DOI: http://doi.org/10.4038/jdza.v8i2.63

Journal of Dry Zone Agriculture, 2022, 8(2): 68 – 82

Optimizing pressurized agriculture pipe network through simulation modeling techniques in home gardening in Vavuniya area of Sri Lanka

M.E. Sutharsan*

**National Water Supply and Drainage Board, Vavuniya, Sri Lanka*

Received on December 05 2022; Accepted on December 26, 2022

Abstract

Home gardening is identified as one of the remedial measures for food security issues caused by the economic downfall in Sri Lanka. Home gardening contributes to household food security by providing direct access to food. Further, it is also an important source of supplementary income for households. The appropriate function of a pressurized agriculture pipe network system is vital to supply sufficient quantity of water to the plants at sufficient pressure through the sprinkler output. Despite this, very few computer simulation techniques studied the optimization for the case of the home gardening agricultural pipe system. In this study, the WaterGEMS V8i software simulator was used and hydraulic analyses were conducted to design an optimal pressurized agriculture pipe network suitable for home gardening in the Vavuniya area. The water flow rate at sprinkler outlet points for chilli and onion were considered 600 L/h and 325 L/h respectively.

Citation:
Sutharsan, M.E (2022). Optimizing Pressurized Agriculture Pipe Network through Simulation Modeling Techniques in Home Gardening in Vavuniya Area of Sri Lanka. *Journal of Dry Zone Agriculture*, *8*(2), 68-82.

*Corresponding author
Postal address: National Water Supply & Drainage Board, Vavuniya, Sri Lanka
Email: edsutharsan@yahoo.com

The total available land area for home gardening was considered as 50 perches in this study. Fifteen models were developed for different combinations of land use for chilli and onion cultivation. The hydraulic parameters such as nodal pressure, flow velocity, flow rate and head requirement were analyzed under steady-state simulation by using the Hazen-Williams friction method. The proposed simulation model was calibrated and validated by using a previous study. The result revealed that all of the nodes in the system are operating above the threshold pressure limit of 2 bars. It was found that a combination of 20% land (10 perches) for onion and 80% land (40 perches) for chilli required the highest power pump capacity of 3.5 kW. The power of the water pump for chilli only and onion only was positively correlated with the cultivated land extent and R^2 values were observed to be 0.9991, and 1.0 for chilli and onion respectively. The flow velocity in all pipes was above the minimum level of 0.5 m/s eliminating silt deposition and below the maximum level of 2.0 m/s avoiding the water hammer issues. The proposed pressurized agriculture pipe network design shall be used for modelling of pipe network for home gardening with different crop types by changing the model input parameters by using the WaterGEMS V8i computer simulator.

Keywords: Home gardening; Optimal design; Sprinkler irrigation; WaterGEMS V8i; Water hammer

Introduction

The Earth's surface is surrounded by water by seventy-one percent, however, approximately only three percent is freshwater. Hence, freshwater is categorized as a limited and vulnerable resource. Water supply to agriculture plays a vital role in the productivity efficiency. The conventional canal system is used to supply water from water sources. However, science is advanced and contributed to inventing the agricultural techniques like lift irrigation, sprinkler, mechanical device, which created rapid developments.

Sri Lanka is primarily an agriculture-based country. Agriculture has contributed to Sri Lanka's GDP by 7.8 per cent in the first quarter of 2021. Home gardening is identified as one of the remedial measures for food security issues caused by the economic downfall in Sri Lanka. Home gardening contributes to access to food and a source income for households.

Gravitational force is used to irrigate the irrigable areas which are topographically situated below the water level. Furthermore, this kind of gravity-based irrigation is a convenient method for the reason that it requires less workforce and low cost. But in the case of a region which is located above the water level, gravitational force cannot be used to carry water to that region or land. Lift irrigation is the solely way to supply water to such regions under irrigation. In lift irrigation, pumps are utilized to lift water from the neighboring water source and followed by distribution to the crop (Shiyekar & Patil, 2017)

A pressurized agriculture pipe network shall be hydraulically analyzed through computerized simulation techniques and simulated for the different scenarios to optimize the pipe diameters and pump capacity. The appropriate function of a pressurized agriculture pipe network system is vital to supply sufficient quantity to crops, gardens, vegetables, etc.at sufficient pressure in the sprinkler output. Hence, the principles of designing such a pressurized system need to be well understood.

The present study aims to model, simulate, and design an optimized pressurized agriculture pipe network system by maintaining adequate flow and pressure head at sprinkler outlet for home gardening suitable for the Vavuniya area of Sri Lanka.

Study area

The area for modelling of optimized pressurized agriculture pipe network suitable for home gardening is the Vavuniya area in the Northern part of Sri Lanka as shown in Figure 1(a). As per the "land use plan" in the Vavuniya district (Ministry of Lands, 2016), the land extent of 12,841.6 ha is identified as an underutilized home gardens area as shown by yellow patches in Figure 1 (b). One of the major reasons is inadequate technical know-how and poor water management.

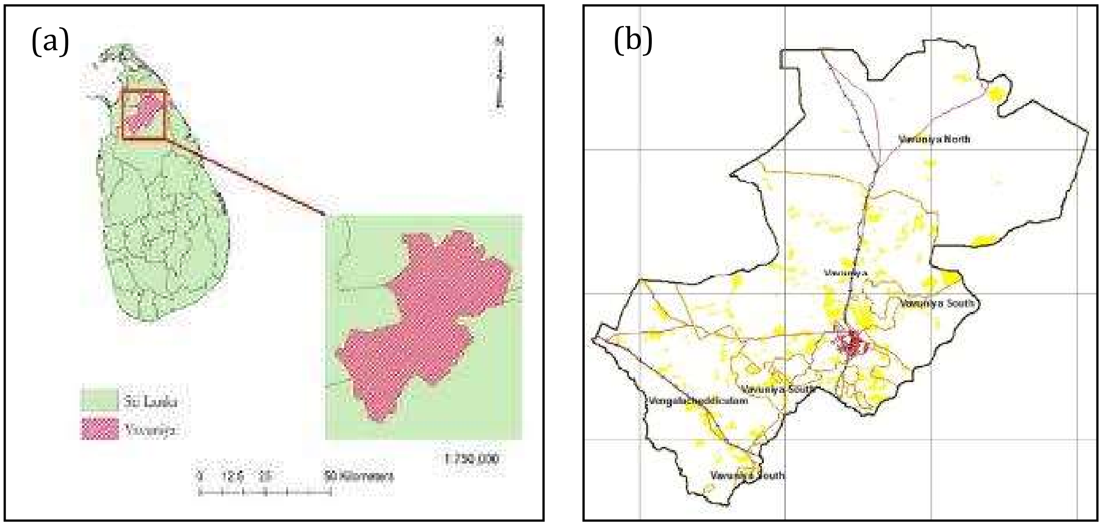

Figure 1: Study area (a); Area with high proportion of underutilized home gardens in Vavuniya(b)

Pressurized agriculture pipe network system

A pressurized pipe network system is a combination of pipes, valves, fittings, water meters, pumps or elevated water tanks, which are analyzed, designed, optimized and installed. A properly designed and installed pressurized agriculture pipe network system can reduce the frequency of maintenance, inspection, and rehabilitation during the operation of the network system. Therefore, analysis and design of the system shall adversely affect the efficiency of any agriculture. A study was done in sprinkler irrigation system in Iraq and revealed the ability of applying these models on other regions other Iraq governorates (Al-adili & Kraidi, 2015). A program namely; EPANET was used to model the pressurized drip irrigation system to understand how the piped irrigation system operated (Sharu & Razak, 2020).

Need for home gardening

The country's economic situation and COVID-19 pandemic brought significant impacts on the society and the threat to immediate food security are on top of the list. Home gardening is identified as one of the remedial measures for this situation. The interest of the society in home gardening has drastically increased especially midst of the pandemic. On the other hand, improper water management for home gardening shall contribute to t increase the domestic per capita water usage in the country.

The district development plan for 2018-2022 of Vavuniya district indicates the annual target of land extent for cultivating the cash crops such as chilli and onion as plotted in Figure 2, by taking the baseline cultivated area as 300 ha and 66 ha for chilli and onion respectively (District Secretariat, 2017).

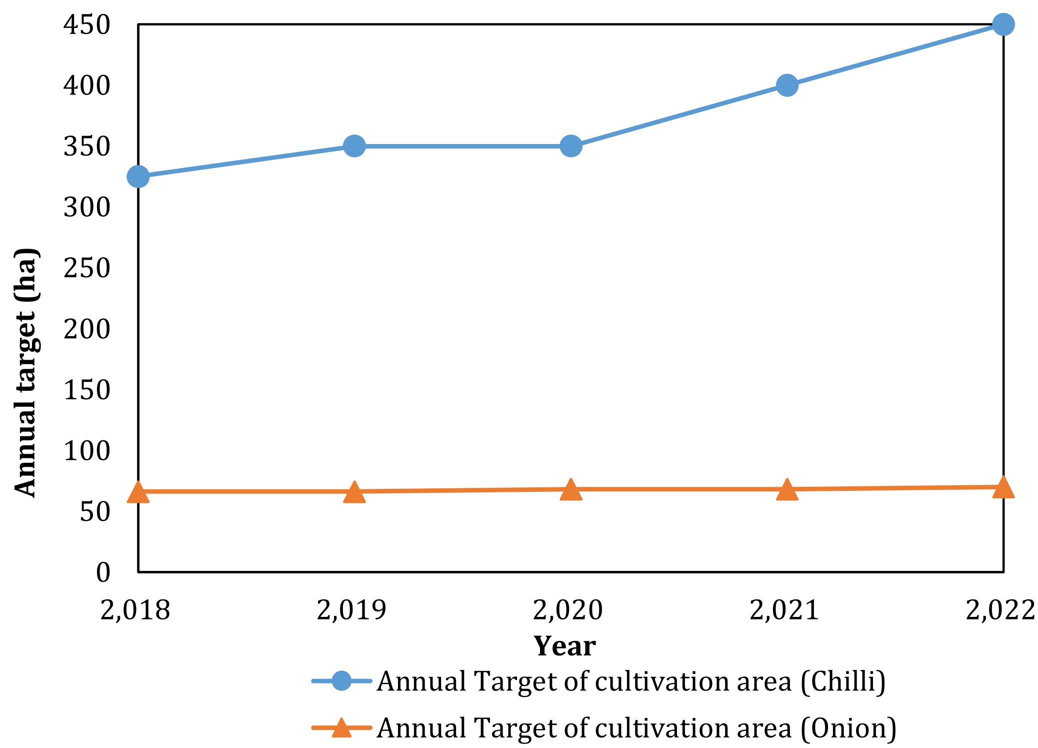

Figure 2: Annual targets of cultivating land extent for chilli and onion in Vavuniya

Need for pipe network design and optimization

Water is one of the most vulnerable and finite resources on earth. Water plays a vital role in the economic development of any nation, fulfilling the human's basic needs, agriculture developments, etc. Climate change is worsening water scarcity, which is a nationwide, within the nation, seasonally-related issue. Hence, using water sparingly for agricultural purposes is inevitable in the current context.

Saving water has become a critical problem particularly when a huge amount of water is being used for the activities such as irrigation and agriculture. Home gardening is a water-consuming process which consumes a considerably higher amount of water than water required for other human activities at the household level. Plants and crops absorb a definite amount of water and the balance supplied water may be wasted via seepage, runoff, evaporations and any other means. Therefore, the supply of water to the crops especially in home gardening is to be dealt with additional care to ensure springy water usage. Properly designed and optimized pressurized agriculture pipe network system for home gardening shall not only supply an adequate quantity of water to the crops and reduce the capital investment cost but also curtail unnecessary wastage of water, by doing so, additional cultivable command area or irrigable area shall be irrigated which will generate additional income to the household and will contribute to achieving the self-sufficiency on food in the country.

Materials and methods

Methods of model preparation and analysis

The peak water flow rate at sprinkler outlet points for cash crops such as chilli and onion was taken into consideration as 600l/h and 325 l/h respectively as per the drip and sprinkler irrigation manual of the Department of Agriculture. The rotary type sprinkler, which is capable to cater the water requirement of the land extent of 5m x 5m, was used in the model. The total available land for home gardening considered in this study was 50 perches, 15 nos of models developed for a different combination of land use for chilli and onion cultivation. Ten models of pipe networks were created for different land used areas as 10, 20, 30 40 and 50 perches for the cultivation of chilli and onion crops each (each crop has 05 models). Balance 05 models were developed for the land use pattern of combination of chilli and onion crop (Onion 0% and Chilli 100%; Onion 20% and Chilli 80%; Onion 40% and Chilli 60%; Onion 60% and Chilli 40%; Onion 80% and Chilli 20%; and Onion 100% and Chilli 0%).

WaterGEMS V8i Simulator

A user-friendly interface to analyze, design and optimize WDN is provided by WaterGEMS V8i software. There are a few important attributes namely hydraulic analysis, water quality analysis, extended period simulation, and steady state simulation. Simplified model building, water quality modelling, fire flow analysis, optimization and scenario management are some benefits of WaterGEMS V8i over other software (Sonaje & Joshi, 2015). Further, it is recorded that, application of using the HydroCalc program can be also used to choose the appropriate design for the irrigation system (Darwish et al., 2022)

Pipe network modeling procedure

The computer simulator software namely WaterGEMS v8i was used for analysis and design. The following steps were carried out to create the computer model of the pipe network using WaterGEMS simulator.

Step 01 – Input data

The input required data for analysis is the first step in any hydraulic analysis programme especially in WaterGEMS. The input data are categorized into four types namely pump data, tank data, junction data and pipe data. However, the tank data part is not included in the methodology, since the system is fed by pumping system

The most important data such as pump number, capacity (kW), base elevation (m), and pump flow rate (l/s) were input under tank input data. Pipe diameter (mm), pipe material, pipe number, dimensionless roughness coefficient, pipe length (m) and minor losses were assigned as pipe data. Under junction data, the important data such as junction number, elevation (m), junction demand (l/s), and demand pattern were assigned.

Step 02 –Network simulation

This is a vital part of the hydraulic analysis in WaterGEMS software. The model was checked for errors after creating the model and input data through a process called the "validate" option. Then the model was simulated with a hydraulic run after inputting all the required data as shown in Figure 3. Nodal pressure (m), flow velocity (m/s), pipe head loss (m) and head loss gradient (m/km) were computed by the software which is vital for decision-making during hydraulic analysis. As per Bentley (2013), waterGEMS V8i programme has a reliable design algorithm to produce precise network design since the WDN parameters namely junction pressure, velocity and water flow along with their optimization are controlled by the programme.

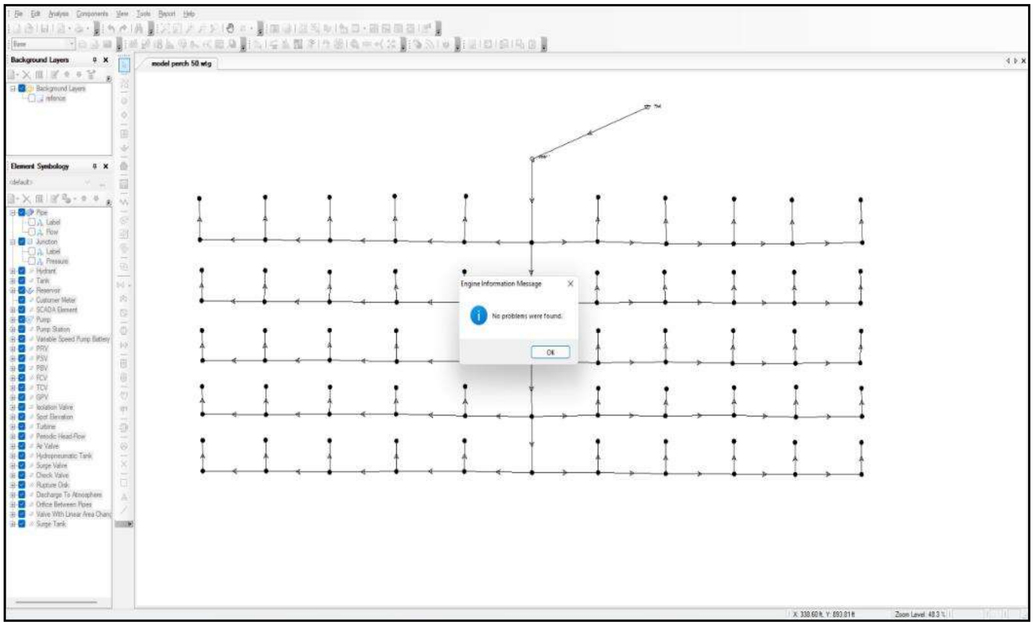

Figure 3: Model validation process

Step 03 –Hydraulic run

The hydraulic run was performed as shown in Figure 4 and the required hydraulic output parameters were extracted from the report section of the software. The important output parameters such as pressure at every junction and the flow velocity in every pipe were checked to have them within the acceptable range.

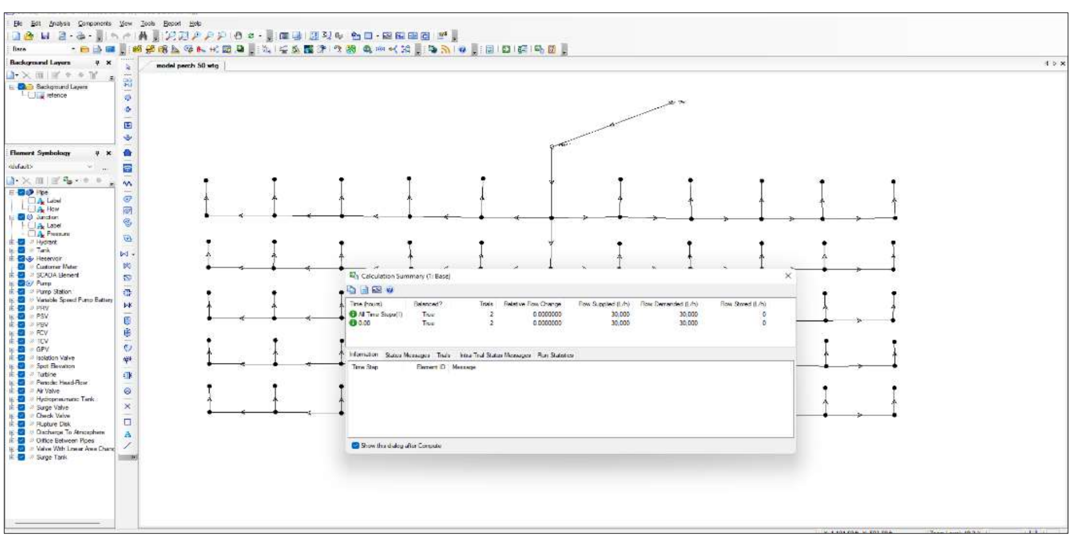

Figure 4: Hydraulic run

Step 04 – Finalization of network configuration

The model was simulated repetitively for several trials by adjusting the data until a satisfactory water network configuration is reached. The network model was created with the relevant elements such as pipes, nodes, bends, valves, and pumps as illustrated in Figure 5.

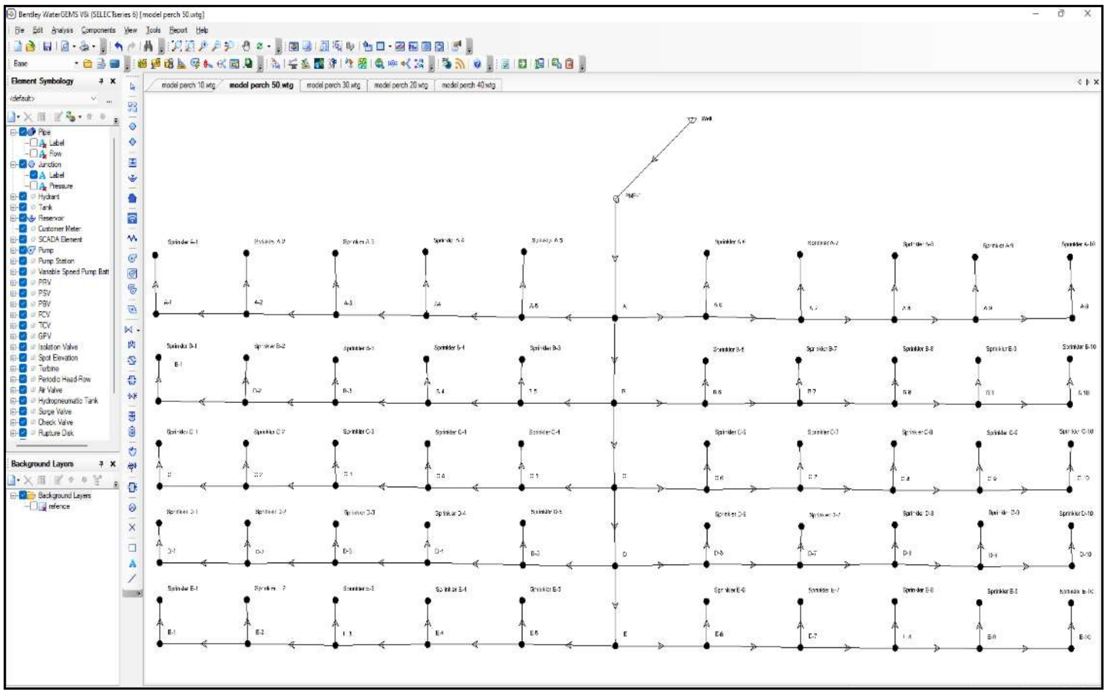

Figure 5: Agriculture pipe network computer model

Step 05 – Result and analysis

The model was run for the last time once the water network configuration is accepted. The required tables and graphs were extracted from the generated results.

This is a simple system fed by a pump which was designed to have sufficient head and water flow. Next, pipe data were created with the following; pipe length, pipe material, internal diameter, and Hazen-Williams friction coefficient. The node data were input with demand and elevation above the given datum. The hydraulic analysis is carried out by using the Hazen-Williams friction method (Equation 1) with steady state simulation in this study.

$$\frac{H_L}{L} = \frac{10.67\ Q^{1.852}}{C^{1.852}\ D^{4.8704}} \qquad \text{Equation 3}$$

Where;

Q = Fluid flow rate (m^3 /s)

C = Dimensionless HW roughness constant

D = Pipe internal diameter (m)

H_L = Head loss (m)

L = Pipe length (m)

Model validation

The model validation is a vital part in any research, in order to confirm the capability of software used for modeling and to confirm whether the researcher has enough knowledge on the modeling. The proposed simulation model was validated and calibrated by using the study done by Revelli & Ridolfi (2002) before the analysis. The results of flow measurement in every pipe were used for validation. The deviation between the flow results of this study model and the study of Revelli & Ridolfi (2002) is tabulated in Table 1, with an average deviation of 1.98%.

Table 1: Summary of model validation

Start Node	*Stop Node*	*Flow (m^3/s) [current study]*	*Flow (m^3/s) [previous study]*	*Results Deviation (%)*
K1	k2	0.452	0.458	1.3%
K2	K3	0.221	0.224	1.4%
K4	K3	0.078	0.076	2.6%
K1	K4	0.227	0.222	2.2%
k2	K4	0.081	0.083	2.5%

Results and discussion

There are few significant output parameters required to analyze the optimizing options to design the agriculture pipe network, in terms of investment cost, operational efficiency and operation cost. Those output parameters mainly nodal pressure, flow rate, flow velocity, and capacity of the pump were extracted from Water GEMS simulation models and discussed in this chapter.

The capacity of the pumps

The models were simulated several times to optimize the pressure in all the nodes (sprinkler points) and the flow velocity in all the pipes for different combinations. Figure 6 illustrates the pump capacity requirement for (a) different combinations of chilli and onion, (b) different land used areas for chilli only and (c) different land used areas for onion only. It can be observed that 20% land (10 perches) for onion and 80% land (40 perches) for chilli required a higher power water pump. The power of the water pump for chilli only and onion only is positively correlated with the cultivated land extent and R^2 values were observed to be 0.9991, and 1.0 for chilli and onion respectively.

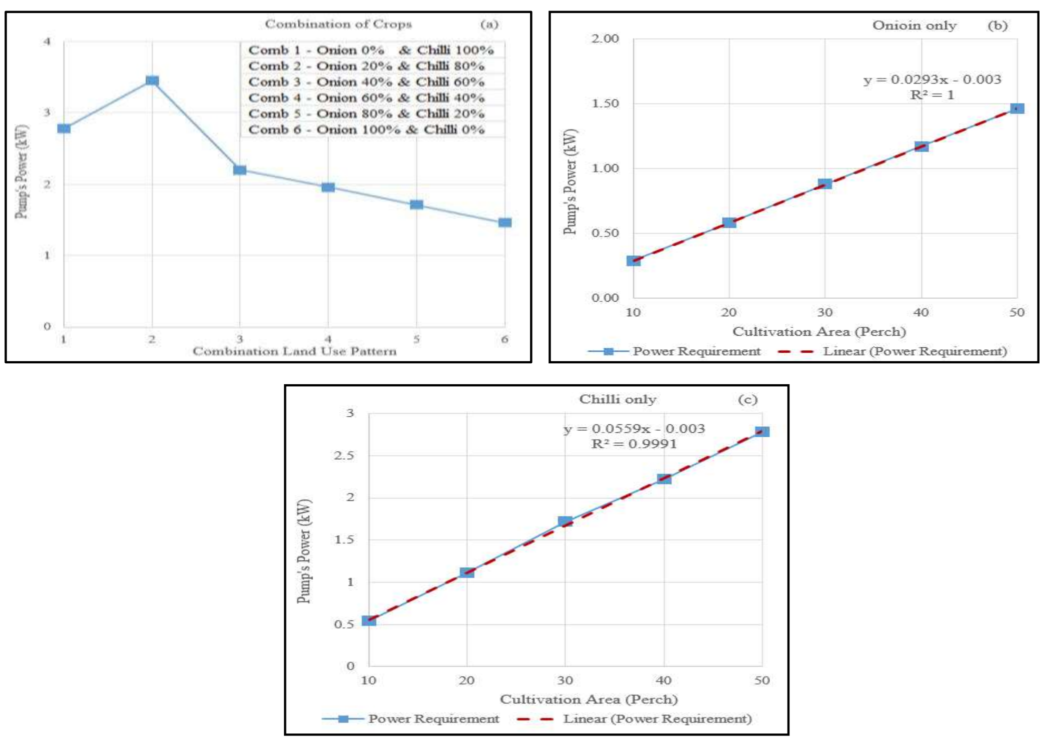

Figure 6: Power requirement for different combinations of cultivation (a); combination of crops Onion only (b); Chilli only (c)

Flow velocity

The minimum flow velocity in WDN is specified as 0.5 meters per second to eliminate the chance of slit deposition which may occur due to the low velocity as specified in the design manual of the water network(National Water Supply & Drainage Board, 1989). As Figure 7 shows, the flow velocity in all pipes was observed to be above the minimum level. The maximum velocity level is specified as 2.0 m/s to eliminate the water hammer scenario, which can cause failure in the pipe, however, the velocity is well within the maximum level in the system.

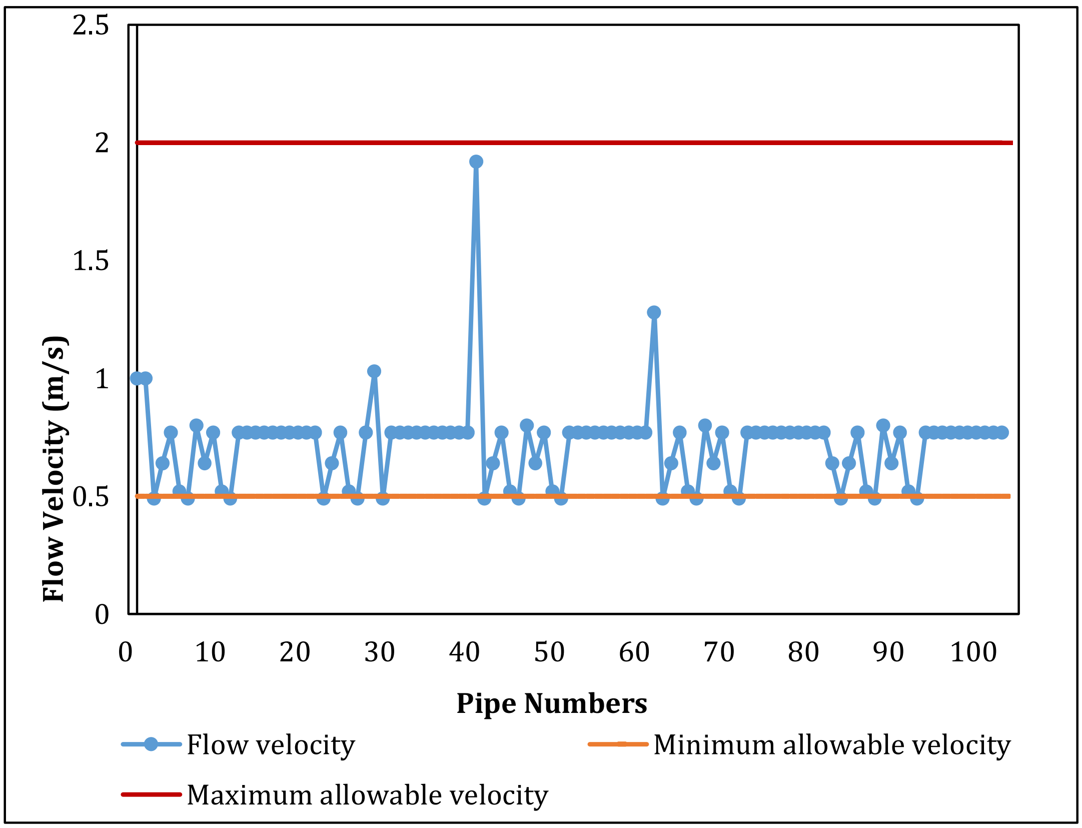

Figure 7: Flow velocity in the pipes

Pressure at sprinkler point

The pressure at the end point of each sprinkler is plotted in Figure 8.The pressure is one of the critical output factors which shall give an idea of ensuring the supply of water through every sprinkler for the efficient watering of the plants. The pressure in the pressurized agriculture pipe network mainly depends on pipe diameter, roughness coefficient of pipe material, and elevation (Liang et al., 2004). As mentioned in the drip and sprinkler irrigation manual of the Department of Agriculture, the minimum pressure is to be maintained above 2 bars at the sprinkler when using rotary type sprinkler. As such the result indicates that the nodal pressure in this particular pipe network is above the minimum level and adequate for the effective performance of the agriculture pipe network designed for home gardening.

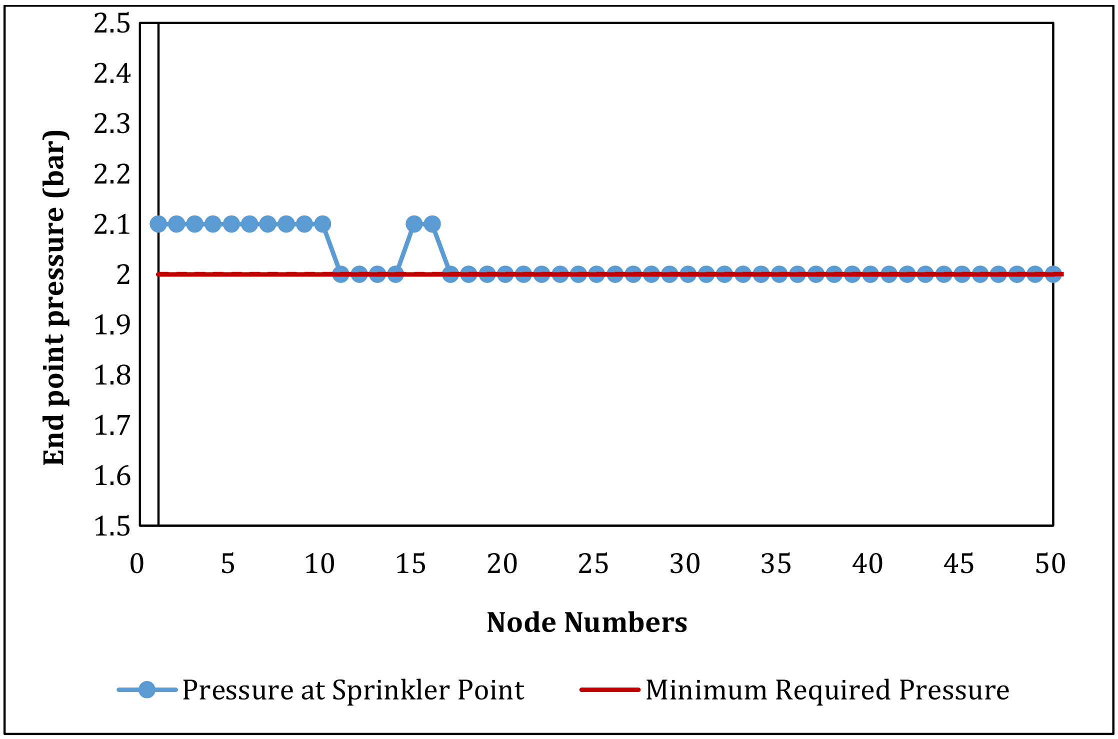

Figure 8: Pressure at sprinkler point

Conclusion

Based on this study, the vital output parameters such as the flow velocity in all the pipes and nodal pressure at all the nodes are sufficient enough to supply water as per crop water demand in the study area. The designed and optimized pipe sizes of the pressurized agriculture pipe network are adequate to meet the water demand while maintaining adequate pressure in the system. A network designed using WaterGEMS satisfied the design criteria considered for pressurized pipe networks. The optimal design of the pipe network was carried out to satisfy the positive pressures at all the nodes which indicate an assured supply of water up to the tail end sprinkler. The proposed pressurized agriculture pipe network design shall significantly reduce the seepage losses if implemented in practice for home gardening. The results suggest that WaterGEMS is a reliable simulating tool for developing drip irrigation systems especially suitable for home gardening in selecting the economic pipe diameter, reducing the capital cost of establishing an agricultural water network, and achieving the optimal pumping operating pressure. The WaterGEMS simulators used for this design can handle various pressurized agriculture pipe network problems. Computer-aided network simulation techniques provide great advantages over conservational computations in terms of optimization, results in accuracy, monitoring of the system during operation, time consumption and room for future modification. The proposed pressurized agriculture pipe network design shall be used for modeling of pipe network for home gardening with different crop types by changing the model input parameters.

References

Al-Adili, A., & Kraidi, H. H. Simulation Techniques for Sprinkler Irrigation Design System At Adiwaniyah Government–IRAQ.

Bentley WaterGEMS Connect edition. Bentley Communities. https://communities.bentley.com/products/hydraulics___hydrology/m/hydraulics_and_hydrology_gallery/272257

Thayaparan, A., Gunathilaka, G. Y. N., Pirathepan, T., & Rukshan, A. (2019). Technical efficiency of brinjal farmers in Sri lanka: Translog production frontier approach.

Liang, R., Li, R., Yan, X., Xue, Z., & Wei, X. (2022). Evaluating and selecting the supplier in prefabricated megaprojects using extended fuzzy TOPSIS under hesitant environment: a case study from China. *Engineering, Construction and Architectural Management*.

Muhammad Bassiouni Darwish, W., Ahmed Al-Hwaity, M., Muhammad, Sabri Al-Balkimy, & Muhammad. .(2022) Application of the hydraulic program to choose the optimal design for the drip irrigation system. *Egyptian Journal of Agricultural Engineering* .152-133 ,(1) *39* ,

Ministry of Lands (2016). Land Use Plan Vavuniya District. In Implementations of the Recommendations given by the Lessons Learnt and Reconciliation Commission (LLRC), Sri Lanka.

National Water Supply & Drainage Board (1989). Design Manual D2, Urban Water Supply and Sanitation (1st ed.). National Water Supply & Drainage Board, Sri Lanka.

Revelli, R., & Ridolfi, L. (2002). Fuzzy approach for analysis of pipe networks. *Journal of Hydraulic Engineering*, *128*(1), 93-101.

Sharu, E. H., & Razak, M. S. A. (2020). Hydraulic performance and modelling of presurerized irrigation system. Water, 1–14

Shiyekar, S., & Patil, N. K. (2017). Design of Lift Irrigation System-Angar as A Case Study. *IRJET*, *4*(01).

Andres, L., Boateng, K., Borja-Vega, C., & Thomas, E. (2018). A review of in-situ and remote sensing technologies to monitor water and sanitation interventions. *Water*, *10*(6), 756.