DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR THE DESIGN OF IRRIGATION MAIN

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Abstract

A web-based application has been developed to optimize the design of main pipe in a pressurized irrigation system, with several submains connected to it and operating simultaneously. The software uses routine procedures generally adopted in drip main design and advancements in software development methodologies to optimize the design of drip irrigation mains. The software features an easy-to-use interface which makes it easy for non-technical users to navigate the software and create main designs without needing extensive training or expertise. The design report can be downloaded in the user-required format. Additionally, the software has the capability to visually depict pressure head distribution curves, required pressure head, and ground profile in a more usable and intuitive way for designers. Pre-processing of input data for the web application is minimal. The application has undergone several tests using different sample data covering all use cases to ensure its accuracy and reliability. Demonstrations were conducted for designers to assess the effectiveness of the developed web application, and we received favourable feedback from

them. The application can be accessed via the website http://www.dripdesigncheck.in/ or by contacting the corresponding author.

Keywords: Drip irrigation, Main, Python, Energy gradient line,

1. Introduction

Pressurized irrigation systems are becoming increasingly important for modern agriculture due to their ability to conserve water and increase crop yields. These systems use pumps and a network of pipes to deliver water directly to the crops, reducing water wastage and ensuring precise water delivery. Several studies reported that pressurized irrigation systems can provide increased crop yields compared to traditional irrigation systems with improved water use efficiency (Battikhi and Abu-Hammad 1994; FAO 2011; Attia et al. 2019; Nikolaou et al. 2020). This is due to the ability of pressurized systems to deliver water directly to the crop roots, reducing water loss due to evaporation or runoff.

The main pipe in a pressurized irrigation system serves as the backbone of the system, delivering water from the source to the submain. Its design is critical in ensuring that water is delivered efficiently and sufficiently to the entire field. A properly designed main pipe can help to minimize pressure losses, reduce the need for additional pumps and ensure even water distribution throughout the field (Kooij et al. 2013; Sidhu et al. 2021). All of these factors can lead to a more efficient and cost-effective irrigation system (Carrion et al. 2013). If the main pipe is undersized, it can lead to excessive pressure losses, resulting in reduced water flow to the emitters or sprinkler heads. This may cause uneven water distribution in the field, leading to areas that are overwatered or underwatered. In addition, an undersized main pipe may require additional pumps to maintain adequate pressure, leading to increased energy costs and maintenance requirements (Keller and Bliesner 1990; Ame and Shouhua 2022).

The advancements in main pipe design have helped improve the efficiency and effectiveness of these systems. Therefore, designing the main pipes properly for drip and sprinkler irrigation systems is very important, as this can result in significant cost savings (El-Hazek 2016). Conventionally the main pipe size is selected based on the maximum flow rate required to meet the crop water demand over the entire field to be irrigated. Standard tables, which account for the flow rate, were used to achieve this. But this methodology is not economically viable because it does not consider the actual conditions in the field (Ravikumar 2022).

By designing the main pipe based on actual field conditions and taking into account factors such as water supply and demand, pipe sizing, pressure requirements, and friction losses, it is possible to optimize the irrigation system for maximum efficiency and cost-effectiveness. For example, Wu and Gitlin (1974) developed a methodology called the 'Minimal Capital Method' based on the energy gradient line, which is a widely used methodology for designing drip irrigation systems (Wu 1975; Anyoji and Wu 1994; Chamba et al. 2019; Saldarriaga et al. 2020). This methodology was developed from the principle of the total energy gradient line and is designed to maintain a single or segmented total energy gradient line from the control head or pump to the outlet to yield a near-minimum cost solution for designing an irrigation system (Ravikumar 2022). Even though this methodology was developed during the early 1970s, it is still widely followed today due to its accuracy in optimizing drip main design (Ravikumar 2022).

While the minimal capital method is appropriate for determining the necessary pipe size, manually drawing segmented straight lines and solving equations can be a tiresome and lengthy process, particularly for complex and large systems. With the help of software, designers can automate many of the calculations involved in designing the main pipe, making the process faster, more accurate, and less prone to errors. The software can also account for variations in flow rates, pipe lengths, and friction losses, which can be challenging to calculate manually (Pedras et al. 2009; Carrion et al. 2013; Palau et al. 2018; Patel et al. 2018). In addition to improving accuracy and reducing errors, web-based software can offer added benefits. It can be accessed from anywhere with an internet connection, making it easier for designers to work on their projects from different locations or devices.

There are various programming languages that can be used to develop such software, including Java, C++, MATLAB, Python, etc. Python, in particular, is a popular choice for developing simulation and design software due to its ease of use, flexibility, and rich set of libraries and tools. For example, designers can use the NumPy library in Python to perform numerical calculations, the Pandas library for data analysis, and Matplotlib/Plotly library for data visualization. Additionally, Python provides a simple and intuitive syntax that makes it easy to read and write code, which can save time and reduce errors in the design process (Johansson 2018).

In light of the above discussions, it is understood that developing a decision support system for designing the main pipe of pressurized irrigation systems can be highly beneficial for engineers and designers. Therefore, this paper presents a web-based decision-support system aimed at designing irrigation mains using Python. Furthermore, a sample use case is tested with the developed decision support system.

2. Methodology

The minimal capital method was adopted to design irrigation mains with multiple pipe segments, as it is a widely used method by irrigation engineers (Wu and Gitlin 1974; Ravikumar 2022).

2.1 The steps involved in the design of the main using the minimal capital method are:

1. Determine the available water supply: The first step is to determine the available water supply for the drip irrigation system. This can be done by measuring the flow rate and pressure head of the water source, such as a well or a pump.
2. Measure the distance from the pump/control head to each submain inlet location and the elevation difference. The ground profile on which the main pipe is laid must be plotted, as shown in Fig. 1 (Choose the proper scale for drawing).
3. Mark the pressure head available at the control head/pump (say y) on the vertical axis corresponding to x=0 (i.e., (0, y)).
4. To design a drip main, it is important to determine the pressure head required at each submain location along the main pipe (For example, A, B, C and D in Fig. 1). This can be done by drawing a vertical line from each submain location along the main pipe to a height corresponding to the pressure head required at that submain start. The pressure head available at the control head should always be greater than the pressure heads needed at each submain inlet location.
5. Drawing energy gradient line: After determining the pressure head at each submain location, the energy gradient line can be drawn by joining the point corresponding to the pressure head required at the last submain to the point representing the pressure head available at the control head (h). If all intermediary submain points lie below this line, it can be proposed as the energy gradient line. However, if any intermediary points are above this line, the energy gradient line can be segmented by connecting the control head point to the point with the highest ordinate value, and then to the last ordinate value (Fig. 1).

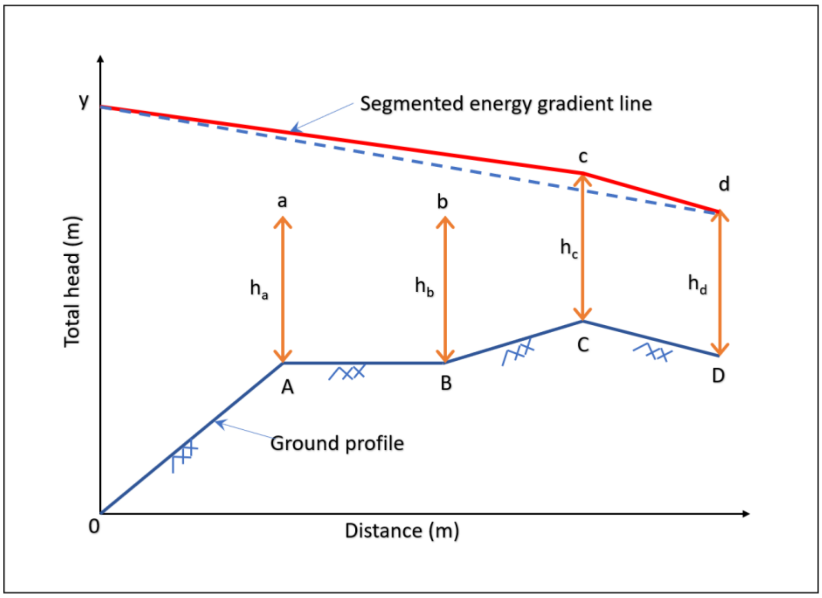

Fig. 1 Segmented energy gradient line

6. The slope of the proposed energy gradient line: Total head difference between the two edge points ($\Delta h, m$) of the segment divided by the physical length (L, m) of the segments gives the slope of that particular segment (i.e., Δh/L).
7. Calculate the discharge rate: The discharge rate should be carefully determined. Each pipeline segment is connected to the next segment, forming a continuous conduit. Therefore, each pipe segment should also carry the discharges to the succeeding segments. The pipe segments till the first submain location from the control head/pump should carry discharges equal to the sum of all the individual discharges of the submain.
8. Determining the diameter of the pipe (D): The diameter of each segment is computed using the Darcy-Weisbach equation (Eq. 1) using slope values and discharge rate values obtained in steps 6 and 7, respectively.

$$\frac{\Delta h}{L} = \frac{789000 \times q^{1.75}}{D^{4.75}} \qquad (1)$$

Where q is in l/s and D will be obtained in mm. From the computed diameter, the user can select the nearest higher diameter available in the market as any pipe with our interest is not available in the market.

9. Water hammer management: Water hammer management is an important consideration in designing the pipeline system. To prevent water hammer, it is necessary to ensure that the velocity of each segment is within safe limits. The velocity is calculated using the discharge rate and the diameter of the pipeline segment. The velocity in main pipes should be kept below 1.5 m/s to minimize the risk of water hammer (Ravikumar 2022). If the calculated velocity is greater than 1.5 m/s, the diameter of the pipeline segment is adjusted to bring the velocity within the safe range.

2.2 Development of Web Application for Main Design:

Based on the above-said procedure, the web application was developed for designing the main pipes for irrigation systems, especially for pressurized irrigation. The Python programming language was used for the back-end development as it is straightforward, powerful, and contains many built-in libraries. In addition, the Bootstrap framework, HTML, and JavaScript were also used to develop simple, responsive, and user-friendly user interfaces. Furthermore, a powerful jQuery plugin called *DataTables* was used for creating table listings and adding interactions to them. Finally, the *Plotly* library was used for the data visualization. The powerful flask-RESTful API technology was used to integrate the back end with User Interfaces since future updating will be easier with such APIs. The steps involved in the development of the application are summarized in Fig. 2.

Input validation: Input validation is an important aspect of software development as it helps ensure that the user input is correct, complete, and consistent. One way to provide feedback to the user when they have not entered proper values/texts is by displaying warning/error messages. In this study, the input validation was implemented using JavaScript.

Testing the application: The developed web application was tested with different test data since it is an important part of the software development process to ensure that the application is working as expected and can handle different types of input.

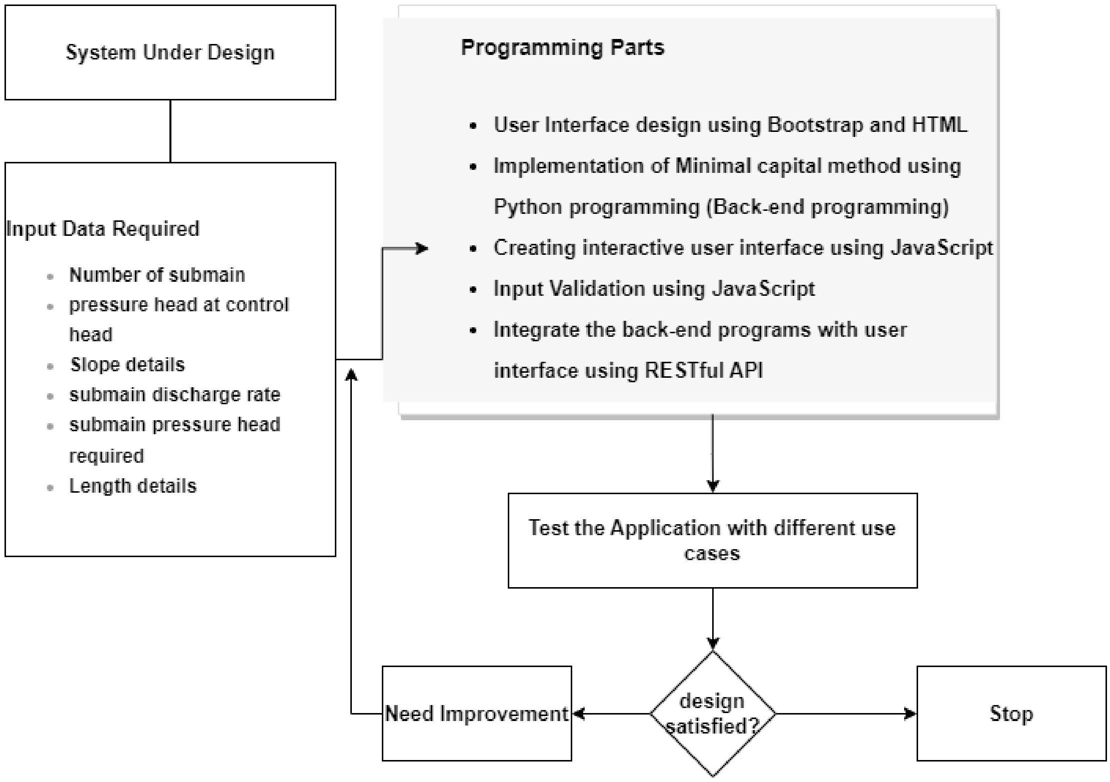

Fig. 2 Process flow involved in the development of web application

3. Results and Discussion

3.1 Features of the developed web-application

The developed web application is very simple, user-friendly, and has an attractive user interface where users can enter the required data needed for the design. The features of the developed web applications are:

Input data: In the first level, the user must enter the details corresponding to the number of submains connected to the particular main, which will be designed, also the pressure head at the inlet of the main pipe. Once the user enters the number of submain values, a table will be popped up, which contains the rows to enter the details regarding each submain. The user must provide details regarding the submain position, which is the distance on the mainline where the submain starts, measured from the previous submain location. For the first submain segment, the distance is measured from the control head. The user must also provide slope details, the discharge rate required for each submain, and the pressure head required at each submain inlet. The developed user interface is shown in Fig. 3.

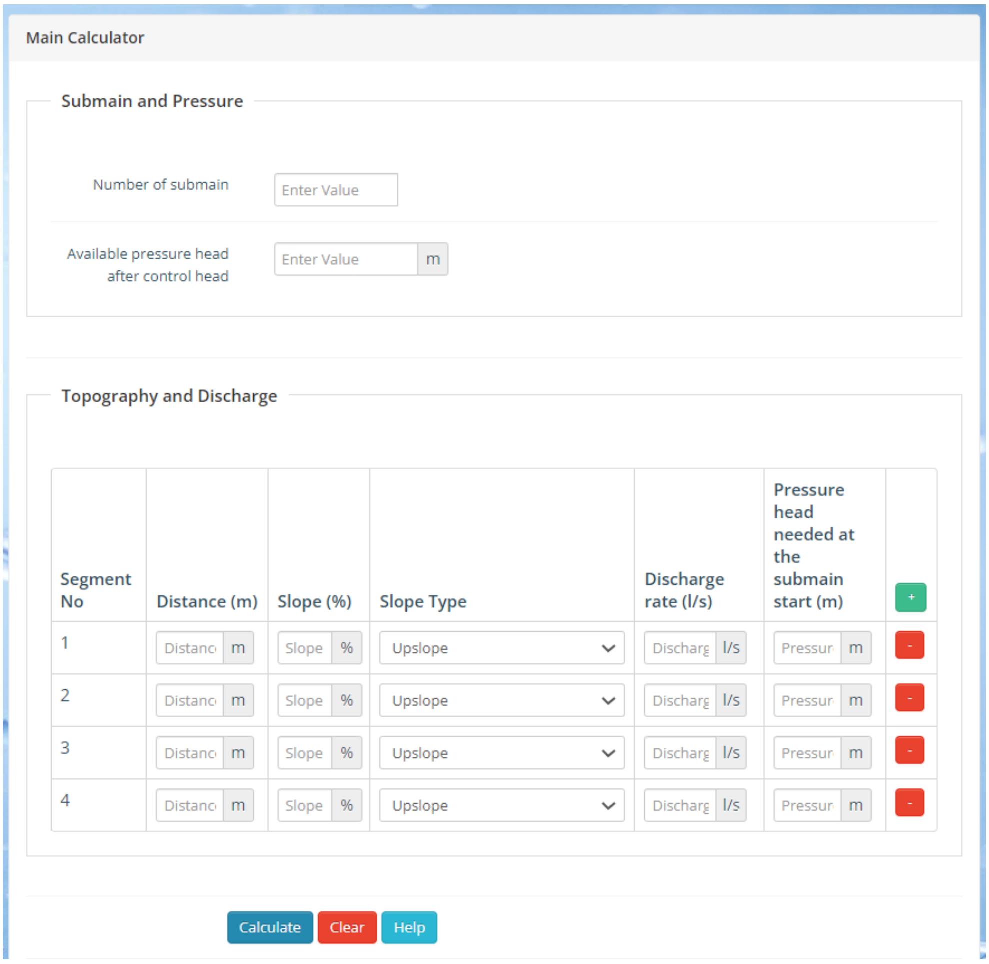

Fig. 3 User interface of the developed web application

Output details: Once the *calculate* button is pressed, the screen will display the summarized results as a table. The results contain the designed diameter of the individual segments and the pressure head available at each submain starts. In addition, the results would also contain the details regarding the individual main segment, which includes discharge rate and cumulative length measured from the main pipe inlet/or control head. Since the diameter of any size is not available in the market, it is recommended to use the nearest higher diameter available. The results will also provide the flow velocity in the pipe. The provision was also given to export the result table into .xlsx, .csv, or .pdf formats so the user can save the designed output for future use.

Data Visualization: Data visualization is the graphical representation of data and information. It involves creating visual displays such as charts, graphs, maps, and diagrams to communicate complex data in a way that is easy to understand and interpret. In this study, the developed web application is capable of visually representing the ground profile, the pressure head required at each submain inlet, and also the pressure head available at each location with the designed diameter. In addition, the provision for saving (to .png format), zooming out, zooming in, and hovering the graphical results obtained were also given.

Software Testing: The design problem from Ravikumar (2022, pp. 363-364) was solved using the developed web application. The input data as per the design problem was entered in the user interface, as shown in Fig. 4. The main pipe was designed for which the four individual submains to it are to be operated simultaneously.

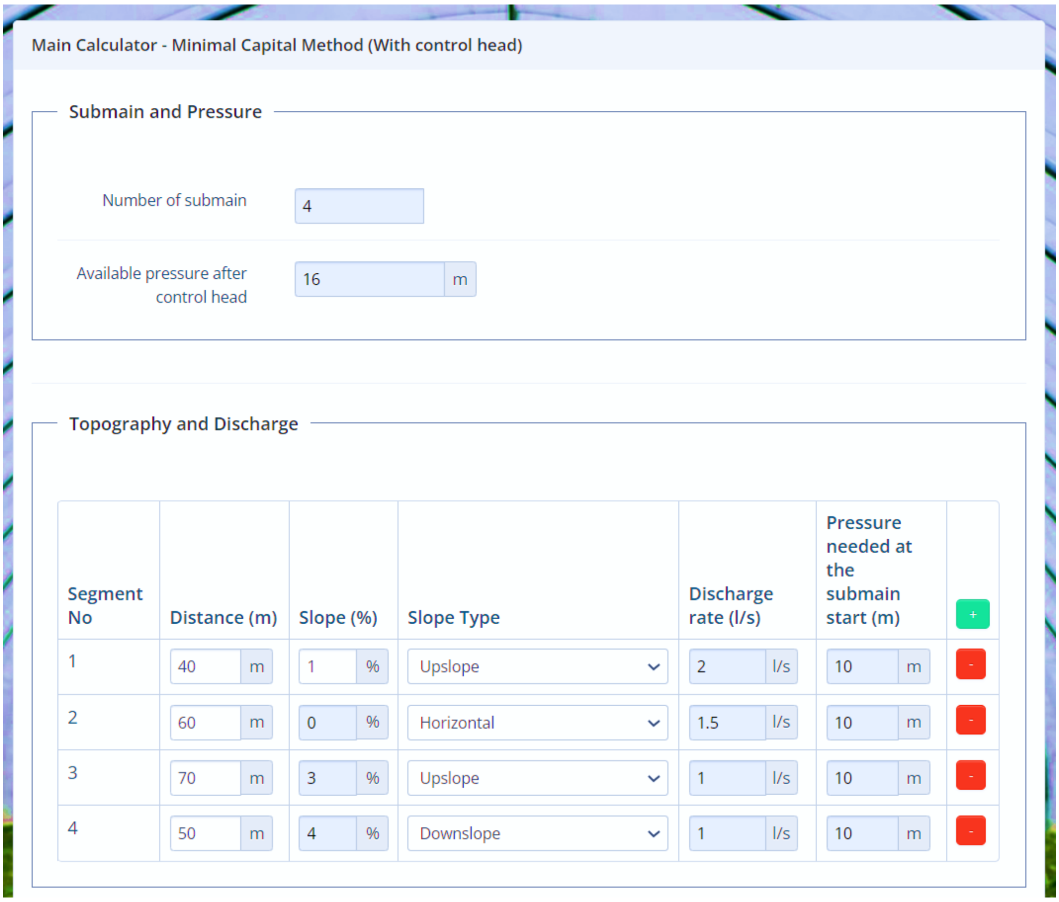

Fig. 4 user interface for entering input data

Solution: The solution to the design problem was obtained using the developed software. The software recommended four segments with different diameters, which allowed the system to achieve the required pressure head at each submain inlet. The result table obtained from the application is shown in Fig. 5, which includes the suggested diameters and their respective lengths, flow velocity, and the pressure head available in the main when using the recommended diameters.

Results

Excel CSV PDF Search:

Segment No	Distance (m)	Discharge Rate (l/s)	Cum length (m)	Design Diameter (mm)	Velocity (m/s)	Ordinate of pressure head available (m)
1	40	5.5	40	74	1.28	15.18
2	60	3.5	100	62.7	1.13	13.94
3	70	2	170	51	0.98	12.5
4	50	1	220	34.3	1.08	10.5

Showing 1 to 4 of 4 entries Previous 1 Next

Fig. 5 Tabular representation of result in developed web application

According to the findings, the pressure head at the inlets of each submain was greater than the required pressure head. As a result, the proposed design meets the requirements of all submains and can be approved. The visual representation of the designed problem is shown in Fig. 6, which will help the user to identify the pattern that may be difficult to discern from raw data or textual descriptions.

The application was tested with a set of test data that covers a range of scenarios, including valid and invalid input and ensured that the application works properly as proposed.

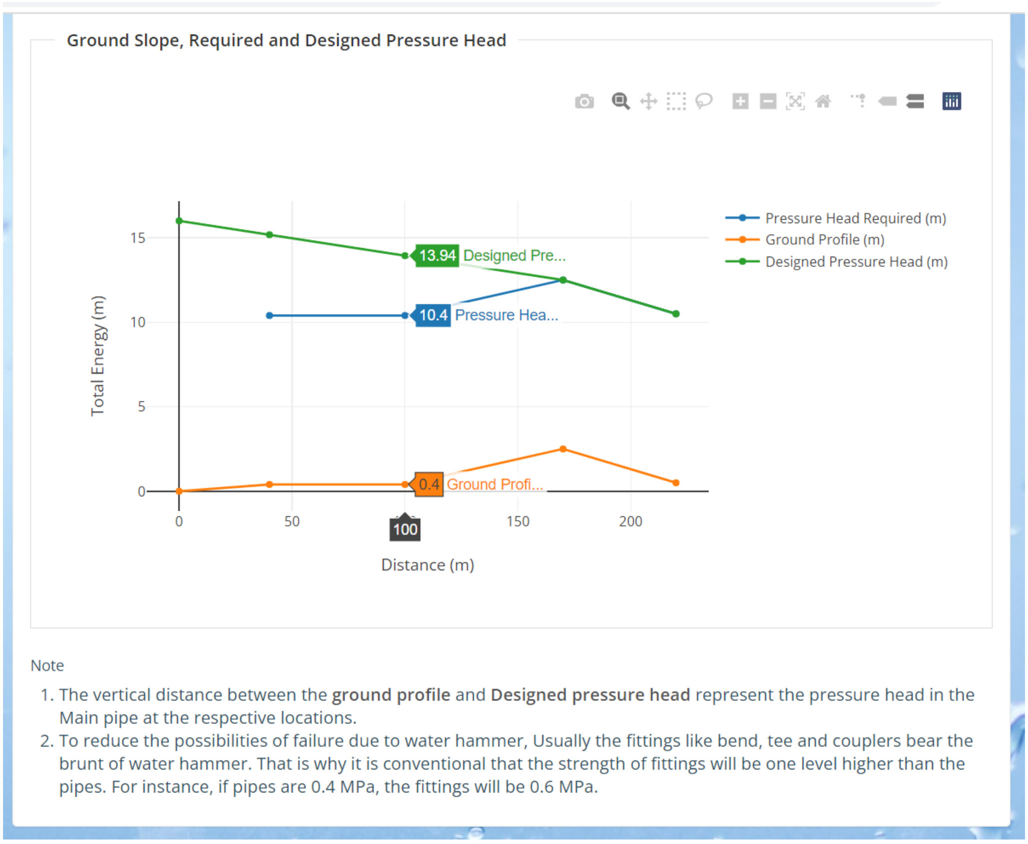

Fig. 6 Visual representation of a designed problem

The newly developed irrigation main design software is available for use on the website http://www.dripdesigncheck.in/. This software offers several benefits to users. Firstly, it is capable of producing the desired output within a short time due to its automated features that simplify complex procedures and calculations, such as plotting energy gradient lines and determining slopes, etc., thereby reducing the need for manual effort and time. Moreover, the software is designed with an intuitive user interface that is easy to navigate, even for non-technical users. It is accessible from any device with an internet connection, making it convenient for users to design and modify irrigation main plans from anywhere. Any changes made to the design are updated in real-time since the software is hosted on a server. Additionally, as it is a web-based application, users do not need to purchase or install software on their devices.

There are several software programs available for irrigation main design nowadays, each with its own unique features and benefits. Popular software options include IRRICAD, HydroCalc, Aquaflow, and Irrigation Management Calculator (Narayanan et al. 2002; Sharu et al. 2020; Darwish et al. 2022). IRRICAD, developed by Lincoln Ventures Limited, is a high-end, advanced standalone software that is available for purchase (Lincoln Agritech Limited 2013). It may require some training or experience to use effectively. The vast range of features and tools available in IRRICAD can be overwhelming for new users, but it may take some time to become proficient in its use. Our developed main design software is not advanced as IRRICAD, but it meets user's perceptions regarding drip main design and can be used by non-technical users because of its easy-to-understand user interfaces. Since it is developed based on the Minimal capital method, which provides the optimal solution for mains laid on the uniform slope and near-global optimum solution even for the main with multiple outlets laid on non-uniform slope situations. By using this approach, our software is able to create cost-effective main designs that are still efficient and effective. Another advantage of our software is that it is freely accessible to a wider range of users since it is web-based software. While IRRICAD can be expensive, our software is designed to be affordable and accessible freely to users who may not have the budget for more expensive tools. While our software may not have all the advanced features and capabilities of tools like IRRICAD, it is still a useful and effective option for those seeking an optimal and economic solution for main pipe design.

Other software options are also available for designing main systems, namely HydroCalc, developed by Netafim (Halbac-Cotoara-Zamfir 2009; Mansour and Aljughaiman 2020; Darwish et al., 2022) and AquaFlow developed by Toro (Philipova 2012; TORO 2014). These software programs offer both standalone and web-based options for designing the main system. However, our software is more user-friendly compared to these alternatives.

Unlike HydroCalc and AquaFlow, our software provides the optimal pipe diameter, eliminating the need for users to check different options until they find a satisfactory design. Furthermore, although visualizing outputs such as plotting field slopes and pressure head distributions are important tasks for developers, they can be easier to perform by solving the hydraulic equations discussed in the methodology section of the paper. However, providing graphical representations that are based on the intuition of the user is more necessary, and this is where our developed software stands out from existing softwares like HydroCalc and AquaFlow.

Another application commonly used by the designers is Irrigation Management Calculator (http://irrigation.wsu.edu/Content/Select-Calculators.php) provided by the universities of the Pacific Northwest states of Washington, Idaho, and Oregon. This is a web-based application with a simple user interface, but its design capabilities are comparatively limited. Although it lacks visual representation of the pressure head distribution, it has a useful feature that allows users to input data in any unit. The software then preprocesses the data to match the units required by the hydraulic equations and returns the output to the user in their preferred units.

In our future versions, we plan to incorporate this unit conversion feature in our software as well. Additionally, while our current methodology, the Minimal Capital Method, helps to reduce capital investment, it does not consider the operation cost of the system. To address this, we plan to add a life cycle cost analysis feature in the future, which will incorporate the operation cost and provide a more comprehensive analysis for systems with a higher time of operation.

3.2 Demonstration of the software

Collecting feedback and recommendations from designers can be very valuable in assessing the performance of a software application. To evaluate the performance of our Main design software, we conducted a demonstration for designers involved in irrigation systems design. Following the demonstration, participants were asked to provide feedback on their experience using the software and to make recommendations for improvements. Overall, feedbacks from participants were positive, with many noting that the software was easy to use and developed based on the user's perceptions. Several participants also provided recommendations for improving the software's functionality, by providing unit conversion of inputs used in the design. These recommendations will be taken into consideration in future versions of the software.

4. Conclusion

The web-based application was developed to optimize the design of irrigation mains with a number of submains connected to it and operating simultaneously. This software works based on the minimal capital method. It provides a minimum pipe diameter, which can withstand the pressure head developed in the pipes. The minimum diameter selection also considers the requirement of keeping the flow velocity under 1.5 m/s to minimize the risk of water hammer-related failure. In addition, the software has the capability to visually depict pressure head distribution curves, required pressure head, and ground profile in a more usable and intuitive way for designers. To showcase the capabilities of the developed application, a sample design problem was worked out in the paper, which helps users understand how the software works. Future versions of the application will include the life cycle cost analysis with the consideration of operation cost, and preprocessing of the input data, including unit conversion to enhance the software’s capability and usability. The application can be accessed via the website https://dripcheckdesign.pythonanywhere.com/ or by contacting the corresponding author.

Declarations

Ethical approval: Compliance with Ethical Standards Conflict.

Consent to participate: The authors declare that they are aware and consent with their participation on this paper.

Consent to Publish: The authors declare that they are consent with the publication of this paper.

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Availability of data and material: The data and codes that support this study are available from the corresponding author upon request.

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