016/B978-0-08-050684-5.50008-2

[6] Devendra, R. (2019). Challenges in planning, design and implementation of pipe irrigation network at command level. International Commission on Irrigation and Drainage (ICID). New Delhi.

[7] Elbeltagi, A. (2020). Modeling monthly crop coefficents of maize based on limited meterological data; A case study in Nile Delta, Egypt. Computers and Electronics in Agriculture, 173. DOI: 10.1016/j.compag.2020.105368

[8] World Bank. (2019). Helping India Manage its Complex WaterResources.https://www.worldbank.org/en/news/feature/2019/03/22/helping-india-manage-its-complex-water-resources. Retrieved from www.worldbank.org /en/news/ feature/ 2019/03 / 22 / helping-india-manage-its-complex-water-resources

[9] Ewaid, S., Abed, S., & Al Ansari, N. (2019). Crop water requirements and irrigation schedules for some major crops in southern Iraq. Water 2019, 11. DOI:10.3390/w11040756

[10] Gajgate, P., & Mirajkar, A. (2019). Irrigation pipe network planning at Tertiary level: An Indian case study. KSCE Journal of Civil Engineering, 322-335.DOI:10.1007/s12205-020-0272-2

[11] Gajgate, P., Mirajkar, A., Shaikh, U., Bokde, N., & Yaseen, Z. (2021). Optimisation of layout and pipe sizes for Irrigation Pipe Distribution Network using Steiner Point Concept. Hinawi Mathematical Problems in Engineering, 2021. DOI: 10.1155/2021/6657459

[12] Giudicianni C., e. (2018). Topological Taxonomy of Irrigation Networks. Water, 10(4). DOI:10.3390/w10040444

[13] Gong, X., Zhang, H., & Ren, C. (2020). Optimisation allocation of irrigation water resources based on crop

water considering effective precipitation and uncertainity. Agricultural Water Management, 239, 106264. DOI: 10.1016/j.agwat.2020.106264

[14] Gorantiwar, S., & Smout, I. (2006). Performance based optimisation of land and water resources within irrigation schemes I: Method. Journal of Irrigation and Drainage Engineering, 132(4), 1-36. DOI:10.1061/(ASCE)0733-9437(2006)132:4(332)

[15] Halagalimath, S., Vijaykumar, S., & Patil, S. (2016). Hydraulic modelling of water supply network using EPANET. International Research Journal of Engineering and Technology, 3(3), 1022-1027.

[16] Jiao L., e. a. (2011). A multi objective genetic algorithm for optimal design of water distribution networks. Water Resources Management, 25(5), 1269-1287.

[17] Jun, L., & Guoping, Y. (2013). Iterative methodology of pressure dependent demand based on EPANET for pressure-deficient irrigation analysis. Journal of Water Resources Planning and Management, 139(1), 34-44. DOI:10.1061/(ASCE)WR.1943-5452.000022

[18] Maharashtra, J. (2021-22). Schedule of rates. Government of Maharashtra, India.

[19] Mehanuddin, H., Nikhitha, G., Prapthishree, K., Parveen, L., & Manasa, H. (2018). Study on water requirement of selected crops and irrigation scheduling using CROPWAT 8.0. International Journal of Innovative Research in Science, Engineering and Technology, 7(4), 3431-3436. DOI:10.15680/IJIRSET.2018.0704032

[20] Muranho, J. e. (2014). Technical Performance Evaluation of Water Distribution Network based on EPANET. Proceedia Engineering, 70, 1201-1210. DOI: 10.1016/j.proeng.2014.02.133

[21] Patil, S., Talegaonkar, S., & Nimbalkar, P. (2018, July). Hydraulic design of Pipe Distribution Network for Irrigation Project. International Journal of Civil Engineering & Technology (IJCIET), 9(7), 1109-1116.

[22] Saber, M., Mokhtar, M., Bakheit, A., Elfeky, A., Gameh, M., Mostafa, A., . . . Hamada, A. (2022). An integrated assessment approach for fossil groundwater quality and crop water requirements in the El-Kharga Oasis, Wetern Desert, Kgypt. Journal of Hydrology: Regional Studies, 40, 101016. DOI: 10.1016/j.ejrh.2022.101016

[23] Satpute, M., Khandve, P., & Gulhane , M. (2012). Pipe distribution network for irrigation- an alternative to flow irrigation., January 3-7, pp. 106-114.

[24] Savic, D., & Walters, G. (1997). Genetic Algorithns for least cost design of water distribution networks. Journal of Water Resources Planning and Management, 123(2), 67-77. DOI :10.1061 /(ASCE) 0733-9496 (1997)123:2(67)

[25] Sayyed M.a.H.A, e. a. (2014). Modelling Pressure Deficient Irrigation Networks in EPANET. Procedia Engineering, 89, 626-631. DOI: 10.1016/j.proeng.2014.11.487

[26] Sharu, E., & Ab Razak, M. (2020). Hydraulic Performance and Modelling of Pressurised Drip Irrigation System. Water, 12. DOI:10.3390/ w12082295

[27] Singh, R., & Sahoo, R. (2013). Drip Irrigation-A tool for water productivity in agriculture: A review. Agricultural Reviews, 34(3), 210-217.

[28] Sivanappan, R. (1994). Prospects of Micro Irrigation in India. Irrigation and Drainage Systems, 8, 49-58. DOI:10.1007/BF00880798

[29] Srivastava, R., Mohanty, S., Singandhuppe, R., Mohanty, R., Behera, M., & Ray, L. (2010). Feasibility evaluation of pressurized irrigation in canal commands. Water Resource Management, 3017-3032. DOI:10.1007/s11269-010-9592-1

[30] Surendran, U., Sushanth, C., Mammen, G., & Joseph, E. (2015). Modelling the crop water requiremnet using FAO-CROPWAT and assessment of water resources for sustainable watre resources management: A case study in Palakkad district of humid tropical, Kerala, India. Aquatic Procedia, 4, 1211-1219. DOI: 10.1016/j.aqpro.2015.02.154.

[31] Abdelouahid Fouial, Juan Antonio Rodríguez Díaz. (2021). An Integrated Decision Support System for the Planning, Analysis, Management and Rehabilitation of Pressurised Irrigation Distribution Systems. Modelling 2021, 2(2), 308-326; doi.org/10.3390/modelling2020016.

[32] Preeti Walmik Gajghate , Ashwini Mirajkar, Uzma Shaikh, Neeraj Dhanraj Bokde, Zaher Mundher Yaseen (2021). Optimization of Layout and Pipe Sizes for Irrigation Pipe Distribution Network Using Steiner Point Concept. DOI. 10.1155/2021/6657459.

[33] Uchit Sangroula, Kuk-Heon Han, Kang-Min Koo, Kapil Gnawali, Kyung-Taek Yum. (2022). Optimization ofWater Distribution Networks Using Genetic Algorithm Based SOP–WDN Program. Water 14, 851. DOI.10.3390/w14060851.