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Optimal Water Quality Simulation of the Proposed Water Distribution System for the University of Kashmir Using EPANET 2.2 and Leakage Modelling of the Network Using EPANET Extension—WaterNetGen †

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Abstract: Water quality is the most important parameter of portable water. Therefore, water quality simulation is of the utmost importance, along with carrying out the hydraulic analysis of a water distribution network. In the current study, it has been attempted to carry out the water quality simulation of the proposed distribution network for the University of Kashmir using EPANET 2.2 software. The study also aims to obtain the optimal performance of the designed network in terms of water quality parameters. Furthermore, the leakage modelling for the network has been carried out using the EPANET extension—WaterNetGen. It was found that important water quality parameters, like residual chlorine at nodes and water age, were within the standard ranges throughout the simulation period. The minimum concentration of chlorine up to the 11th hour of the simulation was 0.2 mg/L, and the maximum age of water in the storage tank was 12.5 h throughout the simulation period. The total leakage discharge obtained was negligible, equal to 0.1% and 0.15% of the design discharge for WDS part I and part II, respectively. The objective function of maximum efficiency of performance, with respect to water quality of the proposed network, was achieved.

Keywords: water quality simulation; EPANET 2.2; leakage modelling; EPANET extension—WaterNetGen

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1. Introduction

The quality of water is representative of its suitability for domestic and institutional use. Water quality analysis and modelling is an important aspect of the water distribution system (WDS) design, along with the efficient hydraulic performance of the network [1,2]. A water quality model has to be an optimal solution, like that of the hydraulic model, to achieve the maximum efficiency of the performance of a WDS [3]. Important water quality parameters like concentration of chlorine, decay of chlorine in the system [4,5] and water age [6] have to be modelled, so as to ascertain that the quality of the water is as per the standards [7]. Standard values of these parameters are vital for the optimality of the water quality model, indicating that these parameters are the decision variables for the optimal model, with the standard ranges of these variables as constraints. Leakage modelling is another important requisite of an optimal WDS model. Estimation of the amount of leakage discharge is vital for the efficient performance, with respect to hydraulics, as well as water quality of a WDS [8]. EPANET extension—WaterNetGen is an effective tool for modelling the leakage with a fair degree of accuracy and ease of use [9].

An optimal solution of the hydraulic design of WDS for the University of Kashmir (UOK) was proposed by using EPANET 2.0 in the earlier study. The WDS consists of two separate networks for two different divisions of the study area. Current work is an extension of the work done earlier, such that an optimal water quality model for the proposed WDS is formulated using the pressure driven analysis (PDA) approach of EPANET 2.2. The leakage modelling of the proposed network has been done by WaterNetGen.

2. Methodological Approach and Analysis

A quantitative pressure driven analysis approach (PDA) was used to produce an optimal water quality model of the proposed water distribution system (WDS) for the University of Kashmir (UOK) by using EPANET 2.2. Study of the literature was conducted and the most important water quality parameters, like chlorine concentration, decay of chlorine and water age, were taken as the decision variables for optimal modelling. Standard codes and books were consulted to set out the constraints for the decision variables. Finally, the leakage modelling of the network was carried out by using EPANET extension—WaterNetGen—to access the amount of leakage discharge at the nodes.

2.1. PDA of Water Quality of the Network Using EPANET 2.2

A more realistic PDA approach was used to carry out the water quality modelling, such that the variables were a function of the available pressure head at the nodes. Water quality parameters like chlorine concentration, decay of chlorine and water age were modelled using a PDA approach of the EPANET 2.2 [10]. Various input parameters, like reaction order, reaction coefficient for the bulk and wall reactions of chlorine and limiting concentration of chlorine equal to 0.2 mg/L [7], were provided to run the software successfully. The initial concentration of chlorine added to the supply tank was equal to 2 mg/L (optimum dosage of chlorine, as per the ground water quality test data provided by UOK).

2.2. Leakage Modeling by EPANET Extension—WaterNetGen

The background leakage discharge $Q_k{}^{leak}$ in any pipe (k) of length (L_k) was estimated after entering the values of background leakage coefficient per unit pipe length (β_k) and background leakage exponent (α_k) for each pipe, as per the following equation [11,12]: $Q_k{}^{leak} = \beta_k \, L_k \, (P_k)^{\alpha k}$; $\beta_k = 10^{-7}$, $\alpha_k = 1.18$. The nodal leakage flow at any node 'i' due to the background leakage of the pipes connected at the node was estimated after running the software, as per the following equation [11]: $Q_i{}^{leak} = \frac{1}{2} \, \Sigma \, Q_k{}^{leak}$, where 'k' iterates over all the pipes connected at 'i'

Finally, the emitter discharge at the nodes was obtained after providing the value of emitter coefficient 'β_i' to each node, which was calculated from the following equation [11–13]: $Q_i{}^{leak} = \beta_i \, (P_i)^{0.5}$, where ($P_i$) is the node pressure.

2.3. Optimization of the Water Quality Model

An optimal solution of the water quality model was obtained by selecting the following objective function subject to the decision variables and constraints, as given below:

Objective function: maximization of efficiency of performance, with respect to the water quality of the proposed WDS, without affecting the hydraulic performance.

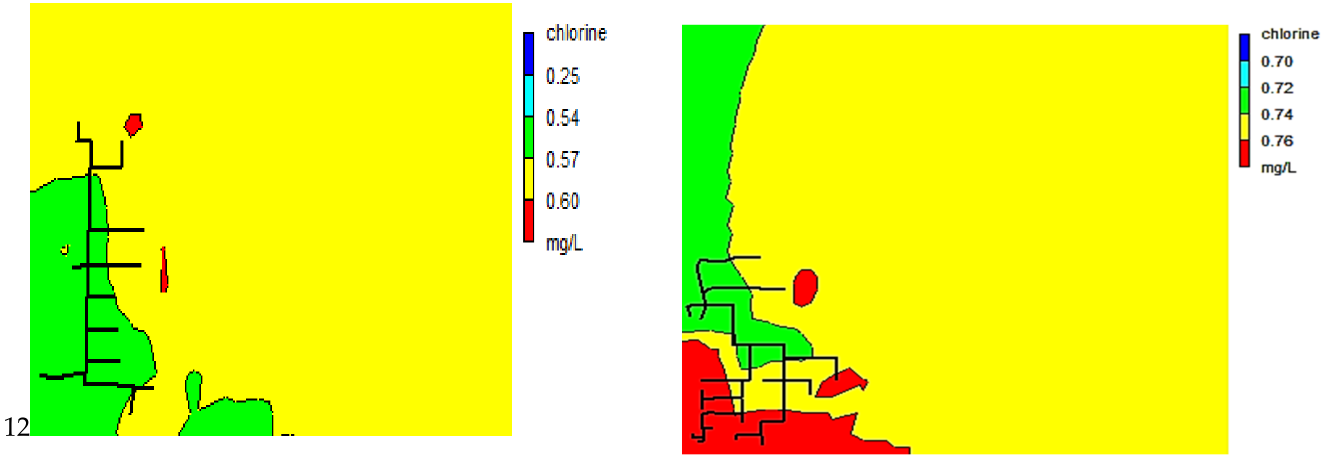
Decision variables: the following water quality parameters were taken as the decision variables; chlorine concentration, water age.

Constraints: chlorine concentration $\geq$ 0.2 mg/L [7], average water age $\leq$ 1.3 days and maximum water age $\leq$ 3 days [6].

3. Results and Discussion

3.1. Chlorine Concentration at the Nodes

The minimum required concentration of residual chlorine at any point in a WDS is 0.2 mg/L. Figure 1a,b indicates that the chlorine concentration at all the nodes of WDS, part I and part II, at the hour of peak demand is above 0.2 mg/L. From the analysis, 0% of the nodes have a chlorine concentration below 0.58 mg/L at the hour of peak demand in WDS part I, 0% nodes have a chlorine concentration below 0.735 mg/L in WDS part II. Figure 2a,b indicates that there is a drop in the concentration of chlorine, below 0.2mg/L, at the peak demand nodes and the storage tank at 12 pm and onwards. Thus, there is a need to re-add the chlorine at the source node (storage tank) at 12 pm.



(**a**) (**b**)

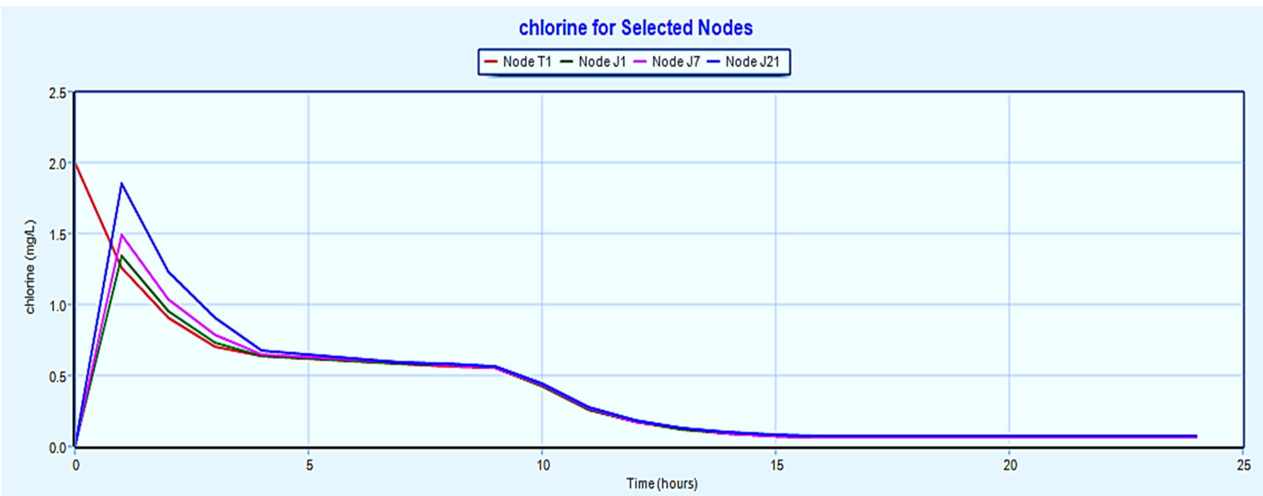
Figure 1. (**a**) Contour plot of chlorine concentration at nodes at 9:00 am for WDS part I; (**b**) contour plot of chlorine concentration at nodes at 9:00 am for WDS part II.

3.2. Decay of Chlorine in the System

As indicated in Figure 3a,b, the maximum percentage decay of chlorine is taking place in the storage reservoir in both parts of the WDS, due to the reaction within the bulk of the fluid in the storage tank. The decay, due to wall reactions, is lower due to the assumption of the use of lined G.I pipes. The decay percentage is due to the reaction of chlorine in the bulk of the water in pipes.

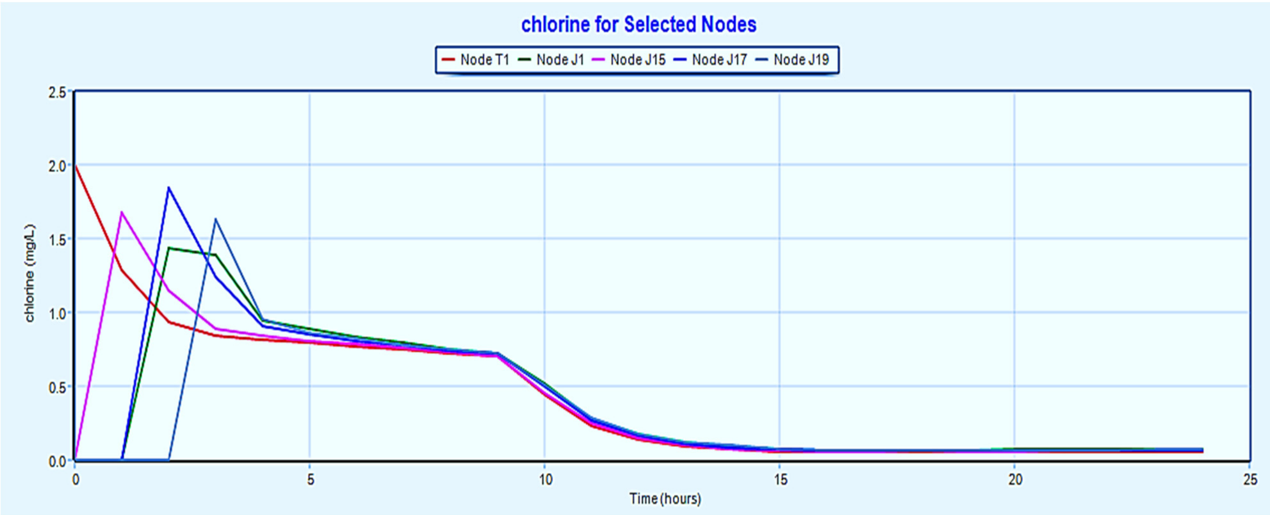
3.3. Time Series Graph for Age of Water in the Storage Tank

The increased age of water in a WDS is related to the growth of disinfection by products like trihalomethanes, microbial growth, etc. The maximum age of water in a WDS is limited to about 3 days [6]. In both the WDS, part I and part II, the maximum age of water in the storage tank is 12.5 h (Figure 4a,b).



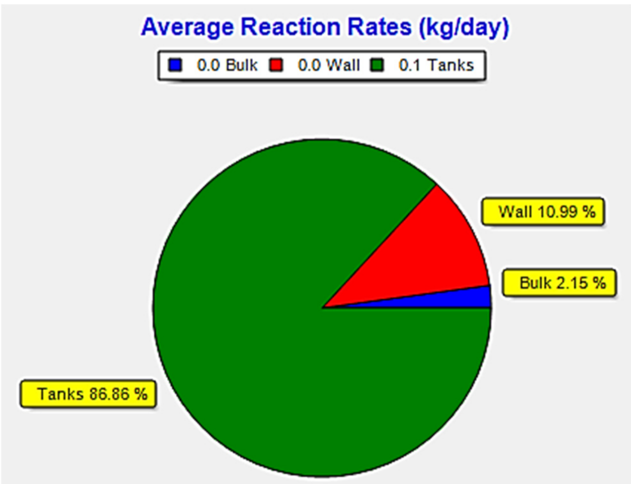
(**a**)

Figure 2. *Cont.*

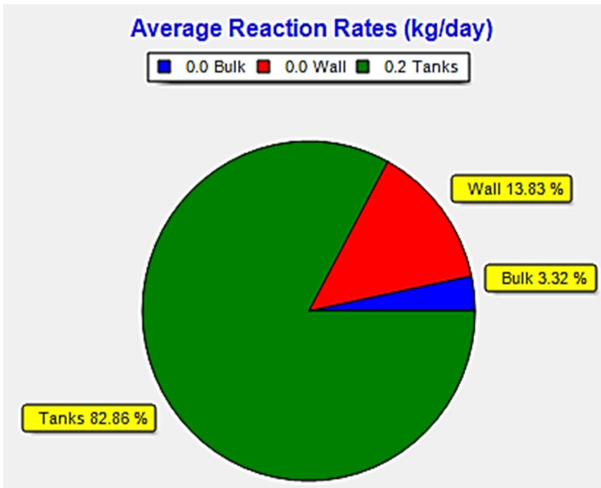


(**b**)

Figure 2. (**a**) Time series plot of chlorine (mg/L) at the storage tank and peak demand nodes for WDS I; (**b**) time series plot of chlorine (mg/L) at the storage tank and peak demand nodes for WDS II.



(**a**)

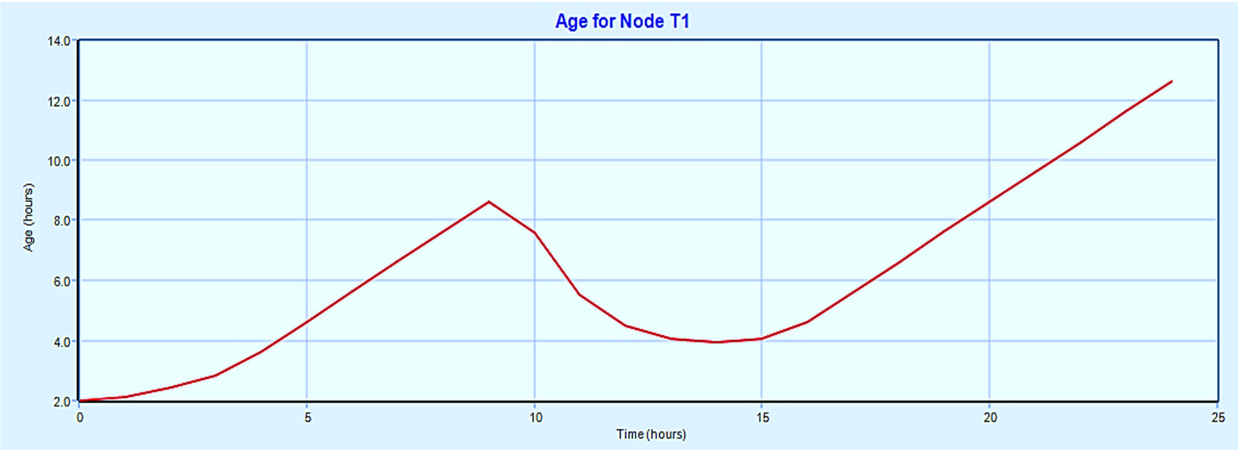


(**b**)

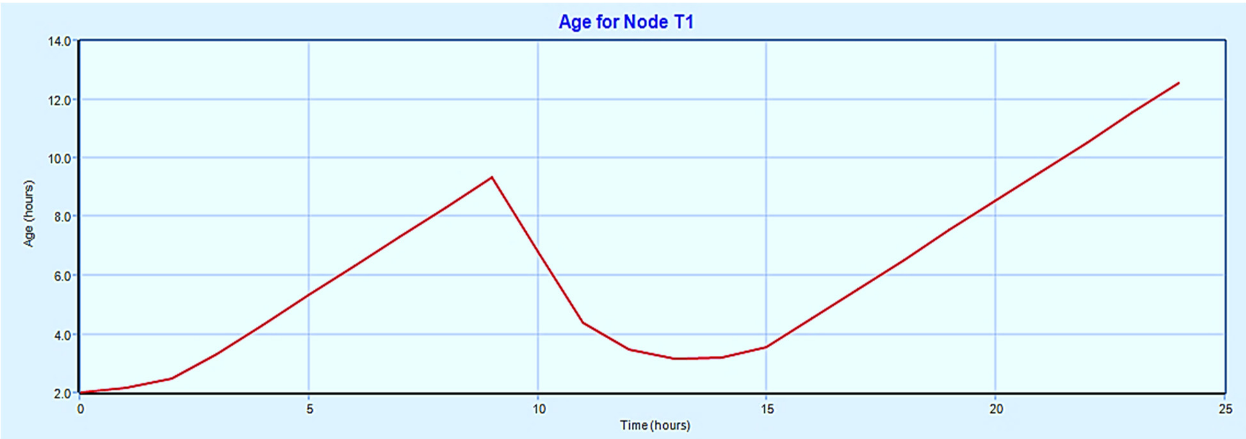
Figure 3. (**a**) Pie chart for chlorine decay, WDS part I; (**b**) pie chart for chlorine decay, WDS part II.

3.4. Leakage Modelling of the Network by EPANET Extension—WaterNetGen

The emitter discharge at the nodes, which is contributed to the background leakage of the pipes connected at a node, was modelled. The emitter coefficient for each node was evaluated, as explained in Section 2.3. The emitter coefficient corresponding to the time of occurrence of the maximum background leakage and pressure head at the node was taken as the design value. For WDS part I, the emitter coefficient corresponding to 4 h, and for WDS part II, that corresponding to 3 h, was entered for each node. The values of emitter discharge at the nodes at the hour of peak demand were obtained, as in Tables 1 and 2, indicating negligible leakage discharge in the WDS—0.1% for WDS part I and 0.15% for WDS part II.



(a)



(b)

Figure 4. (a) Age of water in the storage tank, WDS part I; (b) age of water in the storage tank, WDS part II.

Table 1. Emitter flow at nodes for WDS part I.

Node	Pressure (m)	Emitter Flow (lps)	Node	Pressure (m)	Emitter Flow (lps)	Node	Pressure (m)	Emitter Flow (lps)
Junc J1	34.39	0.00038	Junc J11	24.79	0.00069	Junc J21	28.64	0.00055
Junc J2	29.66	0.00033	Junc J12	24.58	0.0002	Junc J22	27.17	0.00018
Junc J3	27.41	0.00016	Junc J13	25.36	0.00036	Junc J23	27.78	0.00019
Junc J4	31.62	0.00041	Junc J14	25.43	0.0005	Junc J24	25.07	0.00015
Junc J5	29.43	0.0004	Junc J15	25.02	0.00039	Junc J25	26.27	0.00049
Junc J6	32.83	0.00036	Junc J16	25.87	0.00011	Junc J26	24.14	0.00014
Junc J7	31.28	0.00026	Junc J17	25.55	0.00042	Junc J27	23.93	0.00036
Junc J8	28.75	0.00073	Junc J18	25.81	0.00041	Junc J28	34.09	0.00041
Junc J9	25.86	0.00024	Junc J19	25.44	0.00037	Junc J29	27.4	0.00073
Junc J10	26.5	0.00113	Junc J20	25.36	0.00005	Junc J30	30.19	0.00031
							total	0.013

Table 2. Emitter flow at nodes for WDS part II.

Node	Pressure (m)	Emitter Flow (lps)	Node	Pressure (m)	Emitter Flow (lps)	Node	Pressure (m)	Emitter Flow (lps)
Junc J1	27.73	0.00012	Junc J19	23.57	0.00043	Junc J37	24.61	0.00036
Junc J2	27.99	0.00039	Junc J20	23.65	0.00084	Junc J38	24.05	0.00014
Junc J3	28.66	0.00021	Junc J21	24.65	0.00023	Junc J39	24.77	0.0001
Junc J4	29.07	0.00017	Junc J22	25.4	0.00021	Junc J40	23.9	0.00031
Junc J5	34.61	0.00025	Junc J23	25.01	0.0002	Junc J41	23.69	0.00031
Junc J6	34.84	0.00067	Junc J24	24.76	0.00011	Junc J42	25.04	0.00097
Junc J7	34.61	0.00088	Junc J25	24.29	0.00019	Junc J43	24.78	0.0001
Junc J8	33.36	0.00072	Junc J26	24.04	0.00019	Junc J44	31.08	0.00037
Junc J9	31.97	0.00021	Junc J27	23.86	0.0002	Junc J45	30.87	0.00029
Junc J10	31.53	0.00027	Junc J28	23.53	0.00031	Junc J46	25.26	0.00014
Junc J11	30.75	0.0002	Junc J29	23.49	0.0001	Junc J47	25.39	0.00008
Junc J12	31.57	0.00065	Junc J30	25.15	0.00058	Junc J48	24.63	0.00022
Junc J13	30.98	0.00057	Junc J31	24.81	0.00035	Junc J49	27.28	0.00052
Junc J14	31.62	0.00028	Junc J32	24.74	0.00017	Junc J50	29.22	0.00131
Junc J15	29.13	0.00089	Junc J33	24.65	0.00024	Junc J51	27.77	0.0009
Junc J16	23.89	0.00036	Junc J34	23.48	0.00011	Junc J52	26.07	0.00094
Junc J17	23.64	0.00048	Junc J35	24.53	0.00035	Junc J53	25.78	0.00111
Junc J18	23.52	0.0004	Junc J36	25.43	0.00009	Junc J54	25.08	0.0001
							total	0.029

4. Conclusions and Future Scope

In this work, an optimal solution of water quality modelling of the proposed WDS for the University of Kashmir has been provided. Chlorine concentration and water age were taken as the decision variables for optimal design. Water quality modelling was carried out by the PDA approach of the EPANET 2.2, and the leakage modelling of the network was done by EPANET extension—WaterNetGen. The objective function of maximum efficiency of water quality performance was achieved, subject to the standard values of the decision variables and minimum percentage of leakage discharge, which was verified without affecting the optimality of the hydraulic design of the network. The main highlights of the work include the following:

The standard minimum chlorine concentration of 0.2 mg/L was maintained at each node up to 11 h of the simulation. However, a re-addition of chlorine to the water in the storage reservoir at 12 h was required to maintain the standard residual chlorine at every point in the WDS. The maximum percentage decay of chlorine took place in the storage reservoir in both parts of the WDS, and a negligible decay was observed in the bulk and at the boundary of the pipes, indicating negligible reaction between pipe material and the water and hence, longer life of the pipes of the network. The age of the water in the storage tank was limited to 12.5 h, indicating prevention of the growth of disinfection by-products and microbial growth. From the hydraulic analysis of the network, it was seen that the water age in the storage tank is inversely related to the pressure head of the tank. The leakage modelling for the network has been completed using WaterNetGen and leakage discharge obtained at the peak demand hour. The total leakage discharge obtained for WDS part I is 0.013 L/s and is 0.029 L/s for WDS part II, respectively, which is 0.1% and 0.15% of the design discharge, respectively, and thus negligible. The very small magnitude of leakage discharge indicates the optimality of the overall design of the network.

The extensions available to the EPANET can be used for water security modelling, real time modelling and fire flow analysis of the designed WDS. EPANET-MSX (multi-species extension), the interaction of multiple chemical agents between each other, with the material of walls of the pipes and the bulk of the fluid, can be modelled. Additionally, the auto decomposition of chloramines to ammonia, formation of disinfection by products and biological regrowth can be modelled. EPANET-RTX (real-time extension) allows for the connection of the operational data with a network model, and the resultant model can be calibrated, verified and tested for precision using the operational data. WaterNetGen can be used for the fire flow analysis of the network model.

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Data Availability Statement: All the data required was obtained from the Engineering wing of the University of Kashmir.

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