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A SYSTEMATIC HYDRAULIC ANALYSIS AND EVALUATION OF THE EPANET SOFTWARE AND TECHNIQUES ON THE WATER NETWORK OF ELIZADE UNIVERSITY

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ABSTRACT

In this paper, the hydraulic analysis and evaluation of three head loss techniques (Hazen-Williams, HW, Chezy-Manning, CM and Darcy-Weisbach, DW) available for utilization at the EPANET platform were evaluated. The Elizade University (EU), Ilara- Mokin network was analysed using EPANET software. The hydraulic properties (flow rate, head-loss, Reynold's number, friction factor and velocity of discharge) were determined using the three head-loss techniques available at the EPANENT software and Microsoft Excel Solver (MiExS) as the standard (based on previous studies). The friction factors (f_f) obtained from these techniques were evaluated using relative and square errors. The study revealed that the elevations at the EU were between 339.1 m and 390 m, the diameters of the pipes were between 150 mm and 50 mm and water withdrawals were in the range of 480l/s to 30l/s. The discharges through the pipes were from 2.0 x 10^1 l/s to 3.545 x 10^3 l/s, the f_f of these pipes ranged between 0.019 and 0.012 for MiExS and DW, between 0.0012 and 0.025 for HW and between 2.03 x 10 ^{5} and 3.21 x 10^5 for CM. Effects of techniques on the f_f were significant at 95 % confidence level ($F_{3,160}$ = 803.06; p of 3.45 x 10^{-96}, which was less than 0.05). It was concluded that DW performed better than HW and the least performed technique was CM. It was suggested that CM at EPANET should not be used for pressurised pipelines hydraulically and caution is required in its utilization for pressurised pipe network.

Keywords: EPANET, Pipe network analysis, Hazen-Williams, Chezy-Manning, Darcy-Weisbach

INTRODUCTION

Water supply and distribution schemes are hydraulic and water infrastructures that consist of assorted components. These components include tanks, pumps, reservoirs, valves, and pipes (Sreemathy *et al*., 2017). Water user satisfaction in respect of quantity and quality is a crucial responsibility of potable water and treated water providers. Efficient water distribution and supply are of predominant vital in the engineering design and operation of new and existing water supply and water distribution networks or the flourishing of the existing water supply and distribution scheme (Sreemathy *et al*., 2017). In the case of the water treatment and processing industry, pipeline troubles bring grievous consequences, inducing traffic fatal accidents and death, flooding, financial, time and materials losses and the break of the water distribution supply (Abdulsamad and Abdulrazzaq, 2023; Hamad *et al.,* 2023). Various factors govern the selection of materials for pipe networks and pipelines. The main technical factors are geological structures of the environment, ground conditions and engineering factors such as long-term material and substance changes, length of pipes, durability characteristics, resistance to environmental and chemical attacks, and initial and operational costs (Hang et al., 2013, Oke *et al.,* 2016). In the engineering design of water supply and water distribution schemes for supplying treated and potable water or moving water in pressure conduit pipes for irrigation or potable water distribution and supply, it is crucial to establish hydraulic adequacy (Abdulameer *et al.,* 2022a). This is the basis for the consequent selection of pipe length and diameter (sizes), and the essential hydro mechanical facilities and equipment to guarantee the effective operation of the water supply scheme and pipeline system (Abdulameer *et al.,* 2022b). The Hazen-Williams (HW), Chezy-Manning (CM) and Darcy-Weisbach (DW) formulas are the three most vulgar drag formulas for pressurized discharges. Though the practical application of Hazen-Williams is quite frequent in practice, the latter formulas have a much more sensible basis and are acceptable in the determination of a critical event of f_f through water supply and distribution (Abdulameer *et al.,* 2022a). The empirical equation of Hazen-Williams applies a constant and clear factor for each type of pipe material. The constant of friction (n) of the dimensionally logical equation is apply for Chezy- Manning and the coefficient of friction (f) of the dimensionally consistent equation for Darcy-Weisbach are functions of the material's properties, absolute roughness and Reynolds number (R_e) in turbulent discharges. These are the key formulas presented as follows (Abdulameer *et al.,* 2022a):

Hazen-Williams: $$h_f = \frac{KL}{D^{4.87}}\left(\frac{Q}{C}\right)^{1.85} \quad (1)$$

where h_f stands for equivalent head loss in the pipeline (m); Q stands for equivalent individual section discharge rate in the pipeline (m^3/s); C stands for equivalent Hazen-Williams capacity coefficient of head loss, the values of C range from 80 for very coarse pipes to about 150 for smooth pipes; k stands for equivalent material constant (0.85 for SI units, 1.32 for US units); D stands for equivalent diameter of the individual (m or mm); and L stands for equivalent length of the individual (m). In the case of Chezy-Manning, the equation can be expressed as follows (Abdulameer *et al.,* 2022a):

Chezy- Manning: $V = \frac{a}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$ (2)

V stands for equivalent the cross-sectional mean velocity of discharge (ms^{-1}); n stands for Manning's roughness coefficient ($s.m^{-0.33\ 3}$); R stands for equivalent the hydraulic radius of the pipe (m), which can be estimated from the cross-sectional area of the individual pipe divided by wetted perimeter of the individual pipe of the discharge. In the case of wide rectangular channels, the hydraulic radius of the pipe stands for approximated by discharge depth (Rossman, 2000b; Travis and Mays, 2007; Abdulameer *et al.*, 2022a); S stands for equivalent channel slope (m/m) which is assumed to be equal to friction slope (Liou, 1998); and "a" stands for equivalent conversion factor between SI (a is equivalent 1.00) and English (a stands for the equivalent 1.49) units. Head loss computations using the Darcy-Weissbach equation can be conducted as follows:

Darcy-Weisbach: $h_f = \frac{fLV^2}{2Dg}$ (3)

where h_f stands for equivalent head loss in the individual (m); f stands for equivalent hydraulic resistance coefficient (Darcy-Weissbach friction coefficient) of an individual pipe; D stands for equivalent diameter of the individual pipe (mm or m); L stands for equivalent length of the individual pipe (m); V stands for equivalent mean or average velocity of discharge (ms^{-1}); g stands for equivalent acceleration due to gravity or known as constant of gravitational acceleration (ms^{-2}). It is well known that the hydraulic resistance coefficient is a function of several factors such as the diameter of the individual pipe, which can be expressed as:

$$f = f\left(R_e, \frac{\lambda}{d}\right) \quad (4)$$

$$R_e = \frac{\alpha \delta d}{\gamma} \quad (5)$$

Where; R_e is equivalent to Reynolds number (dimensionless); α is equivalent to the density of the fluid or average discharge density (kgm^{-3}); δ is equivalent to average discharge or discharge rate (m^3s^{-1}); d is equivalent to length index or pipe diameter (mm or m); γ is equivalent to a dynamic viscosity of the fluid ($kgms^{-1}$); λ is equivalent to wall roughness of the individual pipe (mm or m). More studies on head loss computation, water supply and distribution and pipe network analysis can be established in the previous studies such as Nielsen (1989); Swamee and Sharma (2008), Oke (2010), Subhankar (2011); Adeniran and Oyelowo (2013); Gorev and Kodzhespirova (2013); Kovalenko and Prokhorov (2013); Karim and Sahib (2013); Asamaa and Heb (2014); Sabzkouhi and Haghighi (2016); Sonaje and Joshi (2015); Sureh and Meena (2016); Oyebode and Igbi (2018); Zong and Jin-Hong (2018); Kachhawa and Borana (2022); Pati et al. (2023) and Abdulsamad and Abdulrazzaq (2023). These previous studies have reported and documented several computer programs which can easily be used on personal laptops and computers to easy pipe network analysis, water distribution design and pipeline design. These stated programs are known for water supply, distribution and management. The commercial programs include HydrauliCAD, Archimede, H_2Onet, Cross, Synergi Water, Eraclito, Synergi Water, Helix delta-Q, DisNet, Netis, Branch, OptiDesigner, WATSYS, Wadiso SA, UNWB-LOOP, Aquis, EPANET (Karim and Sahib, 2019; Jumanalmath Shivapur, 2017), WADISO, MODPATH, Fluidflow, WATERGEM (Abdulsamad and Abdulrazzaq 2023; Aathira and Elangovan, 2021), MODFLOW, MODFLOW-USG (Georgescu et al., 2014; Anisha, 2016; Jia et al., 2008; Iglesias-Rey et al., 2017)., MT3DMS, SEAWAT, RT3D (Alkali,et al., 2017;_Kachhawa and Borana, 2022), PHT3D, MODFLOW-LGR, H_2O map, EPANET, Flow-THERMX and U of K KYPIPE had been established, accomplished and accessible for utilization in the pipe network analysis. These collections of software are accessible for Water Supply network analysis but their utilization involves unconventional knowledge, skills and training as well as additional expenses such as installation and purchasing costs. With reference to Brkic (2018), Oke et al. (2023 a and b), improvements in the knowledge and the advance of several computer systems, there is a need to evaluate EPANET (which is simple in application and is obtainable at no further cost) in Water Supply analysis, which has been used by various researchers such as Jia et al. (2008); Mehta et al. (2015a and b); Karim and Sahib (2019); Saminu et al. (2013); Lungariya et al. (2016); Rai and Sanap (2017); Oke et al. (2023 a and b) and Ghonim et al. (2024). It is essential to look into the adequacy and establish a dependable network ascertaining adequate discharge rate, velocity of discharge and pressure head at user nodes. The finding of discharge rate, velocity of discharge and pressure in water supply and distribution has been of outstanding value and interest for water resources, hydraulic, and civil engineers, which are people necessitated with the design, construction and maintenance of potable water supply and distribution systems. Analysis and design of water supply networks are considered relatively complex, particularly when the system consists of a wide range of pipes as it commonly occurs in water supply and distribution systems of large municipal and metropolitan areas. Although, several studies used the EPANET software, there is a scientific gap in representing the difference in the hydraulic properties specifically f_f by using the three techniques of different head loss equations. The focal aim of this research is to evaluate the hydraulic adequacy of the three techniques available at the EPANET software platform, with a critical aim of showing the difference in the f_f and of attaining sustainable development goals such as (SDGs 3), clean and potable water, and sanitation, (SDGs 6); and life on land (SDGs 15, Dalampira and Nastis, 2019) as a function of head loss in pipes, which has been found to be a function of operational cost of Water Supply scheme (Ihle, 2013; Luo et al., 2014; Lee et al., 2014a and b; 2015; Shital et al., 2016; Lungariya et al., 2016; Sakr et al., 2018; Perez- Sanchez et al., 2018; Hashemi et al., 2020; Kuok et al., 2020).

MATERIALS AND METHODS

Pipeline and pipe layouts in Elizade University were identified. Elizade University (EU) is one of the private Universities in Nigeria. The University is located in Ilara-Mokin, a mini-city in Ondo State, Southwest, Nigeria (Figure 1). EU has an increasing population of 3,150 people, including students and staff members. EU is one of the promising private Universities in Nigeria (Oke et al., 2023 a and b). Node and valves in these pipelines and pipe layouts were marked. Pipe length, pipe's diameter, and elevations at each marked node were measured using Garmin GPS 72H. The population of the institution was collected from 2011 to 2018. The growth rate of the population was identified and computed. The population was projected from 2019 to 2026 (based on the strategic plan of the University Management and the pattern of the population growth) by using geometrical progression as follows Oke et al. (2023 a and 2023b):

$$G_t = G_0(1 + g_r)^p \quad (6)$$

Where; G_t is equivalent to the EU's projected population; G_0 is equivalent to the EU's population at the base year, g_r is equivalent to the EU's population growth rate and p is equivalent to the life span of the network. Water withdrawals at all the nodes were computed using the projected population at the node and water withdrawal per capita per day as follows (Oke et al., 2023 a and 2023b):

$$Q_{wd} = G_t q \quad (7)$$

Where; Q_{wd} is equivalent to water withdrawal per node and q is equivalent to water withdrawal per capita per day 75 l/p.d for individual students at the hostel, 150 l/p.d for non-students but members at the staff's quarter and 40 l/p.d for all the people or population at the senate buildings, faculty and academic areas (Safitri et al., 2023). The Water supply distribution network was drawn as a pipe network using AutoCAD software (Figure 2). Software EPANET 2.2 (EPANET) is a software application utilised worldwide to model water quality and distribution systems. EPANET software (software package) is a public and free access website or domain, for water quality, pipe network analysis and water distribution modelling developed and made available by the United States Environmental Protection Agency's Water Supply and Water Resources Division) was downloaded from https://www.epa.gov/water-research/epanet and installed (Rossman, 2000a; Jia et al., 2008; Saminu et al., 2013; Mehta et al., 2015; Rai and Sanap, 2017; Muller et al., 2020 and Oke et al., 2023 a and 2023b)). EPANET 2.2 was utilised to analyse the drawn pipe network with the three basic techniques of head loss computation techniques available at EPANET platform. Figure 3 presents the detailed flow chart and procedures for utilizing EPANET 2.2 in a single period. Correlation between the diameter of the pipe, friction factors, Reynold number and headloss coefficients were established using MiExS (equations 8 and 9).

$$f_v = K_m C_{HW}^a R_e^b D^c \quad (8)$$

$$f_{vu} = K_{uw} R_e^b D^c \quad (9)$$

Figure 4 shows the flow chart for using MiExS. The hydraulic properties (f_f in the individual pipes) obtained using the three head loss techniques were evaluated relative and square errors as follows:

a) Sum relative error (SR_v) was computed as follows:

$$SR_v = \sum_{i=1}^{N} \left| \frac{X_{mesi} - X_{cali}}{X_{mesi}} \right| \quad (10)$$

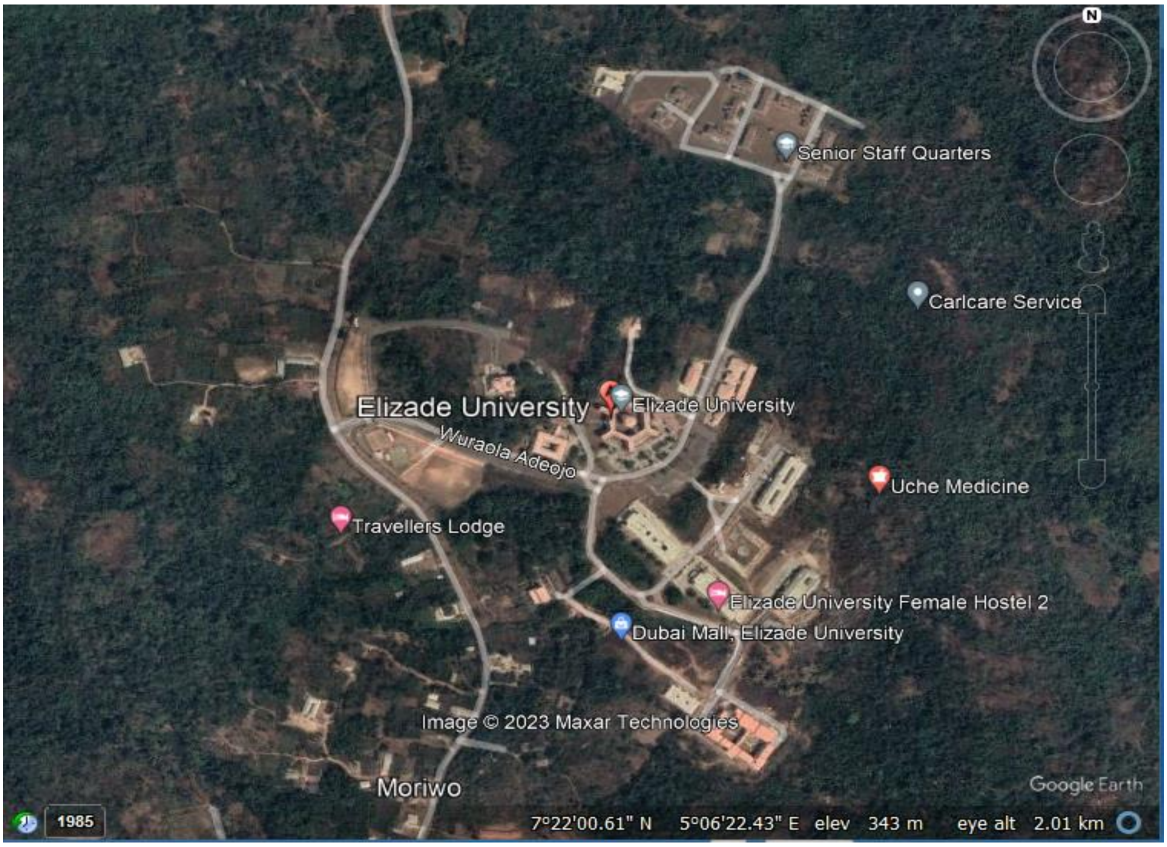

Figure 1: Location of EU and an aerial view of the University environment

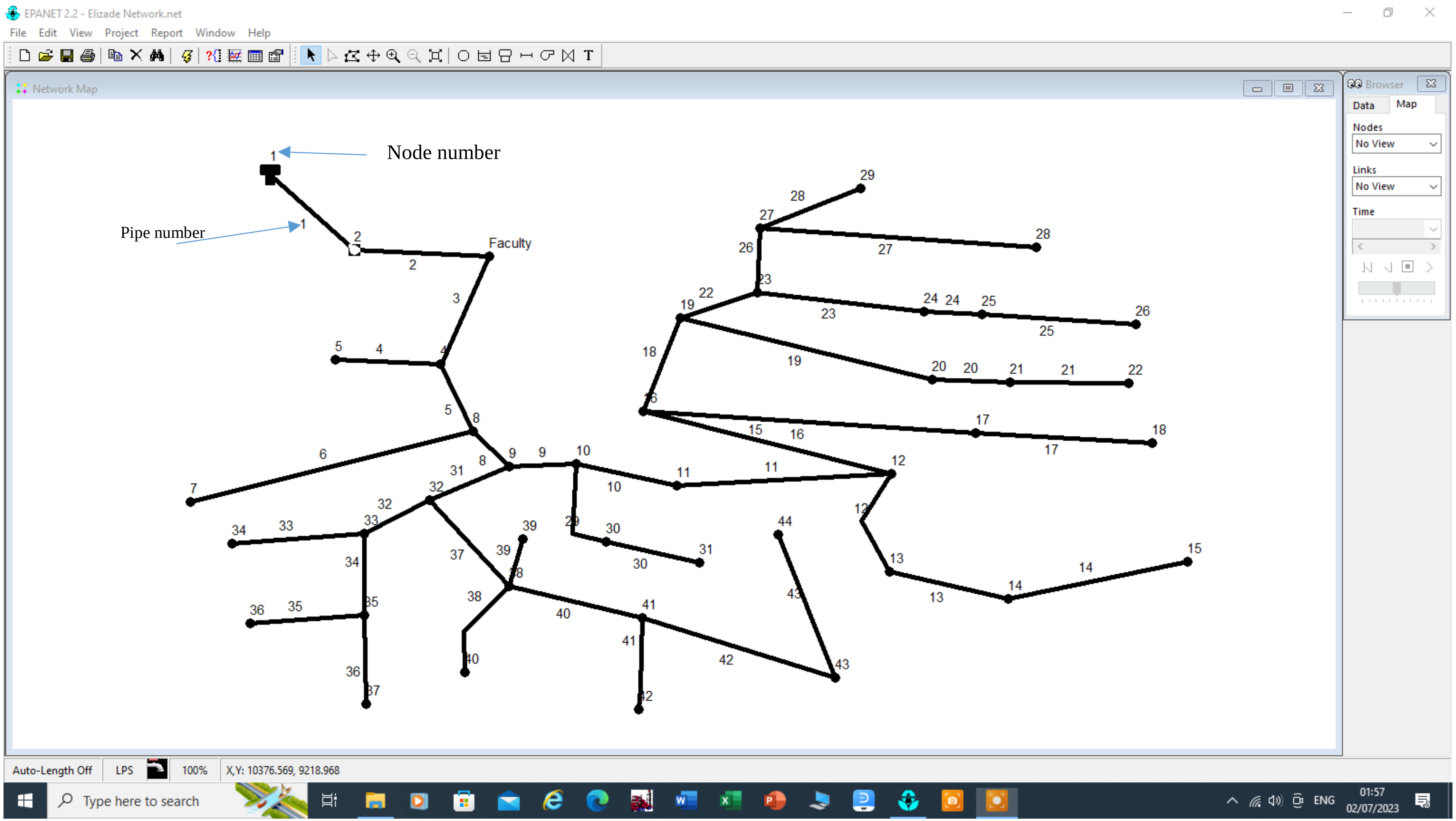

Figure 2: the pipeline and pipe layout and the Label (with nodes and pipes numbers).

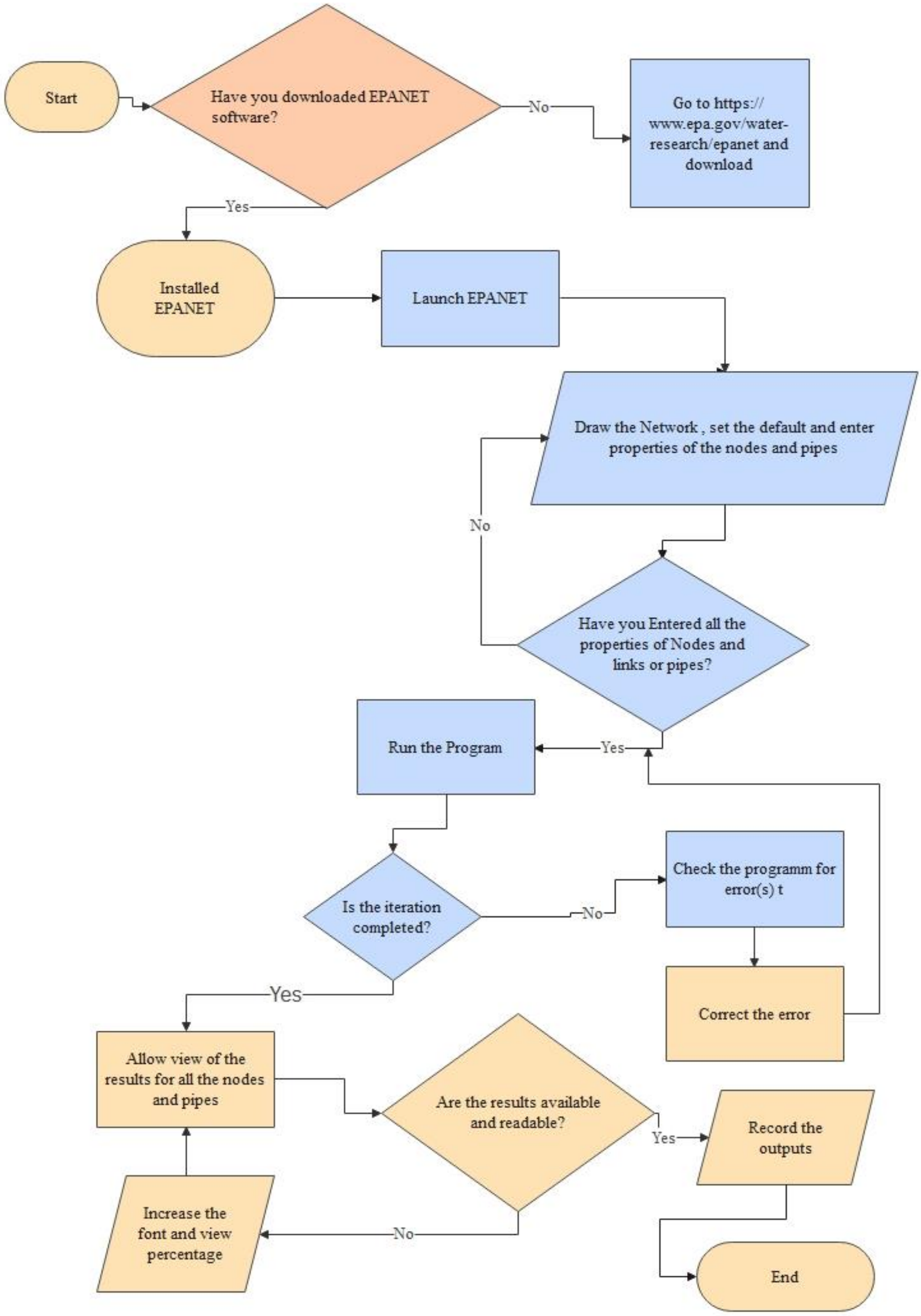

Figure 3: Flow Chart and procedures for the utilization of EPANET

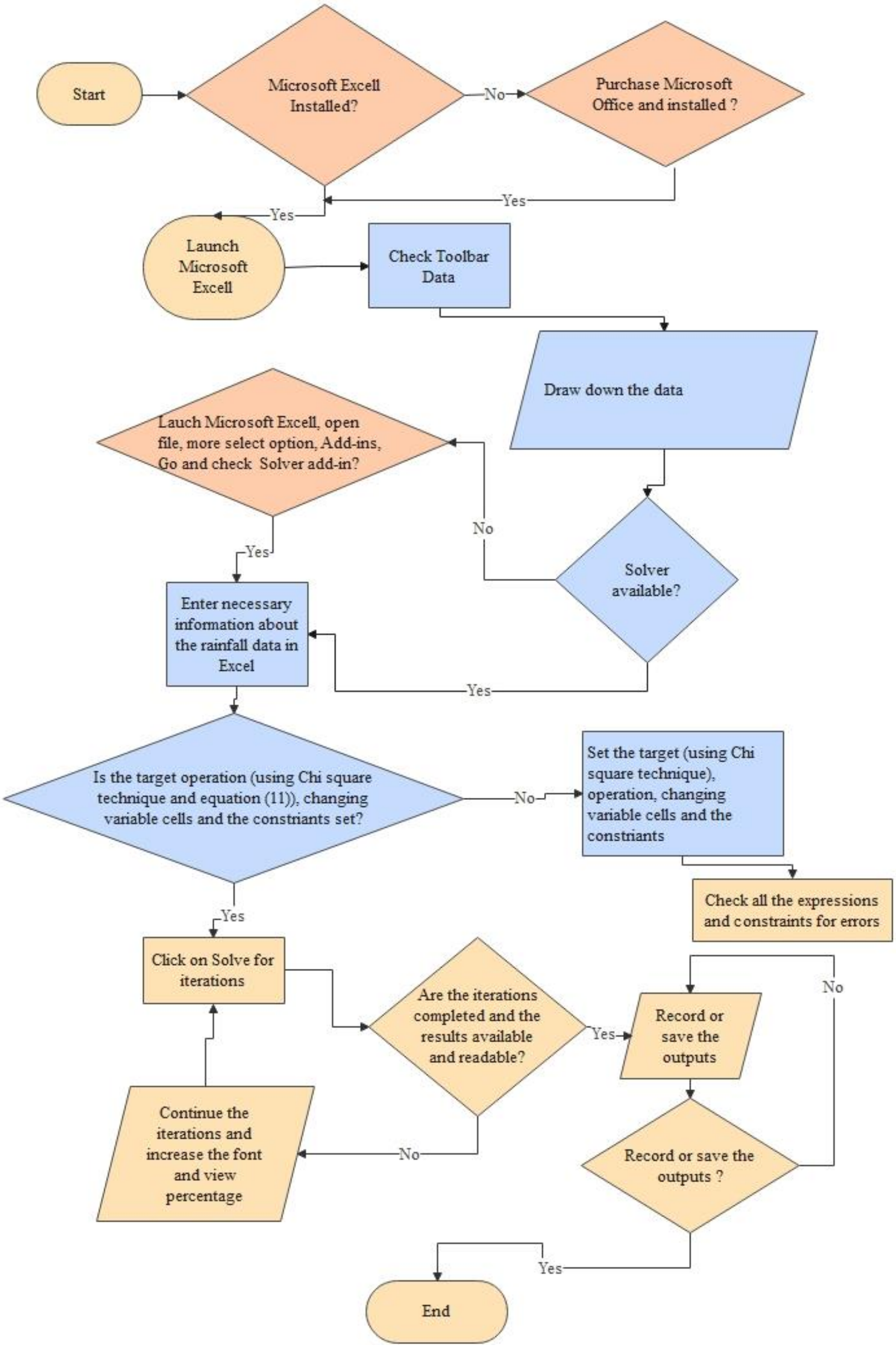

Figure 4: Flow Chart for the utilization of MiExS

Where; X_{mesi} is the expected value and X_{cali} is the calculated values.

b) Average relative error (AR_v) was computed as follows:

$$AR_v = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{X_{mesi}-X_{cali}}{X_{mesi}}\right| \quad (11)$$

c) Root relative error (RR_v) was computed as follows:

$$RR_v = \sqrt{\sum_{i=1}^{N}\left|\frac{X_{mesi}-X_{cali}}{X_{mesi}}\right|} \quad (12)$$

d) Sum Square error (SSS_v) was computed as follows:

$$SSS_v = \sum_{i=1}^{N}\left|\left(\frac{X_{mesi}-X_{cali}}{X_{mesi}}\right)^2\right| \quad (13)$$

e) Average Square error (ASS_v) was computed as follows:

$$ASS_v = \frac{1}{N}\sum_{i=1}^{N}\left|\left(\frac{X_{mesi}-X_{cali}}{X_{mesi}}\right)^2\right| \quad (14)$$

f) Root Square error (RSS_v) was computed as follows:

$$RSS_v = \sqrt{\sum_{i=1}^{N}\left|\left(\frac{X_{mesi}-X_{cali}}{X_{mesi}}\right)^2\right|} \quad (15)$$

RESULTS AND DISCUSSION

The results and outputs of the study are presented and discussed in the following categories as follows:

Water Supply and Distribution line: Figure 5(a and b) shows the water supply and distribution line, the length and the diameter of the pipe, treated water withdrawal and the elevation at all the nodes. The figure showed that the maximum elevation at EU was 3.90 x 10^2 m at the reservoir and overhead tank. The lowest elevation on the water supply and distribution line at EU was 3.391 x 10 ^{2} m which occurred at node 34 on the network. The difference between the highest elevation at EU and the lowest elevation at EU provided hydraulic energy or head of 5.09 x 10^1 m of water. This energy provided by the difference in the elevation supports the distribution or support of the supply of treated or stored treated water by gravity easily to the University (hostels and staff quarter). Figure 5a presents the water supply and distribution network, the elevation at each node and the diameter of the pipes in the water supply and distribution network. The figure showed that the diameter of these pipes in the EU was between 1.50 x 10^2 mm at the reservoir or overhead tank and 5.0 x 10^1 mm at the consumers' or water distribution terminals. This outcome of the analysis shows that the pipe diameters in this water supply and distribution network are a function of water withdrawal at the nodes and the expected water flow of discharge in the pipes. The figure (Figure 5b) unveiled water withdrawal at each of the nodes of water supply in the EU and the pipe length in the water supply network. The figure established that the lowest or minimum treated water demand or water demand in EU was 0.0 l/s at nodes 42. Further study revealed that at node 42 there were no population (it is neither academic building nor residential area). The peak or highest water withdrawal or demand occurred at node 42. The peak water demand was 4.60 x 10^2 l/s a further study that it was the hostels for both male and female students.

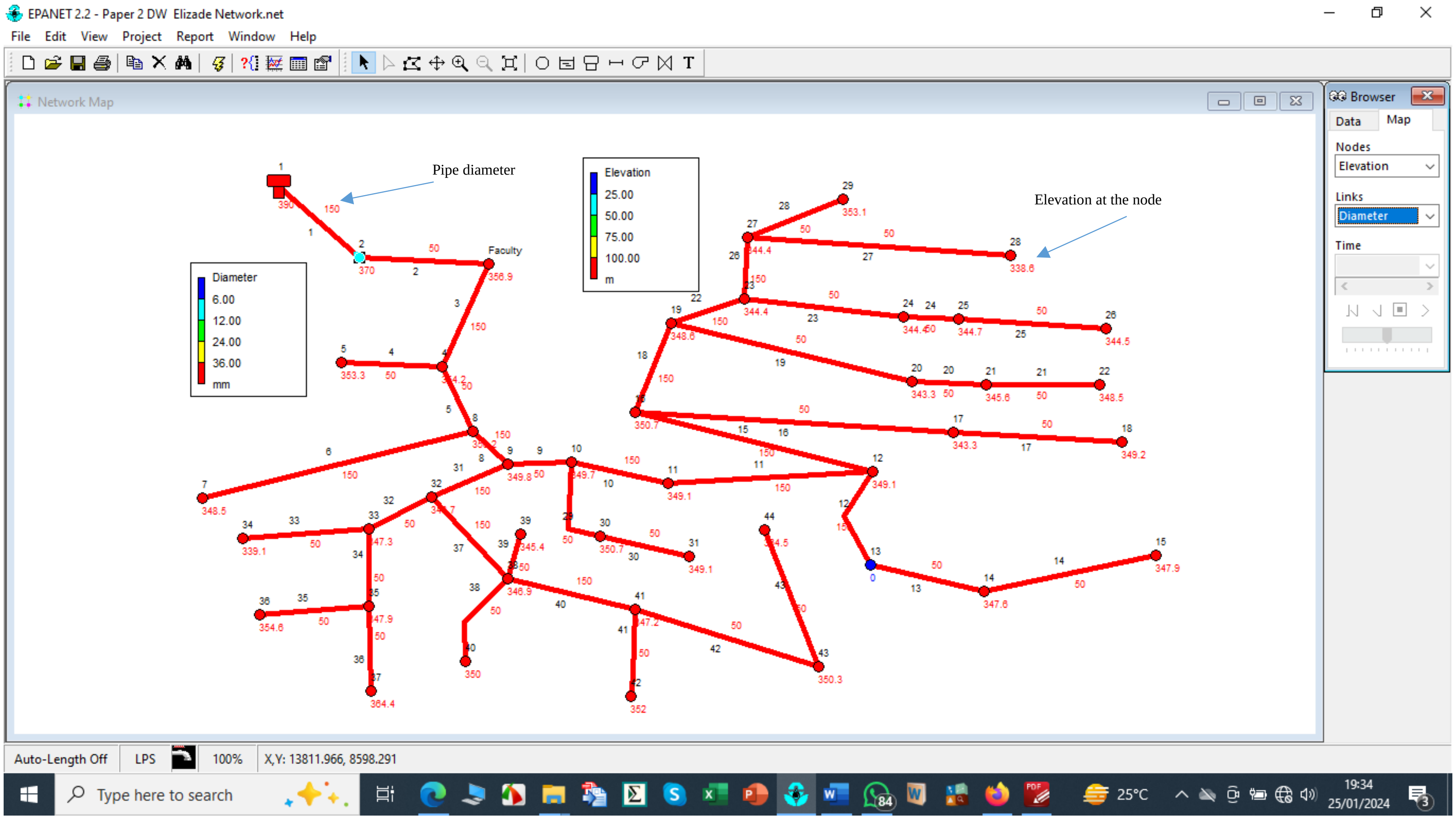

Figure 5a: Analysis of Pipeline and pipe layout Using DW with elevation and the diameter of the pipes

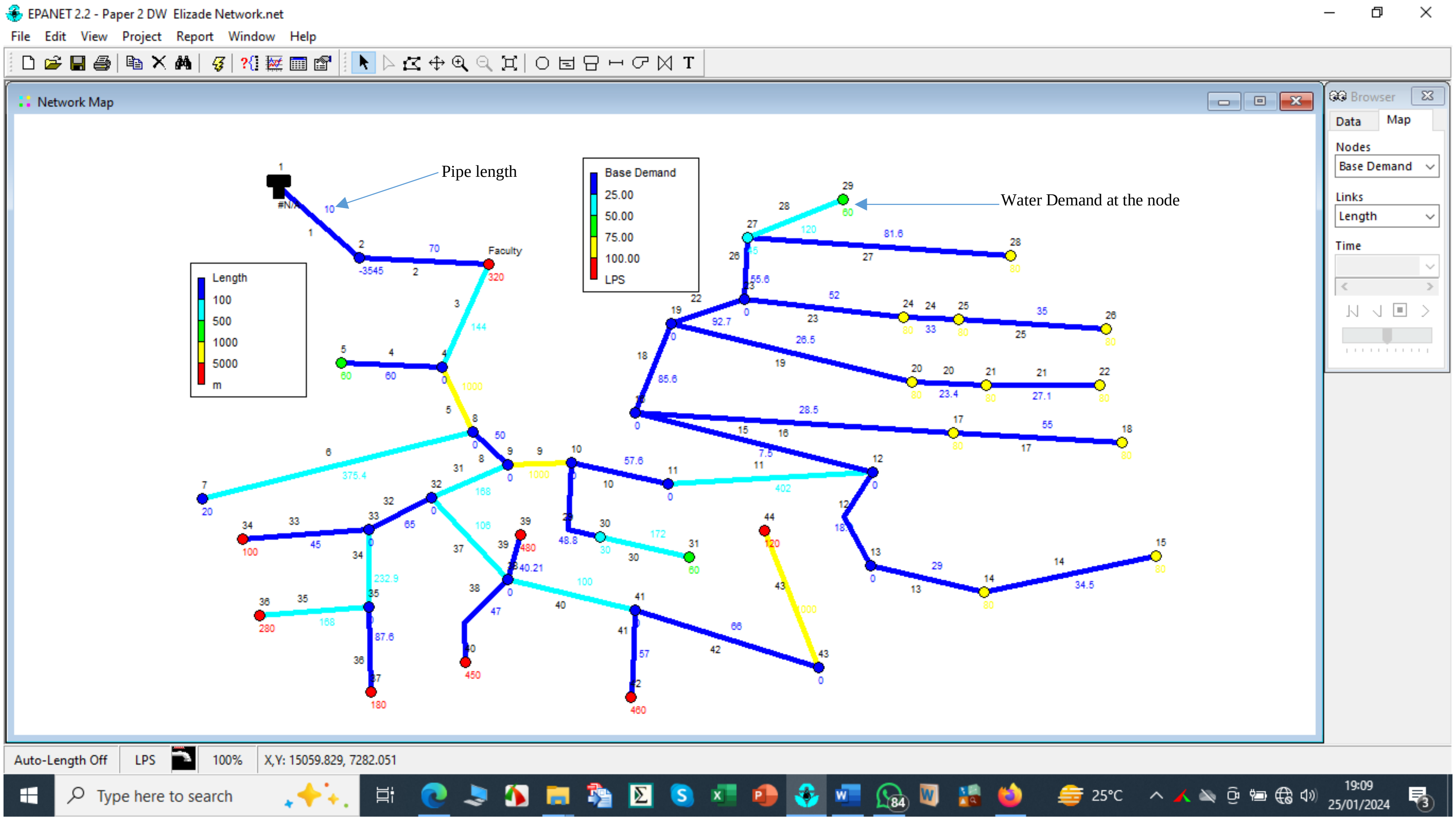

Figure 5b: Analysis of Pipeline and pipe layout Using DW with Base demand (water demand) and length of the pipes

These findings support conclusions and observation in some studies such as Aathira and Elangovan (2021), Agunwamba et al. (2018); Amaral (2020); Anisha et al. (2016); Georgescu et al. (2014); Iglesias-Rey et al. (2017); Jaimovi et al. (2015); Jain et al. (2019); Jumanalmath et al. (2017) and Marui-Paloka and Paanin (2020). The figure revealed that the length of these pipes was between 1.0 x 10^1 m at the tank to node 2 and 1.20 x 10^2 m at the node 27. The indication of this is that the length of pipes in any water supply and distribution network is a function of bend or intersection (Mohapatra et al., 2012; Muranho et al., 2014; Alkali et al., 2017; Nallanathel et al., 2018; Nwajuaku et al., 2017 and Ormsbee and Walski, 2016). More on the water supply and distribution network in the EU can be found in study such as Oke et al. (2023 a and 2023b).

Pipe Network Analysis: The analysis was conducted using three head loss- techniques (HW, DW and CM) available at EPANET 2.2. The results are presented as shown in Figure 6. Figures 6a, b and c exhibited the water supply and distribution network and the direction of discharge, which established that water discharges from higher elevations to lower elevations for DW, HW and CM, respectively. These Figures 6a, 6b and 6c bring home the water supply and distribution network and the discharges in the pipes and direction, which revealed that the highest discharge was 3.545 x 10^3 l/s within pipe 2(the primary pipe from the tank) and the lowest discharge within pipe was 2.0 x 10^1 l/s which occurred in pipe 6. This result established there are primary pipe (which channels water from the major source), and secondary pipe (which acquits water from the primary) and tertiary pipe (which convey water to the consumers). The study revealed that secondary pipes are accessible in the water supply network in the EU. The water supply network without secondary pipes in the EU network can be attributed to the cost-saving technique adopted by the management and profit-making technique implemented by both consultant and contractor. The findings revealed the most frequent flow regime in water supply networks (Rossman, 2000b; Parmar, 2019; Safitri et al., 2023; Sil et al., 2013; Sumitha and Amaranath , 2013 Sunela and Puust, 2015 and Venkata et al., 2015). Consequently, the performance of DW and HW in discharge in the pipes revealed that the manufacturer must have verified the pipe performance using both equations to assure adequate performance of the pipes and that the product meets all applicable codes and standards.

Hydraulic Performance and Evaluation of the Pipe Network Analysis: The technical performance and evaluation are tools that are linked to specific attributes of the water supply system. These tools evaluate the effect of pressure, flow and headloss-dependent analysis on the quantity of water distribution network (Muranho et al., 2014). These evaluations in this study grouped the water distribution behaviour in agreement with merit and specific scale. The tool evaluated the behaviour of each node and link elements by comparison of their values. The analysis was conducted using three head loss techniques available at EPANET 2.2. Figure 7 shows the friction factors for the three techniques and MiExS technique. The friction factor of the pipe is not a constant, function of the diameter of the pipe, discharge and velocity of the pipe. This agreed with the comments and observations made in the study by Brikc (2018) and Oke et al. (2023 a and 2023b). The Figure revealed that in all the cases the friction factors from CM had the highest values, which gave the highest head losses. In addition, the CM technique gives the highest head loss in the pipes, which indicates that CM is not the best technique or among the best formulae for pipe network analysis on the EPANET platform. It can be stated again that in the computation of head loss and friction factors in pressurised pipe of the pipe network. This observation with studies such as Liou (1998), which stated that, unlike CM, the HW equation was developed only for water and is applicable for a pipe with a turbulent discharge, while the DW equation is applicable for all flow regimes and can be used for any type of fluid. The HW equation is fairly easy to utilise compared to the others due to many reasons.

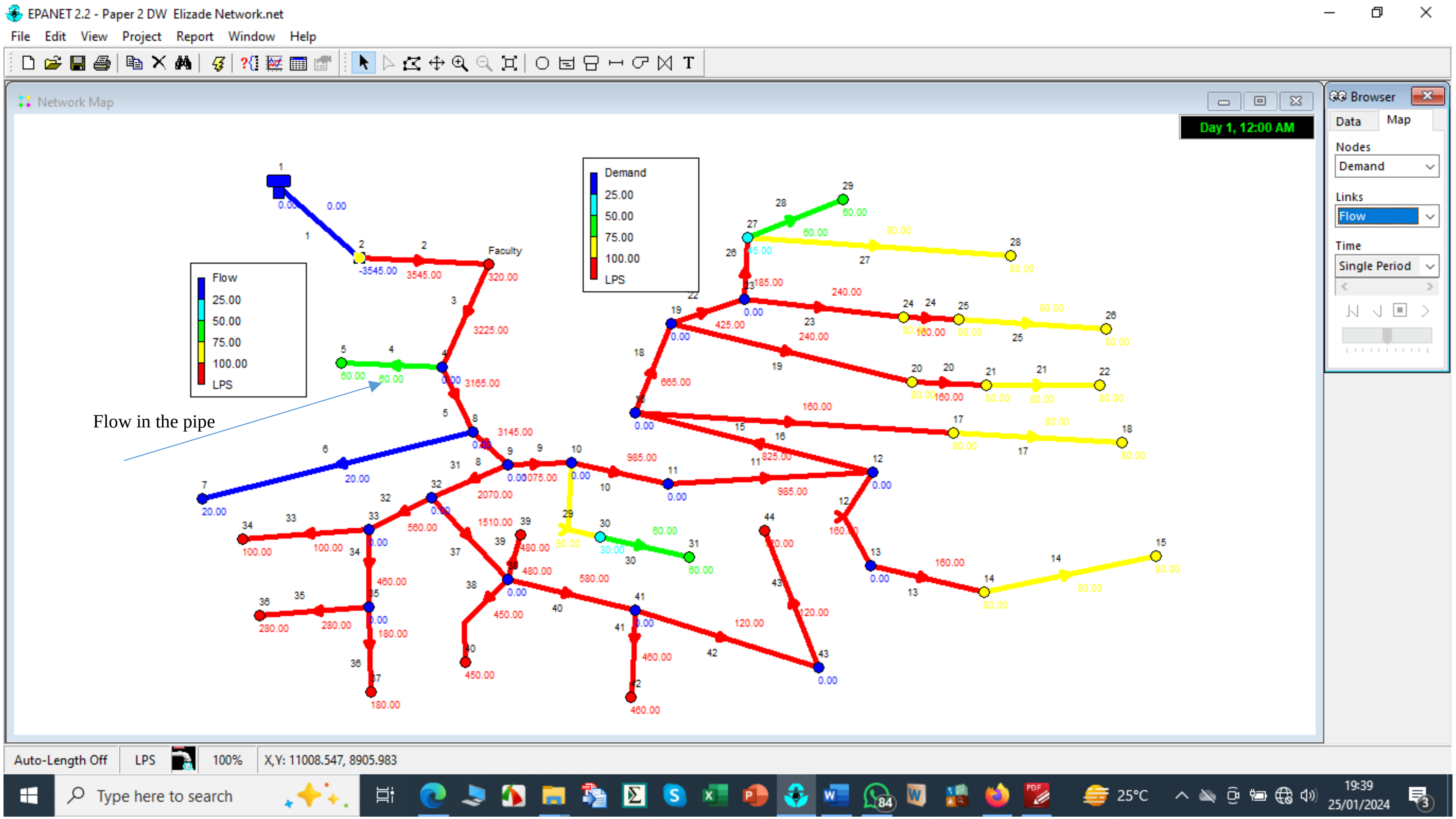

Figure 6a: Flow in the pipes and base demand from the pipe analysis using DW technique

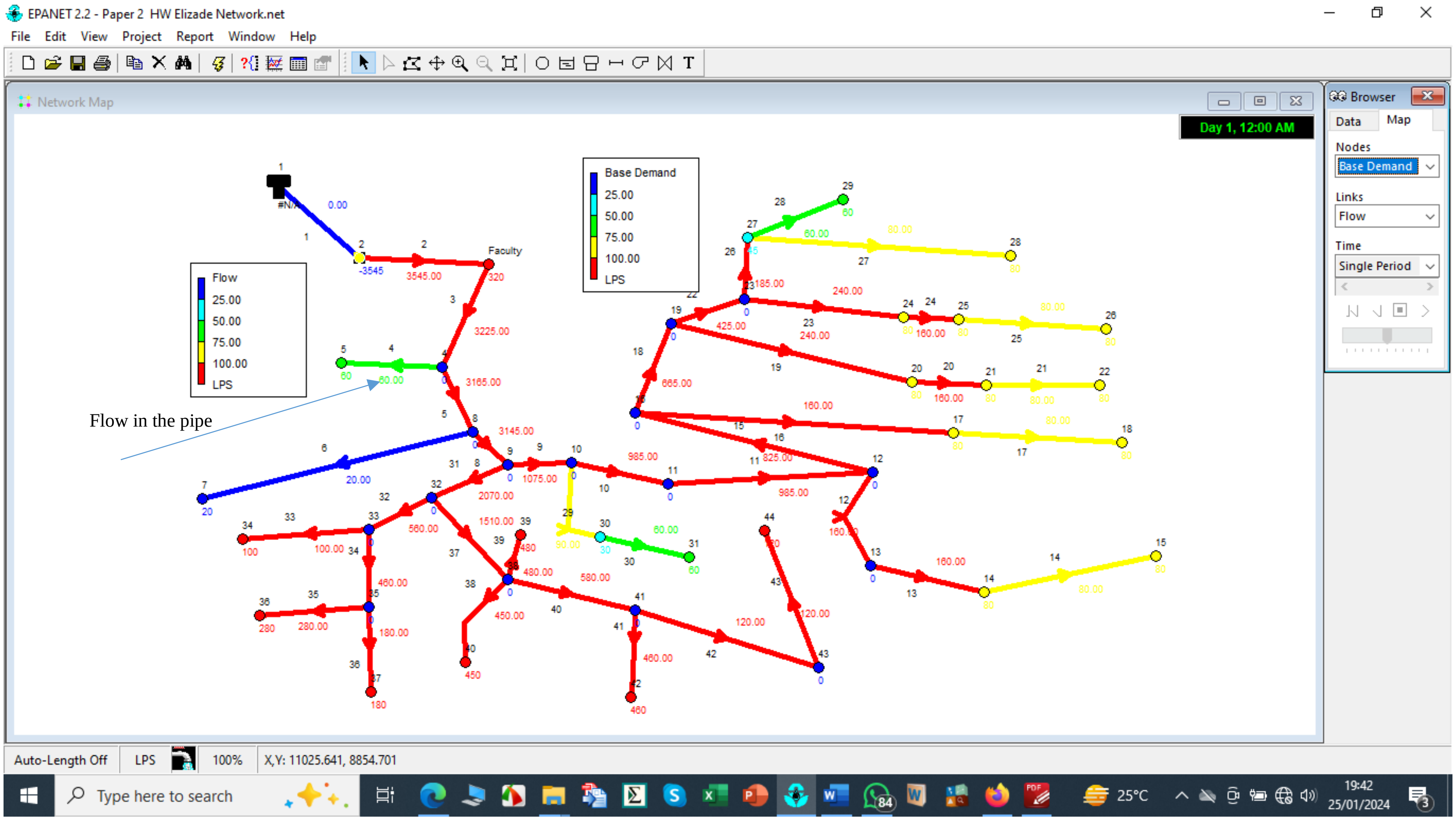

Figure 6b: Flow in the pipes and base demand from the pipe analysis using HW technique

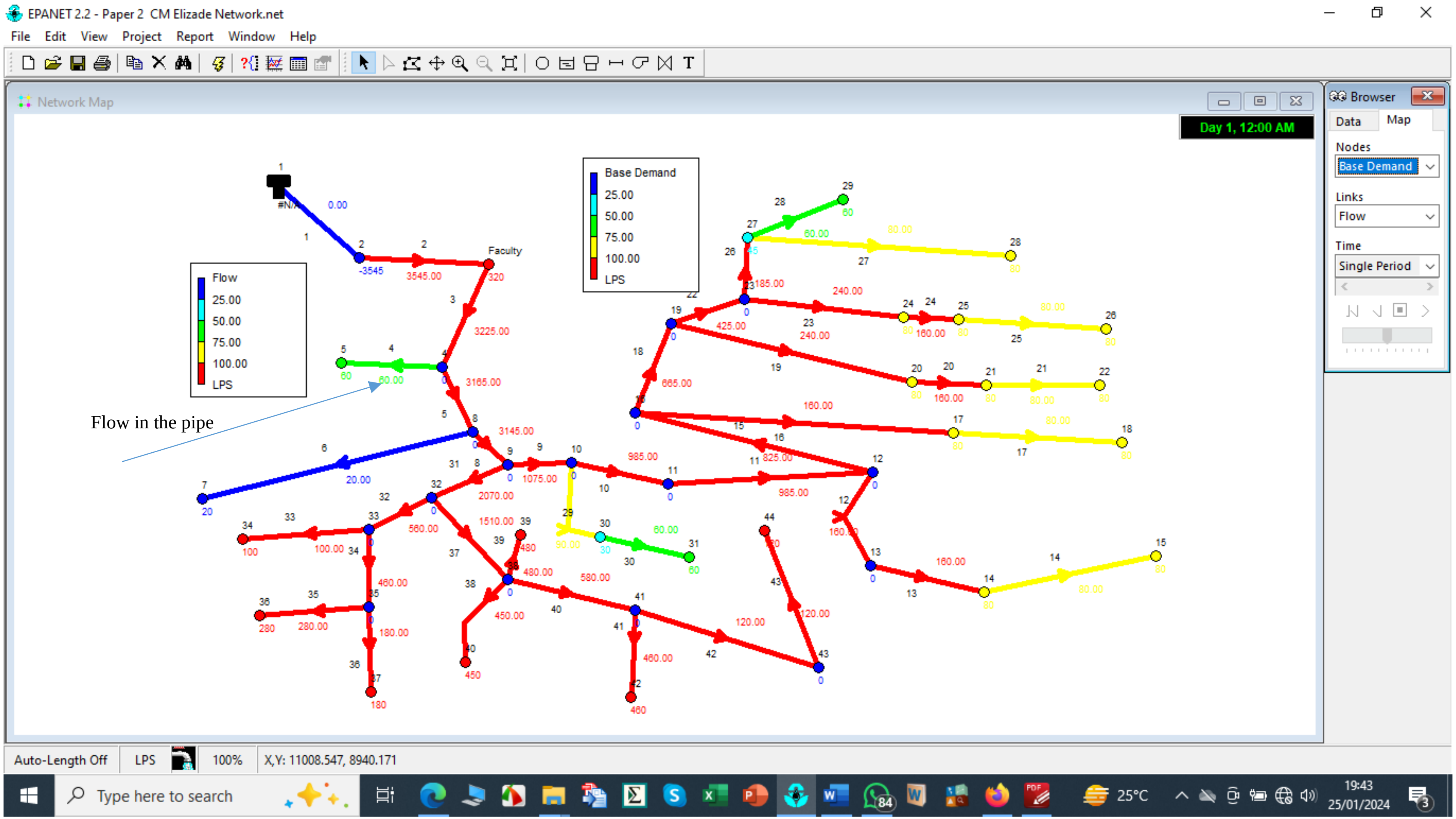

Figure 6c: Flow in the pipes and base demand from the pipe analysis using CM technique

Studies used both of the equations to calculate friction in different engineering fields namely irrigation (Valiantzas, 2005), water supply (Jamil and Mujeebu 2019), pipe age (Kuok et al., 2020), pipe size (Hashemi et al., 2020), pipe network design (Valiantzas, 2008), friction factor estimation (Achour and Amara, 2020), water supply technique (Simpson and Elhay, 2011) and software engineering programming (Abdulameer *et al.*, 2022a and b). Although the stated research utilised the HW and DW equations, there is a scientific gap represented by using the CM head loss equation, which shows the difference between these techniques. This result can give a wide and higher magnitude of energy or head loss through the transmission of fluid for many kilometres (Abdulameer and Dzhumagulovs, 2022; Abdulameer *et al.*, 2021 and 2022). These findings support conclusions and observations in some studies such as Aathira and Elangovan (2021), Agunwamba et al. (2018); Amaral (2020); Anisha et al. (2016); Georgescu et al. (2014); Iglesias-Rey et al. (2017); Jaimovi et al. (2015); Jain et al. (2019); Jumanalmath et al. (2017) and Marui-Paloka and Paanin (2020). The other hydraulic performance analysis and evaluation method is based on three critical components of hydraulic and fluid. The three components are Reynolds number, friction factors and the diameter of the pipe. These evaluation curves state a relation between the variable values and the performance classification scales. Figure 8 presents the correlation between R_e, friction factors and the diameter of the pipes. Figure 8a shows the correlation between R_e, friction factors and the diameter of the pipes for the CM technique. Figure 8b shows the correlation between R_e, friction factors and the diameter of the pipes for the DW technique. Figure 8c shows the correlation between R_e, friction factors and the diameter of the pipes for the HW technique. These three Figures established that there is a correlation between these parameters. These Figures revealed that these correlations are not linear but logarithms, non-linear or polynomial in shape even at a very high friction factor of 10^5 as in the case of CM. These indicate that the correlation between R_e, friction factors and the diameter of the pipes grows not linearly, but rather in the form of logarithms, non-linear or polynomial. Table 1 presents the numerical values of the constant for the correlation between R_e, friction factors and the diameter of the pipes. The table revealed that in the case of equation (8), C_{HW} and D in all the cases are negative factors, which indicates that friction factors increase with decreasing values of C_{HW} and D. The correlation between R_e, friction factors and the diameter of the pipes can be expressed for DW, MiExS, HW and CM, respectively as follows (equations 16 to 19):

$$f_v = 0.7813 C_{HW}^{-0.1333} R_e^{0.0090} D^{-0.3299} \quad (16)$$
$$f_v = 0.7572 C_{HW}^{-0.1533} R_e^{0.0090} D^{-0.3541} \quad (17)$$
$$f_v = 0.7719 C_{HW}^{-1333} R_e^{0.0090} D^{-0.3409} \quad (18)$$
$$f_v = 3.0290 C_{HW}^{-0.1107} R_e^{0.0630} D^{2.7730} \quad (19)$$

In addition, the table revealed that in the case of equation (9), R_e in all the cases is a negative factor, which indicates that friction factors increase with decreasing values of R_e. The correlation between R_e, friction factors and the diameter of the pipes in the case of equation (9) can be expressed for DW, MiExS, HW and CM, respectively as follows (equations 20 to 23):

$$f_{vu} = 0.0273 R_e^{0.00365} D^{-0.2763} \quad (20)$$
$$f_{vu} = 0.0244 R_e^{-0.0101} D^{-0.1394} \quad (21)$$
$$f_{vu} = 0.0273 R_e^{0.0365} D^{-0.2764} \quad (22)$$
$$f_{vu} = 156210.3214 R_e^{0.0471} D^{-0.8553} \quad (23)$$

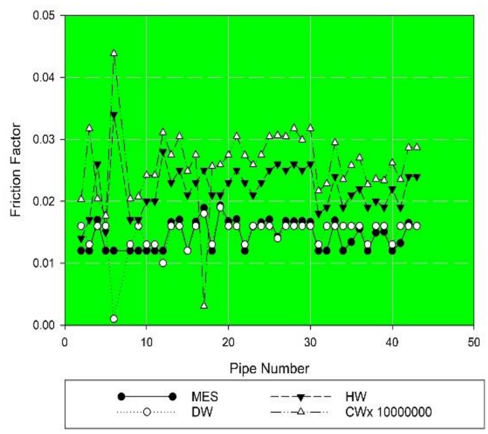

Figure 7: The friction factors obtained using the four techniques (HW, DW, CM and MES).

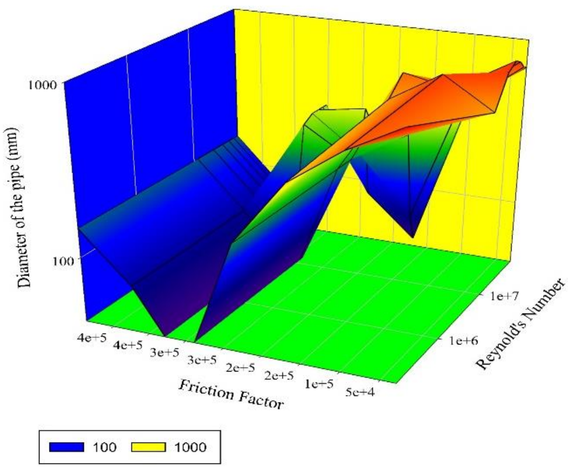

Figure 8a: The relationship between R_e, friction factors and the diameter of the pipes from the CM technique.

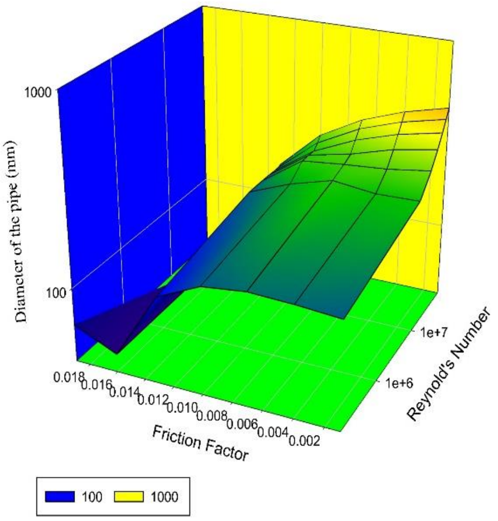

Figure 8b: The relationship between R_e, friction factors and the diameter of the pipes from the DW technique

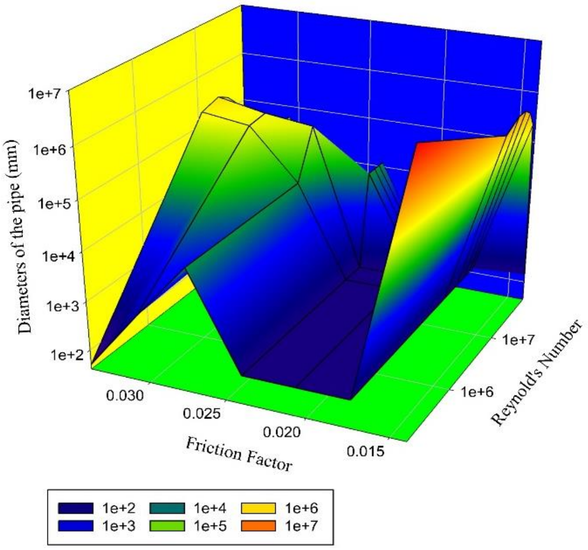

Figure 8c: The relationship between R_e, friction factors and the diameter of the pipes from the HW technique

Table 2 shows the result of the analysis of the variance of the constants and imperial parameters in the relationship between f_f and other selected hydraulic properties. The Table revealed that there are significant differences between these constants and the head loss techniques, which established that there are significant differences between the f_f. These results agreed with previous studies such as Aathira and Elangovan (2021), Agunwamba et al. (2018); Amaral (2020); Anisha et al. (2016); Georgescu et al. (2014); Iglesias-Rey et al. (2017); Jaimovi et al. (2015); Jain et al. (2019); Jumanalmath et al. (2017) and Marui-Paloka and Paanin (2020). Table 3 presents the summary of the statistical evaluations of the three head loss techniques. The Table revealed that average square errors were in the range of 5.9 x 10^{-06} to 7.1x 10^{10} ; the sum of square errors was between 2.4 x 10^{-04} and 2.9 x 10^{12}; root square errors ranged from 1.6 x 10^{-02} to 1.7 x 10^{06} . In all the cases, the errors (relative and square errors) from the DW techniques yielded the lowest errors with 5.9 x 10^{-06}, 2.8 x 10^{-03} and 1.6 x 10^{-02} for average square errors, the sum of square errors and root square errors respectively. In addition, in the case of relative errors, these errors range from 1.2 x 10^{-01} to 1.8 x 10^{07}; the sum of square errors was between 4.8 and 7.5 x 10^{08}; root square errors range from 2.2 to 2.7 x 10^{04}. In all the cases, the highest relative errors originated from the CM techniques with 2.7 x 10^{04}, 7.5 x 10^{08} and 1.8 x 10^{07} for average square errors, sum of square errors and root square errors respectively. These findings established that DW gave the lowest errors of f_f, followed by HW and CM gave the highest errors, which indicates that the degree of accuracy of these three headloss techniques is in order of DW greater than HW greater than CM. This observation agreed with the conclusions from some previous studies (Parmar, 2019; Safitri et al., 2023; Sil et al., 2013; Sumitha and Amaranath , 2013 Sunela and Puust, 2015 and Venkata et al., 2015). It has been reported that the Hazen-Williams (HW), Chezy-Manning (CM) and Darcy-Weisbach (DW) formulas are the three most vulgar drag formulas for pressurized discharges. Though the practical application of Hazen-Williams is quite frequent in practice, the latter formulas have a much more sensible basis and are acceptable in the determination of a critical event of f_f through water supply and distribution (Abdulameer *et al.,* 2022a; Zolapara and Morbi, 2015; Yazici et al., 2023).

Table 1: Constants for friction factors and hydraulic correlation

Summary	HW		DW		MiExS		CM	
K	0.7719	0.0273	0.7813	0.0273	0.7572	0.0244	3.0287	156210.3214
a	-0.1333	0.0000	-0.1333	0.0000	-0.1533	0.0000	-0.1107	0.0000
b	0.0090	0.0365	0.0090	0.0365	0.0090	-0.0101	0.0634	0.0471
c	-0.3409	-0.2764	-0.3299	-0.2763	-0.3541	-0.1394	2.7725	-0.8553

Table 2: Results of analysis of the variance of headloss, Reynolds number and f_f through water supply and distribution

Source of Variation	*Sum of Square*	*Degree of freedom*	*Mean Sum of Square*	*F-Value*	*P-value*
Between the Constants	3.544447	3	1.181482	2.885614	0.064238
Columns	7.134698	6	1.189116	2.904259	0.036829
Error	7.369898	18	0.409439		
Total	18.04904	27			

Table 3: Statistical evaluations of the three hydraulic techniques on the EPANET platform

Parameters	Square Errors			Relative Errors		
	DW	**HW**	**CM**	**DW**	**HW**	**CM**
Average	5.9×10^{-06}	6.9×10^{-05}	7.1×10^{10}	1.2×10^{-01}	5.4×10^{-01}	1.8×10^{07}
Sum	2.4×10^{-04}	2.8×10^{-03}	2.9×10^{12}	4.8	2.2×10^{01}	7.5×10^{08}
Root	1.6×10^{-02}	5.3×10^{-02}	1.7×10^{06}	2.2	4.7	2.7×10^{04}

CONCLUSION

This study evaluated the three head loss techniques available on the EPANET platform. It was concluded based on the error values from f_f, Reynolds number and headloss calculated that

i. there are significant differences between head losses, Reynold number and f_f through water supply and distribution at a 95 % confidence level,
ii. hydraulically, DW performed better than HW and the least performed technique was CM.
iii. in the selection of hydraulic parameters CM at EPANET platform should not be used for pressurized pipe networks and
iv. With respect to dimensioning, caution is required in its utilization for pressurised pipe network

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