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Evaluation of Clean Water Distribution Pipeline Network in Sei Rampah Subdistrict Using Epanet 2.2

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ABSTRACT

The population growth and increasing demand for clean water in Sei Rampah District require the optimal performance of the Regency Capital Drinking Water Supply System (SPAM IKK). However, the clean water distribution network still faces technical challenges. This study aims to evaluate the existing performance of the SPAM IKK Sei Rampah pipeline network based on pressure, flow velocity, and headloss parameters in accordance with the Ministry of Public Works Regulation No. 27 of 2016. The research employs a quantitative approach with a descriptive-evaluative method through the collection of primary data (field observations and operator interviews) and secondary data (customer database, pump specifications, reservoir capacity, and network maps). Data analysis was conducted using EPANET 2.2 software to simulate the hydraulic conditions of the existing network. The results show that the pressure at all nodes meets the required standards (27.98–66.43 m), but 80 pipes have flow velocities below the standard, and 4 pipes exhibit headloss values exceeding 10 m/km. The study concludes that although pressure conditions meet the standards, distribution efficiency is still affected by velocity and headloss issues. The findings imply that this evaluation can serve as a basis for improving the water distribution system and as a reference for future network development.

Keywords: *Preassure, Velocity, Headloss, Epanet 2.2, SPAM IKK Sei Rampah*

1. Introduction

Clean water is a fundamental human need that must be available adequately in quantity and quality. The provision of clean water by the Drinking Water Supply System have to meet three key aspects—quality, quantity, and continuity [1]. While water quality is influenced by the raw water source and its treatment process, the quantity and continuity depend on the capacity of the distribution system to maintain a consistent and sustainable water supply.

A clean water distribution system functions to convey water from the source or reservoir to consumers through a network of primary, secondary, and tertiary pipes arranged in specific patterns [2]. The efficiency of this system depends on the network design as well as the balance of pressure and discharge at each service point. Typically, water is drawn from groundwater or surface water sources, treated at a water treatment plant, conveyed to a reservoir, and then distributed to consumers through the pipeline network.

Several distribution network patterns are commonly used, including branch, loop, and gridiron systems. The branch system has a simple one-way flow but is less reliable during disturbances. The loop system forms a closed circulation that allows two-way flow, providing greater stability, while the gridiron system offers high interconnectivity between pipes, making it suitable for large and densely populated urban areas [3]. Common network patterns include branch, loop, and gridiron systems.

The performance of a distribution network is determined by three main hydraulic parameters: pressure, flow velocity, and headloss. According to the Ministry of Public Works [4], the minimum allowable pressure is 10 meters of water column, while Standard Nasional Indonesia (SNI) 7509:2011 [5] specifies the ideal flow velocity lies in the range between 0.3 and 3.0 m/s. Energy loss can be calculated using the Hazen–Williams, Darcy–Weisbach, or Manning equations [6]. Meeting these parameters is essential to ensure distribution efficiency and prevent damage to the network.

In recent years, the evaluation and planning of clean water distribution systems have widely utilized Environmental Protection Agency Network (EPANET) 2.2, a software developed by the U.S. Environmental Protection Agency. EPANET is capable of simulating hydraulic conditions such as flow rate, pressure, and energy loss within a pipe network over time [7]. With these analytical capabilities, EPANET has become an essential tool for research and optimization in clean water distribution system analysis. EPANET software enables users to simulate a complex pipe network effectively rather than a local analysis based on computational fluid dynamics [8,9]. The latter approach provides three-dimensional modelling and hence may provide detailed insight of flow complexities. However, implementing this approach to model a pipe network requires a prohibitive amount of time and resourceful computing systems.

The availability of clean water is a fundamental need that has become increasingly critical with population growth and regional development. The increasing future demand of clean water is indeed a global issue. Many studies have examined water distribution networks using hydraulic simulations with EPANET software to tackle this issue as first steps [10, 11, 12, 13,14]. These earlier studies emphasize the importance of evaluating the performance of pipe network given the current and future condition. Sei Rampah district, as the administrative center of Serdang Bedagai regency in North Sumatera of Indonesia, has experienced a population increase of 8,207 people since 2012. This puts pressure on managing the clean water distribution by the Regency Capital Drinking Water Supply System (SPAM IKK). However, a specific analysis of the SPAM IKK Sei Rampah system remains limited. The objective of this study is to evaluate the performance of the SPAM IKK Sei Rampah pipeline network based on three main parameters specified in the pressure, flow velocity, and headloss using the EPANET 2.2 software. This study also aims to provide recommendations for improving the efficiency of the clean water distribution system and enhance understanding of EPANET's application in regions that experience population and infrastructure growth. Importantly, by assessing the hydraulic performance, managers of clean water supply systems may prioritize upgrades, prevent overflows, and ensure sustainable service delivery. This is important for further plans including optimally operating the water supply system. Furthermore, regional SPAM administrators use Key Performance Indicator (e.g., water pressure) in annual reports, which are reviewed by centralized units to enforce contract compliance and guide technical upgrades. Given this view and the current global challenges such as water scarcity and urbanization associated with increasing population, it is thus necessary to evaluate the hydraulic performance of the SPAM IKK Sei Rampah based on its latest technical and service conditions.

This study employs a descriptive quantitative approach to evaluate the performance of the clean water distribution network of SPAM IKK Sei Rampah in Serdang Bedagai Regency. The research data consist of primary data, obtained through field observations and interviews with SPAM IKK operators to assess the existing conditions of pipes, pumps, and reservoirs, as well as secondary data, which include the distribution network map, customer database, water consumption rate, reservoir capacity, and pump specifications.

The research stages include a literature review, data collection, network modeling using EPANET 2.2, simulation analysis, evaluation of existing performance based on the standards [4, 5], and manual verification using the Hardy-Cross method. The results of the analysis are used to assess the conformity of the distribution network's performance with the applicable standards and to provide technical recommendations for improving the clean water distribution system in the study area. The methodology described in the following could be replicated for modelling other similar pipe network problems.

2. Method

2.1 Location

The study case of the present study is the SPAM IKK Sei Rampah, which serves as the provider and distributor of drinking water in Sei Rampah District, Serdang Bedagai Regency, Province of North Sumatera, Indonesia. Figure 1 shows the location of Sei Rampah captured from the google earth. It provides a spatial context of the study area within Serdang Bedagai Regency. Figure 2 presents the service areas of the SPAM IKK Sei Rampah system, serving 16 nearby subdistricts and important local government offices. It highlights the extent of the water distribution areas.

2.2. Data Collection Method

The research data consists of primary data obtained through field observations and interviews with SPAM IKK operators to identify existing conditions of pipes, pumps, and reservoirs, as well as secondary data, which include maps of distribution network, number of customers, water consumption rates, reservoir capacity, and pump specifications. The research stages include: literature review, data collection, network modelling using EPANET 2.2, simulation result analysis in accordance with the standards [4, 5]. The analysis results are then used to assess the conformity of the distribution network's performance with applicable standards and to provide technical recommendations for improving the clean water distribution system in the study area.

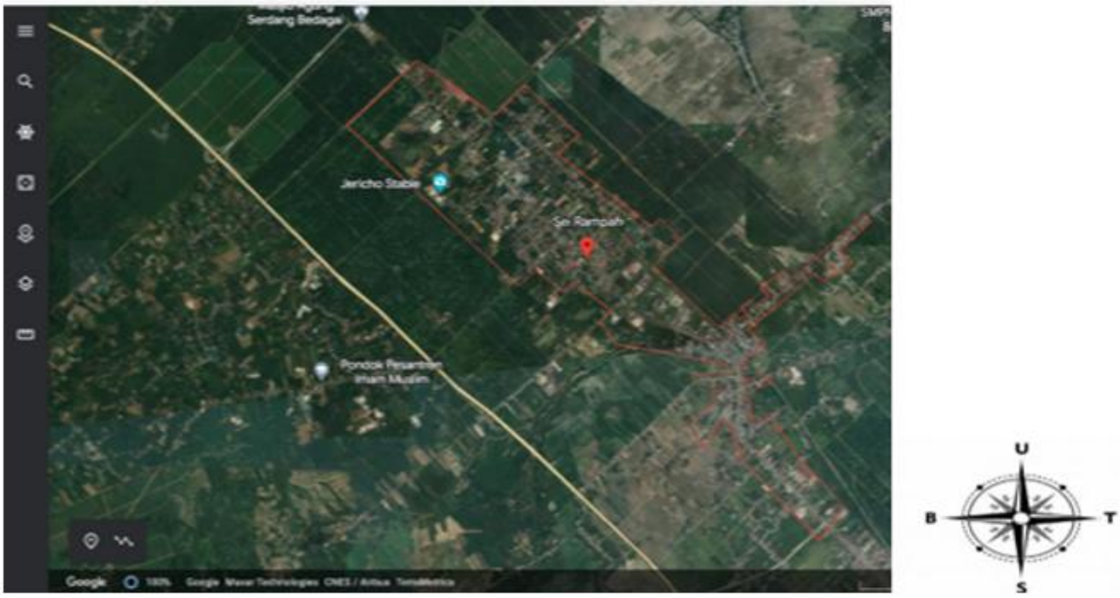


Figure 1. Map showing location of SPAM IKK Sei Rampah.

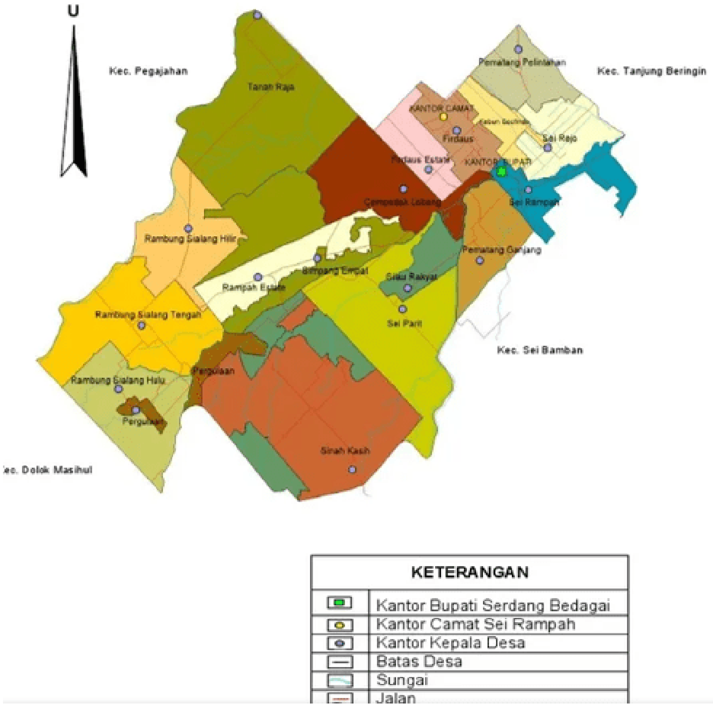


Figure 2. The service areas ministered by SPAM IKK Sei Rampah.

Figure 3 depicts the installation databases of the SPAM IKK Sei Rampah. This figure displays the layout and data overview of the SPAM IKK Sei Rampah water distribution installation, including the main network structure used for hydraulic modelling. Table 1 presents the types, diameters, and total lengths of pipes used in the SPAM IKK Sei Rampah distribution network. The data indicates a predominance of PVC pipes with various diameters, showing the network's structural composition and scale.

2.3 Simulation setting and model construction

This study was conducted to evaluate the hydraulic performance of the clean water distribution network at SPAM IKK Sei Rampah using EPANET 2.2 software. Field data such as pipe length, diameter, material type, pump capacity, and the elevation of the reservoir and pump relatively measured from the mean sea level, were entered as input data into the EPANET network model. The simulation was carried out under existing conditions to obtain values of pressure, flow velocity, and energy loss (headloss) at each node and pipe. The simulation results were then compared with the distribution network performance standards.

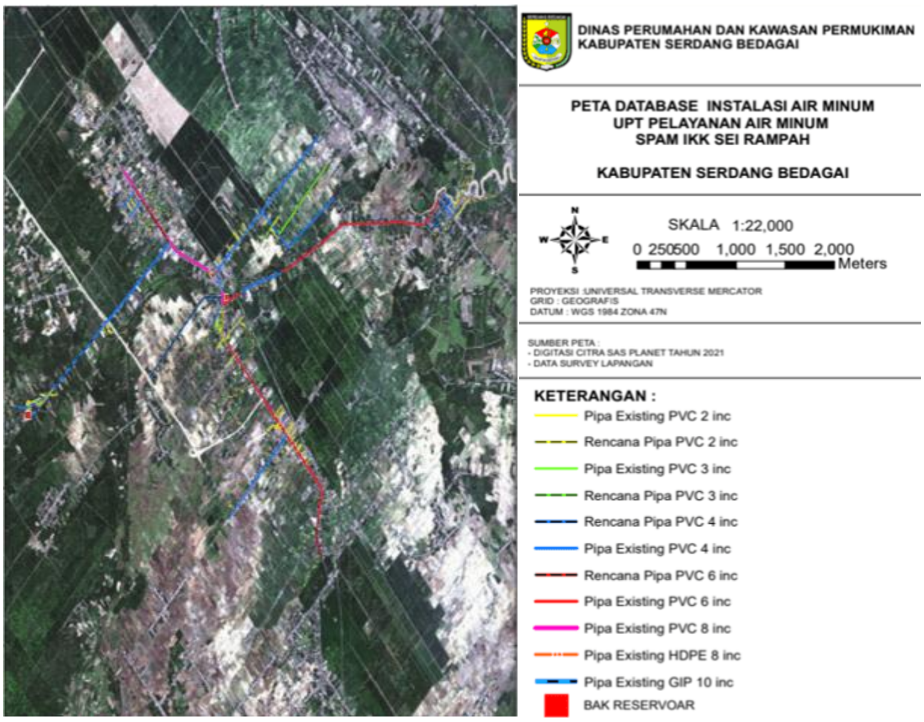


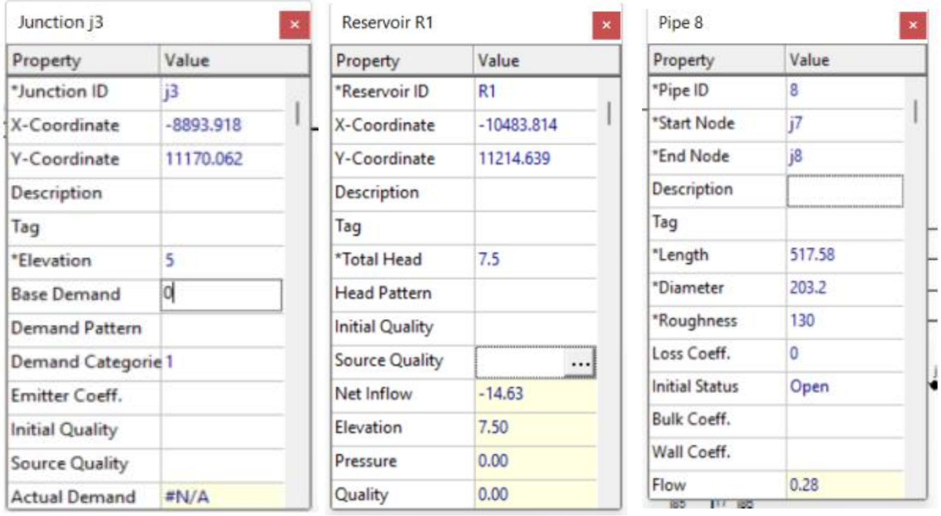
Figure 3. Network showing existing and planned pipe system.

Table 1. Pipe Data of SPAM IKK Sei Rampah.

NO	Type of Pipe	Pipe Size (inch)	Length (m)
1	GIP	10	4.698
2	HDPE	8	150.000
3	PVC	8	3.663
4	PVC	6	15.074
5	PVC	4	24.397
6	PVC	3	6.088
7	PVC	2	10.993
		Total	65.063

To check accuracy, verification was conducted using the Hardy-Cross method [15], which calculates the balance of discharge and energy loss in a closed-loop system. The difference between the simulation results and manual calculations was used to assess the model’s reliability. Based on the analysis results, pipes that did not meet the standards were identified, and technical recommendations were provided, such as pipe diameter adjustments or system pressure improvements, to achieve a more optimal clean water distribution performance.

Figure 4 describes the properties of a junction, reservoir and a pipe. The elevation and base demand at the junction, the total head at the reservoir, the length, diameter and inner wall roughness of the pipe are defined by users. The total head is predicted as the total of its base elevation and the water elevation within the reservoir. The roughness calculation in the model adopts the Hazen Williams formula for steel, copper and brass pipe material; roughness coefficient estimated at 120-130. Furthermore, the coordinates at both the junction and reservoir have to be prescribed prior to the simulation. Other properties shown in Figure 4 are predicted through the simulation.



Junction j3

Property	Value
*Junction ID	j3
X-Coordinate	-8893.918
Y-Coordinate	11170.062
Description	
Tag	
*Elevation	5
Base Demand	0
Demand Pattern	
Demand Categorie	1
Emitter Coeff.	
Initial Quality	
Source Quality	
Actual Demand	#N/A

Reservoir R1

Property	Value
*Reservoir ID	R1
X-Coordinate	-10483.814
Y-Coordinate	11214.639
Description	
Tag	
*Total Head	7.5
Head Pattern	
Initial Quality	
Source Quality	
Net Inflow	-14.63
Elevation	7.50
Pressure	0.00
Quality	0.00

Pipe 8

Property	Value
*Pipe ID	8
*Start Node	j7
*End Node	j8
Description	
Tag	
*Length	517.58
*Diameter	203.2
*Roughness	130
Loss Coeff.	0
Initial Status	Open
Bulk Coeff.	
Wall Coeff.	
Flow	0.28

Figure 4. Properties defined at a junction, reservoir and a pipe.

Having drawn the network and defined all prescribed properties, the general configuration of the SPAM IKK Sei Rampah water distribution network may be displayed. Figure 5 shows the interconnection between main nodes and pipes. It shows the key components used in the hydraulic simulation, including reservoirs, junctions, pumps, and pipes, which were modelled to analyse the system's hydraulic performance. Clearly, the pipe network utilized in the system adopts a combination of branch, gridiron and loop system. The branch system observed from the open-ended nodes predominantly constitutes the pipe network. The total number of hydraulic components modelled in EPANET 2.2 is presented in Table 2. The network consists of 93 junctions, 94 pipes, two pumps, and two reservoirs, representing the complete structure of the SPAM IKK Sei Rampah system. The first reservoir with its capacity of 500 m^3 is installed at the SPAM IKK Sei Rampah and the second one having a lower capacity of 200 m^3 is located at the Cempedak Lobang village. This pipe network was designed to accommodate the distribution of clean water for the consumers located at 16 subdistrict areas.

Table 2. Total number of junction, pipe, pump and reservoir in the network.

Geometry	Total Number (Item)
Junction	93
Pipe	94
Pump	2
Reservoir	2

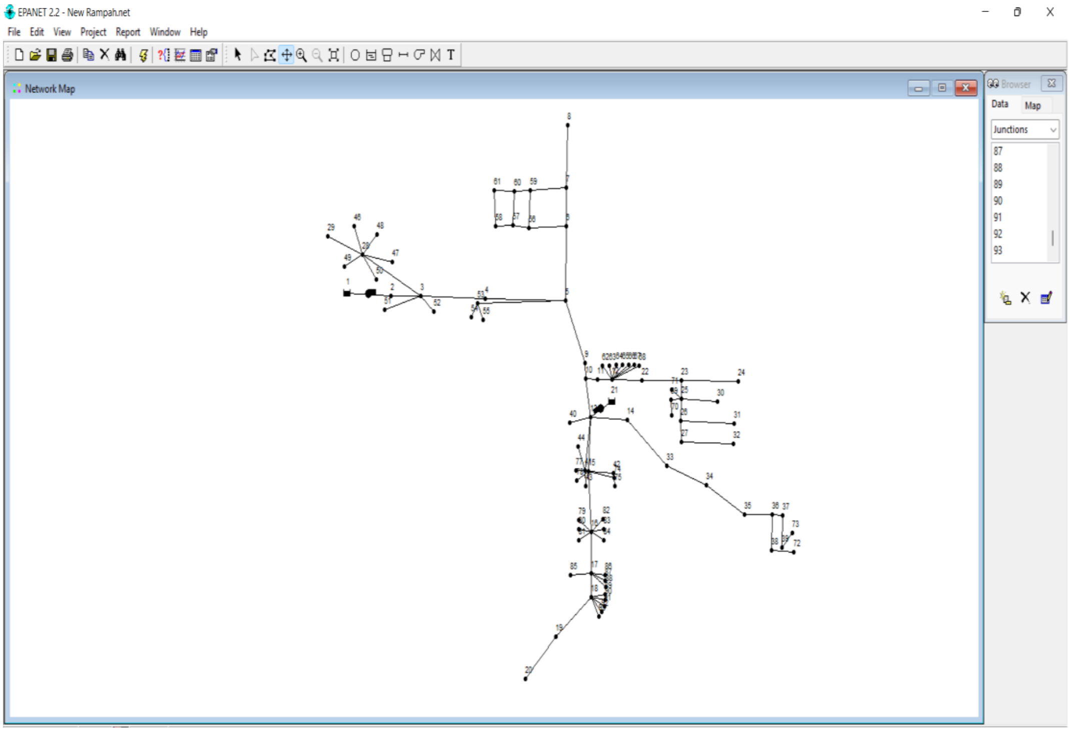
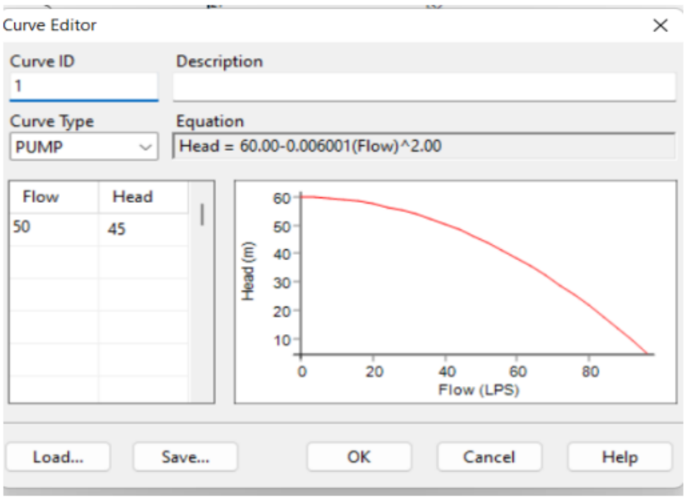


Figure 5. SPAM IKK Sei Rampah water distribution network modelled in EPANET 2.2 software.

Figure 6 presents how the relationship between the discharge of water and pump head is defined in the modelling. It shows a nonlinear function of the flow and indicates the pump head value that may be achieved under a certain flow condition. As such, the highest pump head does not necessarily accommodate high flow discharge. This pump is operated depending on the peak time of consumers' usage. Two range of peak hours spanning from 05.00-10.00 and 15.00-20.00 can be observed from Figure 7. It should be noted that the pump head is required to meet the pressure requirement when the demand of clean water by the consumers is at peak. The simulation was undertaken under the assumption of steady condition; one time period was applied for one simulation run.



Curve ID: 1

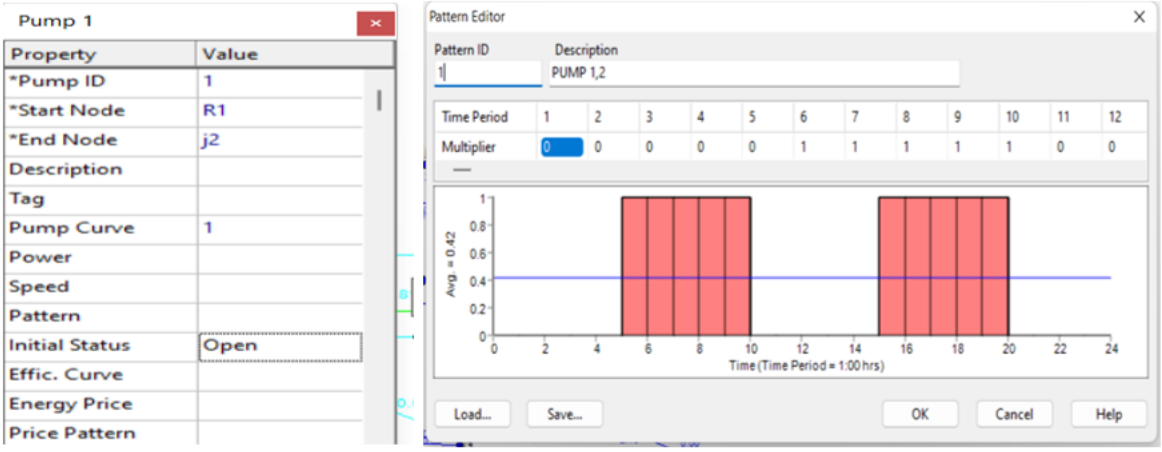
Description:

Curve Type: PUMP

Equation: Head = 60.00-0.006001(Flow)^2.00

Flow	Head
50	45

Figure 6. Curve showing the relationship between flow discharge and pump head.



Pump 1

Property	Value
*Pump ID	1
*Start Node	R1
*End Node	j2
Description	
Tag	
Pump Curve	1
Power	
Speed	
Pattern	
Initial Status	Open
Effic. Curve	
Energy Price	
Price Pattern	

Pattern Editor

Pattern ID: 1

Description: PUMP 1,2

Time Period	1	2	3	4	5	6	7	8	9	10	11	12
Multiplier	0	0	0	0	0	1	1	1	1	1	0	0

Figure 7. Operational schedule of pump depending on peak and non-peak hours.

By analysing the number of service connections and the number of junctions, the base demand (BD) for each node can be computed. The number of service connections was predicted using data from the Google Earth and the database provided by the SPAM IKK Sei Rampah. The latter confirms that the total number of consumers is 1.303. The BD quantity was evaluated by multiplying the base demand for each consumer with the number of consumers and dividing it with the total number of nodes in one service area. In this case, BD is estimated to be 0,0024 l/s/service connection. Table 3 displays the number of service connections (SC) in the Sei Rejo area, illustrating the customer density and the demand concentration within one of the SPAM IKK service areas. It also indicates that the base demand varies with node depending on the number of consumers served by the node. The simulation results from EPANET 2.2, including the flow directions, node pressures, and hydraulic connectivity across the system are shown in Figure 8. This indicates that the simulation has succesfully completed and the results may be post processed for further analysis.

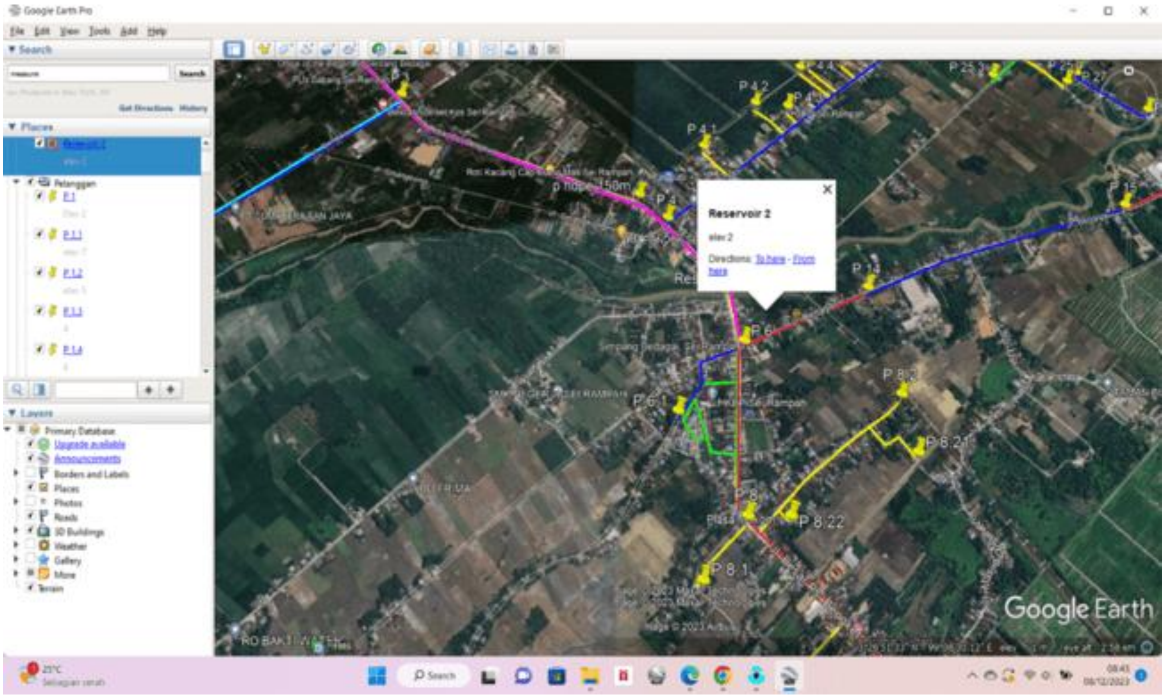


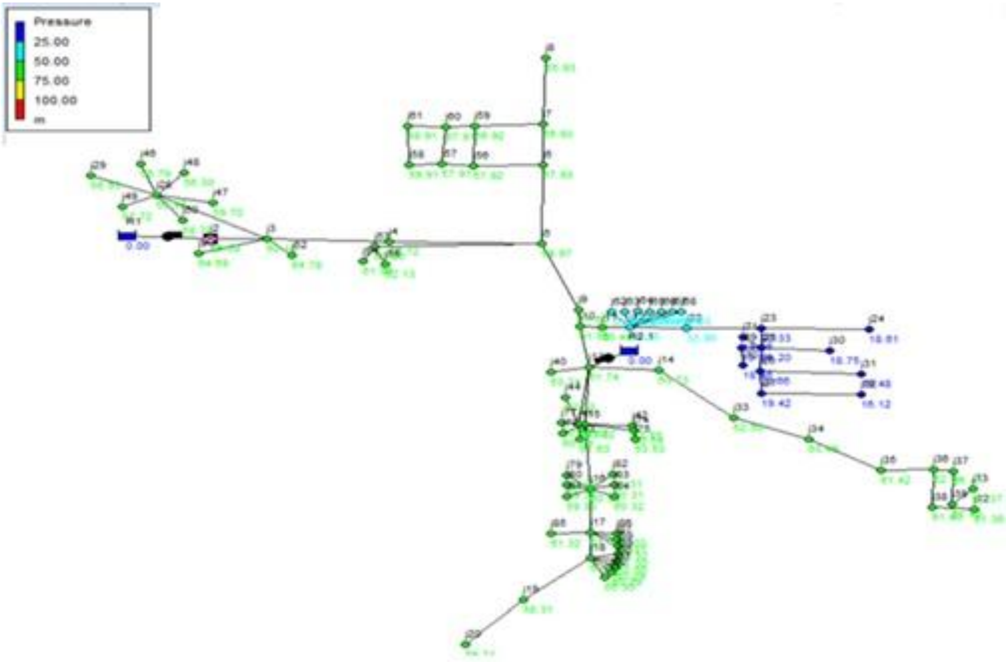
Figure 8. Results of network modelling.

Table 3. Node and Customer Data for Sei Rejo

Number of SC at Sei Rejo			
Node	SC	BDxSC [l/ s]	BD (P) [l/s/cons.]
J10	47	0,1128	0,564
J11	48	0,1152	0,576
J22	46	0,1104	0,552
J23	46	0,1104	0.552
J24	63	0,1512	0,756
J25	42	0,1008	0,504
J26	42	0,1008	0,504
J27	42	0,1008	0,504
J30	40	0,0960	0,480
J31	40	0,0960	0,480
J32	46	0,1104	0,552
J62	25	0,0600	0,300
J63	23	0,0552	0,276
J64	20	0,0480	0,240
J65	25	0,0600	0,300
J66	23	0,0552	0,276
J67	23	0,0552	0,276
J68	23	0,0552	0,276

3.Data Analysis

Figure 9 shows the pressure simulation results predicted at each node. The hydraulic simulation using EPANET 2.2 indicates that the pressure at all nodes in the SPAM IKK Sei Rampah distribution network ranges from 27,98 to 66,43 m. This complies with the distribution standards, where the required pressure range lies in between 10 and 80 m. A pipe network that utilizes adequately sized pipe diameters tend to maintain stable pressure throughout the network [16]. The present finding demonstrates that the present pipe diameters are adequate for the system to ensure water availability up to the consumer level.



.**Figure 9.** Pressure distribution map predicted at all nodes

Figure 10 presents the simulated velocity distribution at all pipes. It shows that the velocity varies with the pipe. Interestingly, pipe flows with velocity conditions exceeding the maximum requirement are not observed from this simulation result. Nevertheless, there are indeed pipe flows with velocity lower than the minimum standard requirement of 0.3 m/s. This is indicated by the light blue and green colours, highlighting needs for local improvements. The smallest flow velocity is estimated to be 0.01 m/s in pipe 61 and the total number of pipes that fails to meet the minimum requirement is 80. These conditions with low velocities mainly occur in large-diameter pipes. As such, it may potentially cause sediment accumulation and a decline in water quality over time.

Figure 10. Velocity distribution map predicted at all pipes.

In addition, the EPANET simulation result provides prediction of the headloss distributions at all pipes (see Fig. 11). It confirms that there are pipes coloured in red, indicating that these pipes fail to meet the standard requirement (i.e. > 10 m/km). In total, there are four pipes that fall within this category. Those are pipe 11, 12, 13 and 14 with its unit headloss ranging from 16 m/km and 37 m/km. These values indicate significant hydraulic resistance caused by a combination of pipe length, material, and operational factors. High headloss levels tend to increase the workload of pumping units and energy consumption, which ultimately impacts the overall operational efficiency of the system.

In order to meet the velocity and headloss requirements, increasing the pipe diameter from 4 into 6 inch is proposed as a solution. Resimulating the pipe network shows that all the requirements have been satisfied. This is observed from Figure 12 showing no red coloured pipe. Specifically, Figure 13 shows the comparisons of the unit headloss simulated under post- and pre-modifications of pipe diameters. Pipe 11, 12, 13 and 14 have reached the headloss condition of 4.97, 4.39, 2.67 and 2.25 m/km, respectively. This thus justifies the replacement of the pipe diameter.

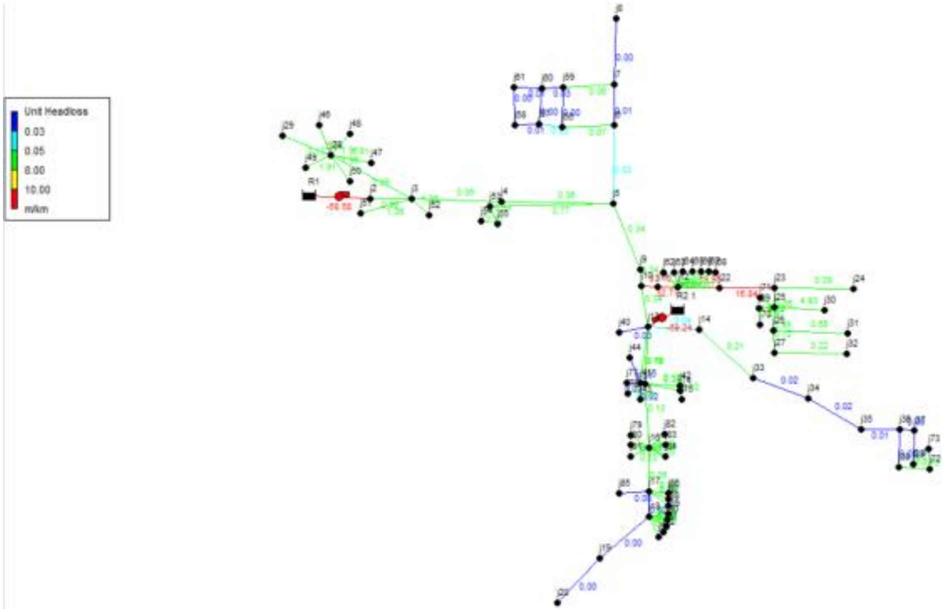


Figure 11. Unit headloss distribution map predicted at all pipes.

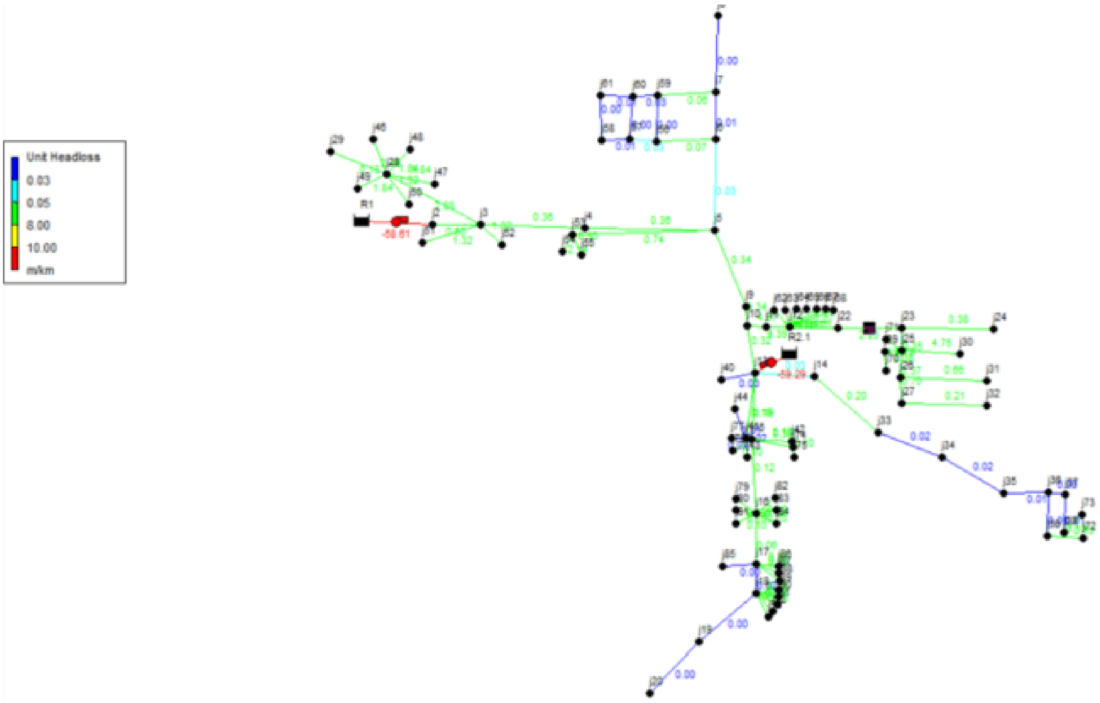


Figure 12. Unit headloss distribution map predicted under post-modification of pipe diameter.

A manual computation based on the Hardy Cross procedure [15] was undertaken to generate prediction of the flow discharge. Figure 14 shows the nodes, the pipes and the three loops covering the loop system. Only result associated with loop 3 is presented due to space effectiveness in this study. The headloss coefficient in the Hardy Cross procedure is computed as $K = 10{,}48LC^{1{,}85}D^{4{,}87}$ with L and D being respectively the pipe length and diameter. The assumed discharge is revised by computing the headloss formula, $h_f = KQ_n$, and the discharge increment, ΔQ. Comparison of this prediction with the simulated flow discharge provides validation of the present simulation results. For this purpose, part of the SPAM IKK Sei Rampah focusing on the loop system was analysed specifically. Figure 15 shows the computation obtained from the first iteration to achieve

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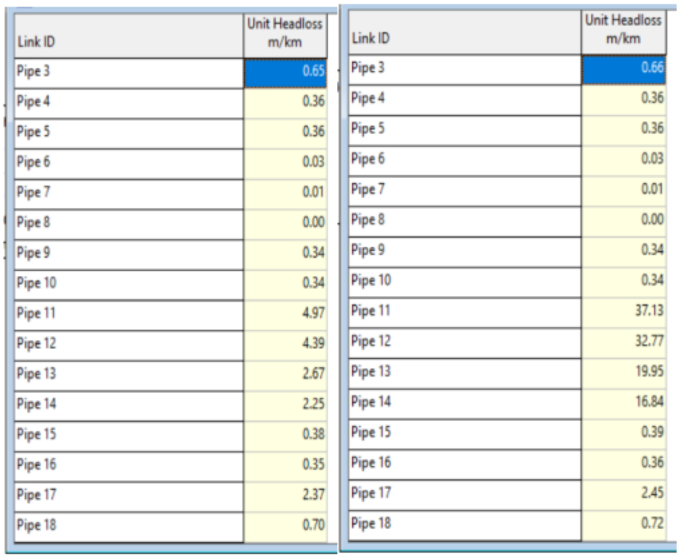
the converged flow discharge at loop 3. Applying similar procedure for the three loops and comparing the results with the previous EPANET simulation confirm that the percentage of error is found to be less than 8%. This confirms that the EPANET simulation is satisfactorily validated.



Link ID	Unit Headloss m/km	Link ID	Unit Headloss m/km
Pipe 3	0.65	Pipe 3	0.66
Pipe 4	0.36	Pipe 4	0.36
Pipe 5	0.36	Pipe 5	0.36
Pipe 6	0.03	Pipe 6	0.03
Pipe 7	0.01	Pipe 7	0.01
Pipe 8	0.00	Pipe 8	0.00
Pipe 9	0.34	Pipe 9	0.34
Pipe 10	0.34	Pipe 10	0.34
Pipe 11	4.97	Pipe 11	37.13
Pipe 12	4.39	Pipe 12	32.77
Pipe 13	2.67	Pipe 13	19.95
Pipe 14	2.25	Pipe 14	16.84
Pipe 15	0.38	Pipe 15	0.39
Pipe 16	0.35	Pipe 16	0.36
Pipe 17	2.37	Pipe 17	2.45
Pipe 18	0.70	Pipe 18	0.72

Figure 13. Comparisons of the unit headloss predicted under post- and pre-modifications of pipe diameters.

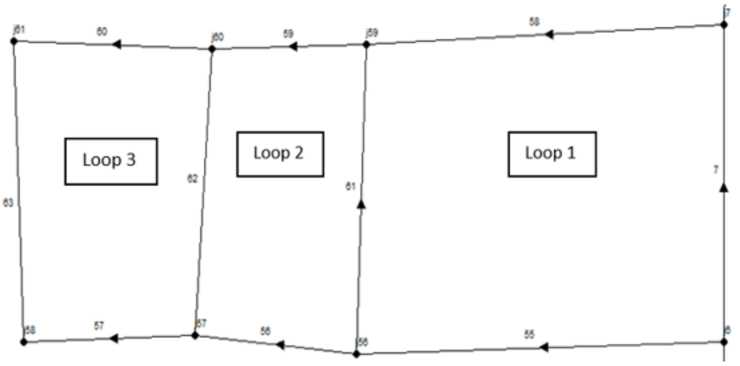


Figure 14. Nodes covering the loop system for validation purpose

First Iteration											
Loop	Pipe	C	D [m]	L [m]	K	Q_{epanet} [m^3/s]	Q_0 [m^3/s]	h_f [m]	h_f/Q_0	ΔQ [m^3/s]	Q_i [m^3/s]
3	57	120	0,1016	172,82	18068,42	0,00014	0,00014	0,001	9,5750	-0,00001	0,00013
	60	120	0,1017	204,29	21358,62	0,00013	0,00013	-0,001	-10,627		0,00013
	62	120	0,0508	231,13	706640,48	0,00001	0,00001	0,000	-39,737		0,00001
	63	120	0,0508	223,76	684107,97	0,00001	0,00001	0,000	-38,470		0,00001

Figure 15. Iterative procedures based on the Hardy-Cross computation for Loop 3.

4. Conclusion

The results of this study indicate that the SPAM IKK Sei Rampah distribution system fulfils the pressure standard but still encounters critical challenges regarding flow velocity and headloss parameters. These findings contribute to the ongoing discussion about the importance of calibrating network design between long-term development needs and existing performance. Therefore, the sustainability of a clean water distribution system is determined by both sufficient pressure and the balance between velocity and headloss.

The research concludes that the SPAM IKK Sei Rampah clean water distribution system meets the pressure standard with a range of 27.98–66.43 m, but 80 pipes exhibit flow velocities below 0.3 m/s, and four pipes have headloss values exceeding 10 m/km. Hence, the research objectives, which aim to evaluate the three main parameters of water distribution performance, have been achieved. The findings confirm that the system does not fully comply with the technical standards. Validation of the EPANET simulation with the Hardy Cross procedure has also been undertaken.

Practically, the results highlight the need for adjustments in network design to ensure that flow velocity and headloss remain within acceptable standards, thereby improving distribution efficiency and service quality. Theoretically, this research emphasizes the importance of balancing long-term network expansion planning with current hydraulic performance. A recommendation for improving the network design has been given. This relates to managing the replacement of the pipes under the low-velocity conditions. A limitation of this study lies in its focus solely on the SPAM IKK Sei Rampah system without examining water quality or non-technical factors. Therefore, future research is recommended to integrate water quality assessment, energy cost optimization, and network development simulations to produce more comprehensive recommendations for improving clean water distribution systems.

5. Acknowledgements

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6. Conflict of Interest

The author confirms the absence of conflicts of interest.

References

[1] Peraturan Pemerintah Republik Indonesia No. 122 Tahun 2015, Sistem Penyediaan Air Minum.

[2] Department of Public Works, Clean Water Distribution System Manual, 2006.

[3] M. J. Hammer and M. J. Hammer Jr., Water and Wastewater Technology, 7th ed., Pearson Education, 2012.

[4] Kementerian Pekerjaan Umum, Peraturan Menteri Pekerjaan Umum No. 27 Tahun 2016 tentang Penyelenggaraan Sistem Penyediaan Air Minum.

[5] SNI 7509:2011, Tata Cara Perencanaan Sistem Distribusi Air Minum, Badan Standardisasi Nasional (BSN), 2011.

[6] R. J. Kodoatie, Hidraulika Terapan pada Teknik Sipil, Andi, Yogyakarta, 2002.

[7] L. A. Rossman, EPANET 2 User Manual, U.S. Environmental Protection Agency, Cincinnati, 2000.

[8] P. Dutta, S. K. Saha, N. Nandi. and N. Pal, "Numerical study on flow separation in 90° pipe bend under high Reynolds number by k-ε modeling", *Engineering Science and Technology an International Journal*, vol. 19, 2016.

[9] E. P. Bangun and N. Mahdi, "Numerical Study of Steady Pipe Flows and Head Loss Coefficients", *Jurnal Teknik Sipil dan Perencanaan*, vol. 26, 2024.

[10] P. Sivakumar, N. B. Gorev, T. T. Tanyimboh, I. F. Kodzzhespirova, C. R. Suribabu and T. R. Neelakantan, "Dynamic Pressure-Dependent Simulation of Water Distribution Networks Considering Volume-Driven

Demands Based on Noniterative Application of EPANET 2”, *Journal of Water Resources Planning and Management*, vol. 146, 2020.

[11] A. K. Habibie, “Evaluasi jaringan perpipaan distribusi air bersih di kelurahan Sei Agul Kecamatan Medan Barat Kota Medan menggunakan aplikasi Epanet 2.2”, *Laporan Tugas Akhir*, Universitas Sumatera Utara (2022).

[12] A. Safitri, S. I. Wahyudi, Soedarsono, “Simulation of Pipe Networks Using EPANET to Optimize Water Supply: A Case Study for Arjawinangun Area, Indonesia”, *Archives of Hydroengineering and Environmental Mechanics*, vol. 70, 2023.

[13] S. Phulpagar, R. M. Sawant, J. R. Gaikwad, P. A. Paikrao, A. K. Ghate, S. N. Gakwad and V. V. Gangawane, “Water Distribution Network Using EPANET: A Case Study of the Pethe Nagar”, *Lecture Notes in Civil Engineering*, vol. 547, 2025.

[14] C. T. Rafols, R. A. Villamor, S. M. Salcedo-Albores and C. D. Dolotina, “EPANET Modeling for Water Distribution System Assessment in a Growing University Campus”, *International Exchange and Innovation Conference on Engineering and Sciences*, vol. 11, 2025.

[15] B. Dejan and P. Pavel, “Short overview of Early Developments of the Hardy Cross Type Methods for Computation of Flow Distribution in Pipe Networks”, *Applied Sciences*, vol. 9, 2019.

[16] A. Saminu, N. Abubakar, and L. Sagir, “Design of NDA Water Distribution Network Using EPANET,” *International Journal of Emerging Science and Engineering* (IJESE), vol. 1, 2013.