MODELLING WATER LOSS IN HYDRAULIC DISTRIBUTION NETWORKS OF SHIRORO WATER DISTRIBUTION SYSTEM MINNA, NIGER STATE.

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Abstract

Minna, Niger State capital has been facing severe water supply scarcity in recent time, this scarcity has been further complicated with high water loses and non-revenue water in spite of government's allocation to the water sector in the state. Hence, there is need for new and modern approaches which will involve increased automation and proper monitoring of leakages and water loss. In this paper, the hydraulic machine, EPANET was used for the hydraulic modelling of the water loss in the networks of Shiroro District Metered Area, DMA. Leaks were collected and measured from 37 nodes in the network which were prone to leakages. 24 hours Extended Period Simulation, EPS, was carried out by varying emitter coefficient from 0.1, 0.15, 0.2 and 0.3 respectively. The water loss or discharge, Q_{leaks} generated from the model using discharge coefficient of 0.2 and the values of observed leaks Q from site were compared statistically using Nash-Sutcliffe efficiency model to check the performance of the model. The performance of the mode suggested that using the emitter coefficient of 0.2 can model the water loss in Shiroro Water Distribution system because of high correlation between the simulated and the observed discharges.

Keywords: Shiroro Water Distribution System, Non-Revenue Water, EPANET, Emitter Coefficient

INTRODUCTION

Water distribution systems are primary means of safe drinking water supply to the system. Water produced and delivered to the distribution system is intended for the customers or users. However, a significant amount of water is lost in the system before it gets to its intended users as leak which is termed a physical component of Non-Revenue Water, NRW. The occurrence of leaks depends on the factors like materials, composition, age, pressure and joining. Due to complexity of the distribution system, it may be difficult for the utility personnel to identify and fix all the leaks. Current statistical surveys indicated that NRW in developing countries is around 45 to 50% (Putri *et al*., 2021) which represents half of the total system input volume. A high level of apparent losses reduces the principal revenue stream to the utility. Zabidi *et al.* (2020) reported that losses in water distribution system in some urban areas in Nigeria is as high as 50%. High levels of water losses are indicative of poor governance and poor physical condition of the Water Distribution System, WDS, (Kamrani *et al*., 2020). The amount of water loss in water distribution systems varies widely from one system to another, from as low as 3–7 % in the well-maintained systems of developed countries to as high as 50 % of distribution input volume in less maintained system in developing countries respectively (Chan *et al*., 2018).

Many water distribution systems in developing countries are operated under intermittent conditions (Simukonda *et al*., 2018). As a result, water supply efficiency in these countries is compromised. Losses from leaks that are discovered and repaired should be measured to determine the rate of loss and the total volume lost during the life of the leak. Other methods of leak detection are suggested (from Leak Detection Productivity) by Douglas (AWWA California

1. Use a container of known volume.
2. Use a hose and a meter.
3. Calculate losses using modified orifice and friction formula.

An effective leakage management strategy should take into account the pressure dynamics of a water distribution network. This is because pressure plays a pivotal role in enhancing the magnitude of water leakage and because there is a physical relationship between leakage flow rate and pressure (Zhou *et al*., 2018). Thus, the pressure exerted by either gravity or by water pumps results in a corresponding change in leakage rate (Kan *et al*., 2022). The frequency of new pipe bursts is also a function of pressure such that the higher or lower the pressure, the higher or lower the leakage (Berardi and Giustolisi 2021). According to Nasrollahi *et al*. (2021), pressure level and pressure cycling strongly influence burst frequency. Some of the most important ways of managing pressure is by either using pressure reducing valves, PRVs (manual or automatic) or by using variable speed pump controllers. Under normal circumstances a PRV is used to maintain a fixed downstream pressure regardless of the upstream pressure dynamics. The leakage from water distribution systems has been shown to be directly proportional to the square root of the distribution system pressure (García-Ávila *et al*., 2019). Past studies have shown that the rate of increase of bursts is more than linearly proportional to pressure (Xu *et al*., 2020; Berardi and Giustolisi, 2021; Mathye *et al*., 2022). Indeed, it has even been suggested that there could be a cubic relationship, i.e. burst frequency proportional to pressure cubed as reported by Farley and Trow (2003) and Wéber *et al.* (2020).

The objective of this study is to model water loss in the distribution network of Shiroro District Metered Area, Minna, Niger State and to investigate sustainability in terms of equity in the distribution of pipe-borne water in Minna metropolis as regular maintenance of infrastructure also helps to maintain water efficiency levels and is more cost-effective than rehabilitation (Libey *et al*., 2020). Simulation software used in the study area is EPANET. The method used in EPANET to solve the flow continuity and headloss equations that characterize the hydraulic state of the pipe network at a given point in time can be termed a hybrid node-loop approach. Assume we have a pipe network with N junction nodes and NF fixed grade nodes (tanks and reservoirs). Let the flow-headloss relation in a pipe between nodes i and j be given as:

$$H_i - H_j = h_{ij} = rQ_{ij}^n + mQ_{ij}^2 \qquad (1)$$

where H = nodal head, h = headloss, r = resistance coefficient, Q = flow rate, n = flow exponent, and m = minor loss coefficient. The value of the resistance coefficient will depend on which friction headloss formula is being used. EPANET contains a state-of-the-art hydraulic analysis engine that include the following capabilities:

- Places no limit on the sizes of network that can be analysed
- Computes friction head loss using the Hazen-Williams, Darcy Weisbach, or Chezy-Manning formulas
- Includes minor head loss for bends, fittings
- Models constant or variable speed pumps
- Computes pumping energy and cost
- Models various types of valves including shutoff, check, pressure regulating, and flow control valves
- Allow storage tank to have any shape (i.e., diameter can vary with height)
- Consider multiple demand categories at nodes, each with its own pattern of time variation
- Model pressure-dependent flow issuing from emitters 9spinkler head)
- Can base system operation on both simple tank level or timer controls and on complex rule-based controls. One

of the challenges of EPANET is it takes a long time to learn.

From an energy standpoint its capacity is limited to the point at which, in certain circumstances it can supply erroneous results.

METHODOLOGY

Study Area

The study area is Distribution Network System of Shiroro District Metered Area, Minna, Niger State which is located within Latitude 9.59467°, Longitude 6.55427° and 9.59389°, 6.56032° with the total area covered by the distribution network as 1.9Sq km (Fig. 1). The flow chart methodology is depicted in Fig. 2

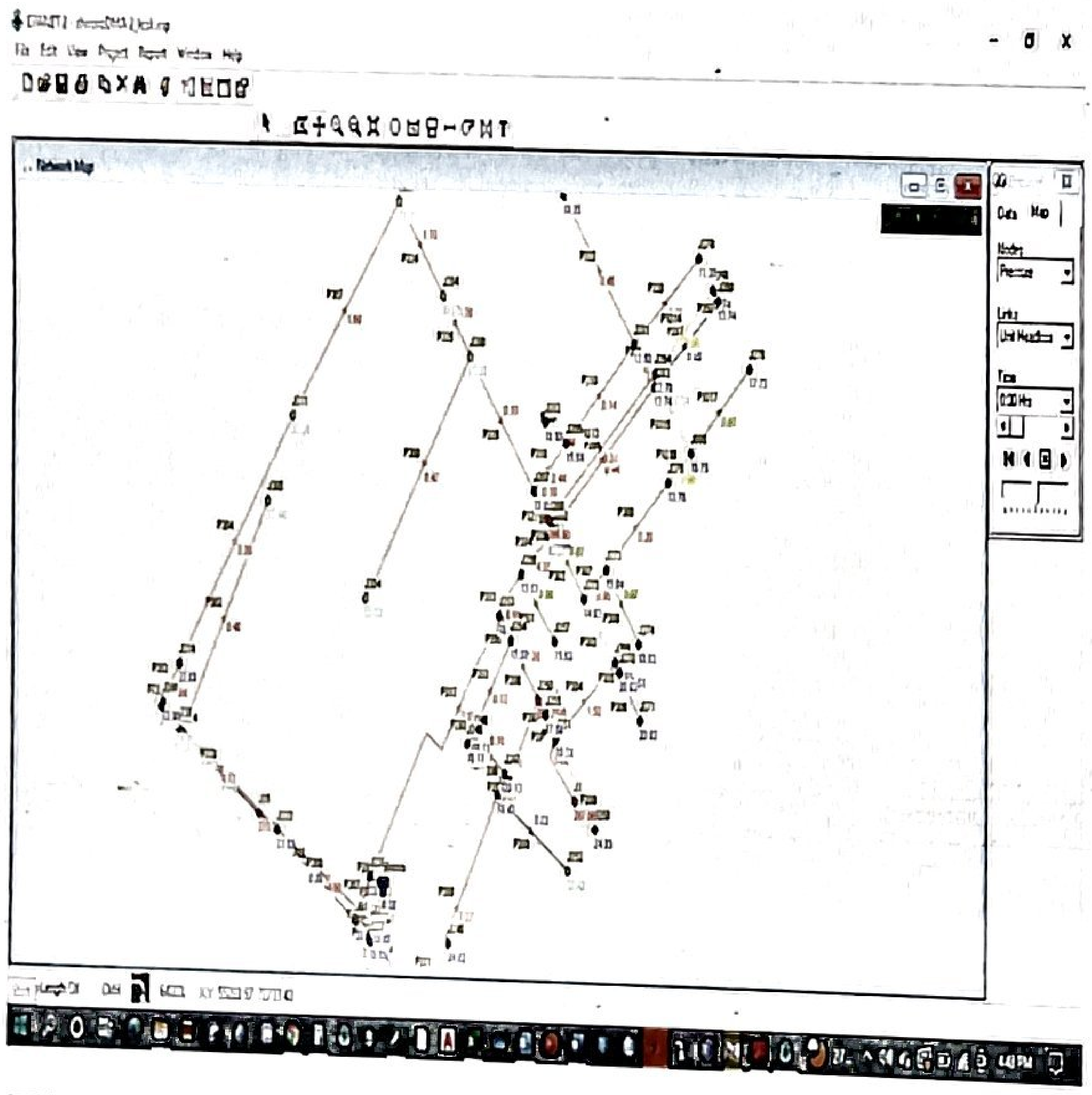

Fig. 1: Shiroro DMA showing the selected nodes for analysis

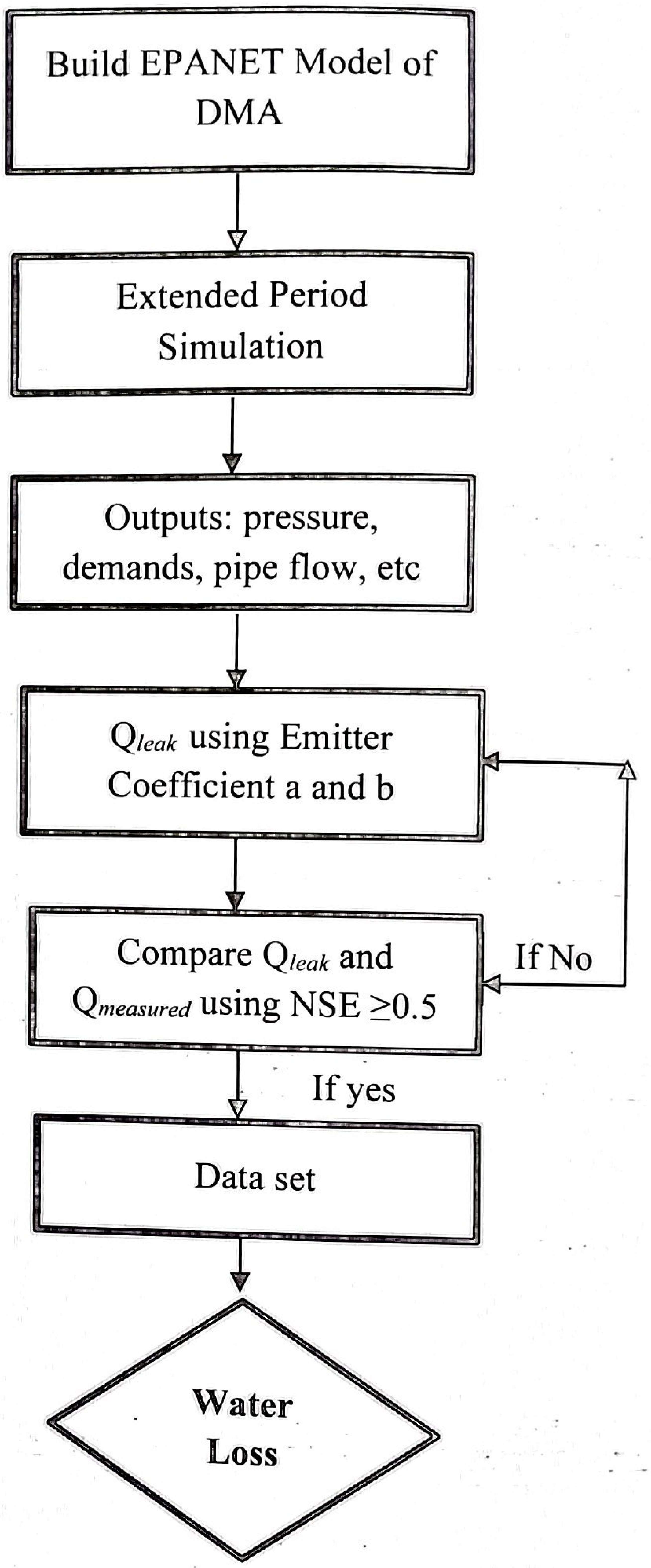

Fig. 2: Flow Chart Methodology

Water Distribution Network Simulation

The hydraulic machine, EPANET was used for the hydraulic modelling of the networks. Other supporting analytical tools for data collection to accomplish this assignment EPANET modelling include: ArcGIS, AutoCAD, EpaCAD, Google Earth Pro and TCX converter. Shape files of digitized maps of transmission and distribution mains, reservoirs, tanks and valves were loaded to AutoCAD and converted to metafiles. The metafiles were used as backdrop in EPANET. The shape files were as well converted to Keyhole Markup Language, KML and superimposed in google earth to obtain nodal elevation values. Networks were then modelled.

Table 1: Velocity and Unit Headloss of the Network

Network Table - Links at 0:00 Hrs	Flow m³/h	Velocity m/s	Unit Headloss m/km
Pipe P91	29.24	0.02	0
Pipe P92	16.1	0.01	0
Pipe P256	-81.51	0.57	1.67
Pipe P257	12.24	0.02	0
Pipe P258	3.62	0.01	0
Pipe P261	-33.1	0.52	2.26
Pipe P262	-77.65	1.22	10.98
Pipe P263	-40.69	0.64	3.32
Pipe P264	-3.86	0.06	0.04
Pipe	6.85	0.11	0.12

Table 2: Elevation and Pressure Values of the Network

Network Table - Nodes at 8:00 Hrs

Node ID	Elevation m	Demand m³/h	Head m	Pressure m
Junc J91	253	3.86	271.3	18.3
Junc J92	254	3.86	271.3	17.3
Junc J228	254	3.86	271.43	17.43
Junc J229	254	3.86	271.35	17.35
Junc J230	254	3.86	271.25	17.25
Junc J231	254	3.86	271.28	17.28
Junc J232	254	3.86	271.25	17.25
Junc J233	250	3.86	269.52	19.52
Junc J234	247	3.62	271.3	24.3
Junc J235	247	3.62	271.3	24.3
Junc J237	254	3.86	271.25	17.25
Junc J238	253	3.86	271.28	18.28
Junc J240	247	3.86	267.67	20.67
Junc J241	247	3.86	267.64	20.64

Leak Identification and Measurement at Nodes Rule Based Leakage identification:

Section of the DMA with old pipes, smaller diameter, Longer lengths of link, more service connections and sections of the network with residual chlorine lower than 0.1mg/l were identified as leak points with high probability. In obtaining the parameters of leakages for analysis in NSE, water samples were taken from different points in the DMA and analyzed using pocket colorimeter DR300 and the reagents DPD. Samples with values of less than 0.1ppm or mg/l were selected for leak modelling. EPANET output is indicated in Fig. 1.and Tables 1 and 2.

Data Observation and Parameter Calibration Steps:

Step 1: The leaks on the 37 nodal demand points were physically measured using calibrated plastic containers, hoses, GPS, stop watch and flow meters.

Step 2: $Q = a * P^b$ (2)

was applied to nodes in the loop or DMA to estimate the leak, Rossman, (2000) and Burrows *et al.* (2003).

Where

Q =Leakage,

a = leakage coefficient and

b = leakage exponent

Rule Based Leakage Identification

To obtain Q_{leak}, nodes with the following conditions were considered to evaluate "a"

1 Nodes with values with residual chlorine less than 0.1mg

2 Nodes between aged Pipes

3 Nodes between longer length of Pipes >50m

4 Nodes with pipes having more service connections.

0.5 was used as leak exponent as default in EPANET for pipes. Leak coefficients of 0.1, 0.15, 0.2 and 0.3 were varied in the emitter for the purpose of calibration and Q_{leak} were generated for each of the leak coefficients. These ranges of numbers are often provided by the manufacturers.

Step 3: Model run was done by logging data obtained through physical measurement of leakages using EPANET. The pressure head at each node was known after Extended Period Simulation of 24 hours

Step 4: The observed and the model values of the leaks were statistically compared using Nash-Sutcliffe Efficiency to indicate how well the plot of the observed and modelled data fits the 1:1-line NSE = 1 which corresponds to a perfect match of the modelled to the observed data.

Step5: Decision taken based on the NASH coefficients values of 0.2 which correlate with the observed values

MODEL CALIBRATION

Nash–Sutcliffe model efficiency coefficient was used in assessing the predictive power of hydrological models, and it is defined as

$$E = 1 - \{ \sum_{t=1}^{T} (Q_o^t - Q_m^t)^2 / \sum_{t=1}^{T} (Q_o^t - \bar{Q})^2 \} \quad (3)$$

Where;

Q_o = mean of observed discharges, and

Q_m = modelled discharge and

Qo^t = observed discharge at time t.

Nash–Sutcliffe efficiency ranges from infinity to 1. The value of efficiency of 1 (when E = 1) means there is a perfect match of modeled discharge relative to the observed data. Therefore, the closer the model efficiency is to 1, the more accurate the model is (Karthikeyan *et al.* 2013). And according to Dongquan *et al.* (2009), a Nash-Sutcliffe simulation efficiency, E_{NS} greater than 0.5 indicates acceptable model performance for model simulation.

RESULTS AND DISCUSSION

Modelled and Observed Data Test in NASH Sutcliffe Coefficient Model

Analyses at 8 hours

The application of the leak coefficients of 0.1, 0.15, 0.2 and 0.3 in the emitter equation at 8 hour, showed the result of the observed and modelled data from NASH Sutcliffe Efficiency Coefficients as -4.552, 0.092, 0.73 and 0.187, respectively. These values deviated from the required standards of perfect or nearly perfect match except at 0.2 which gives a nearly perfect match. Figs. 3, 4, 5, and 6 depicts these NASH coefficients.

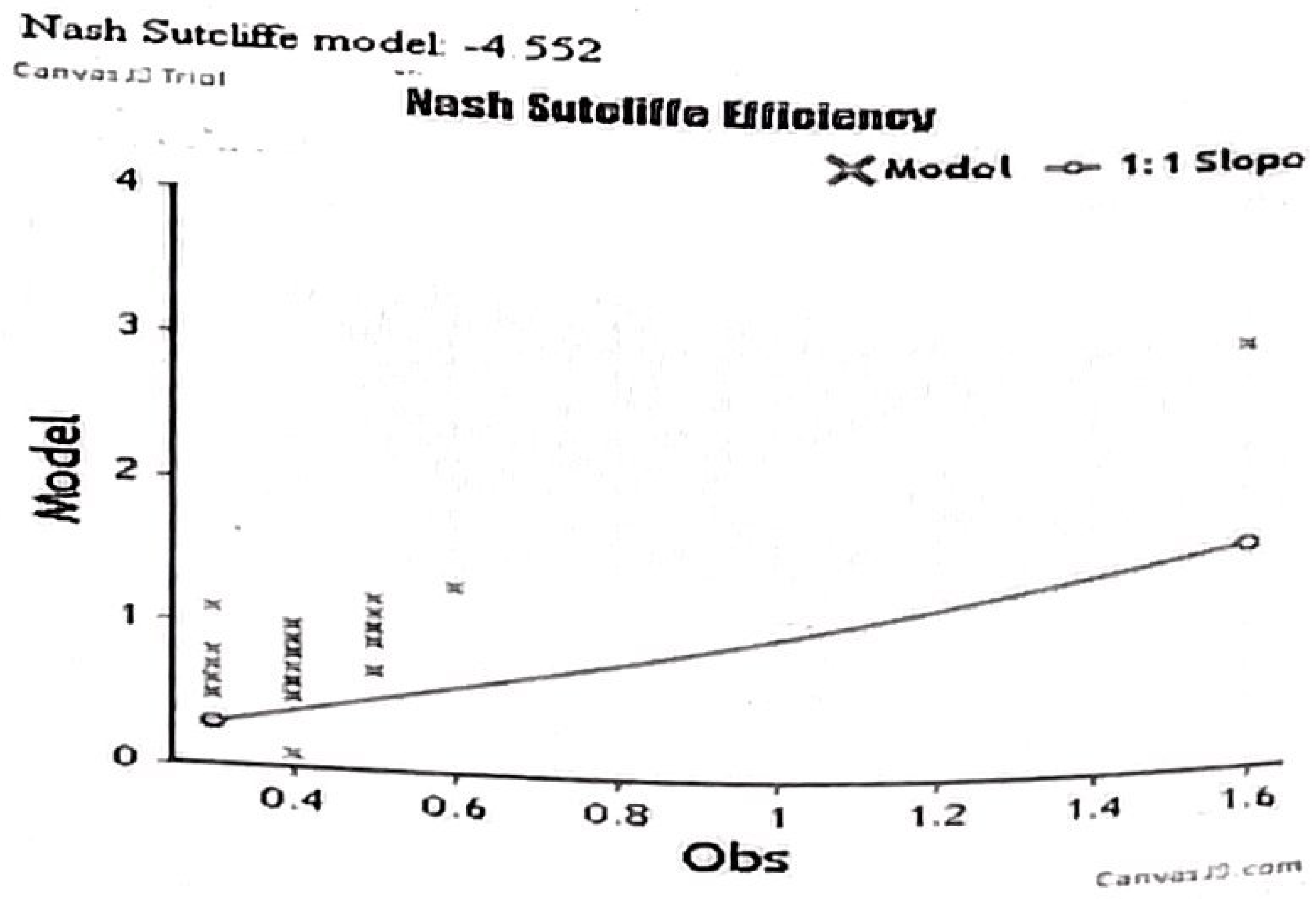

Fig. 3: NASH Coefficient with leak coefficient = 0.1