*Proceeding Paper*

# Water Quality Simulation and Optimization of Performance with Respect to Water Quality 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 †

**Mominah Ajaz** [1,*,‡] **and Danish Ahmad** [2]

[1] National Institute of Technology, Srinagar 190006, India
[2] Department of Civil Engineering, National Institute of Technology, Srinagar 190006, India; Profdanish27@gmail.com
[*] Correspondence: mominah@kgpsrinagar.edu.in.
[†] Presented at the 7th International Electronic Conference on Water Sciences, 15–30 March 2023; Available online: https://ecws-7.sciforum.net.
[‡] Current Address: Gousia Colony Bagemehtab Srinagar, Hno 56, Srinagar 190019, India.

**Abstract:** Water quality is the most important parameter of the portable water. Therefore, water quality simulation is of 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 at obtaining 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 the 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 is 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

## 1. Introduction

The quality of water is a 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 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 these parameters to be the decision variables for the optimal model, with the standard ranges of these variables as constrains. 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 fair degree of accuracy and ease of use [9].

An optimal solution of 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 done and the most important water quality parameters like chlorine concentration, decay of chlorine and water age were taken as the decision variables for the optimal modelling. Standard codes and books were consulted to set out the constrains 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 are 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 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 taken 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 ($\beta_k$) and background leakage exponent ($\alpha_k$) 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 '$\beta_i$' 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 constrains 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.

Constrains: chlorine concentration ≥ 0.2 mg/L [7], Average water age ≤ 1.3 days and maximum water age ≤ 3 days [6].

## 3. Results and Discussions

### 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, 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 of below 0.735 mg/L in WDS part II. Figure 2a,b indicates that there is a drop in 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.
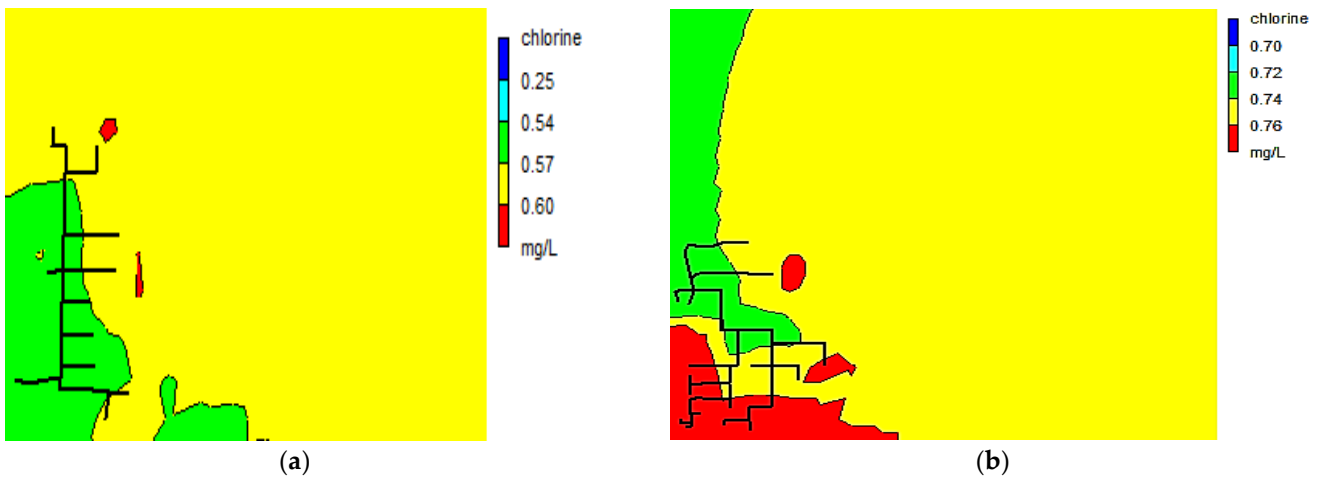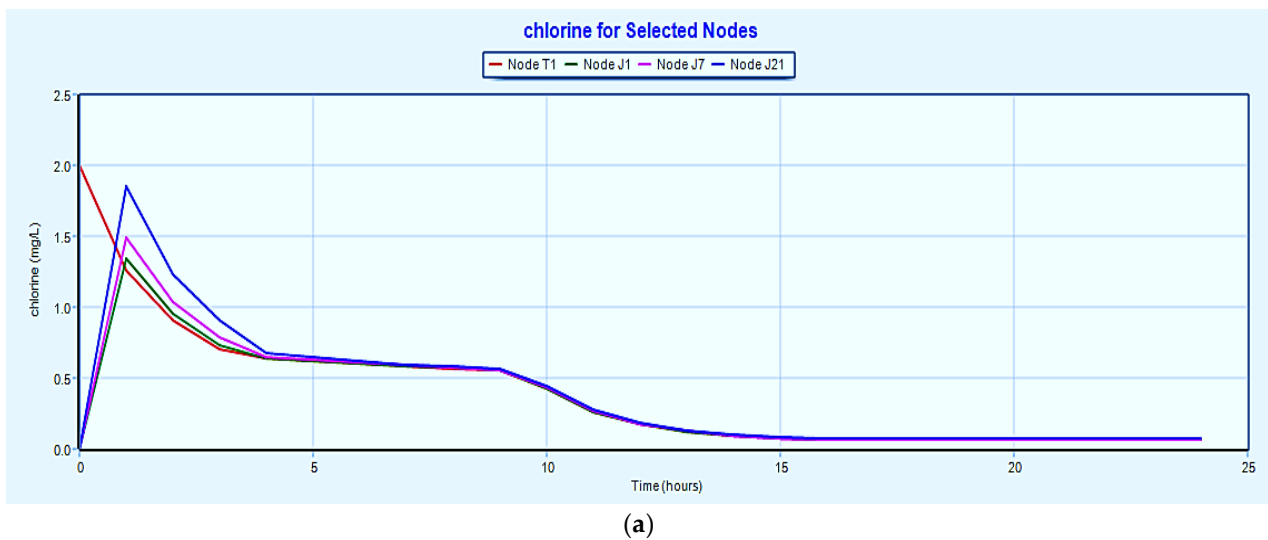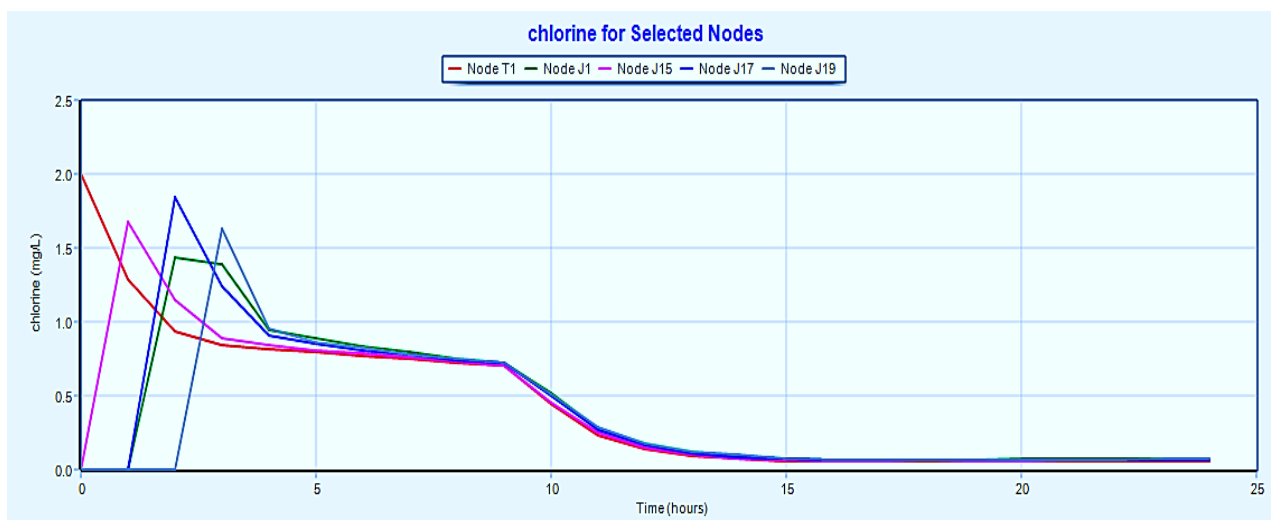


(**a**)          (**b**)

**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.



(**a**)

**(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.

### 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 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 the least due to the reaction of chlorine in the bulk of the water in pipes.
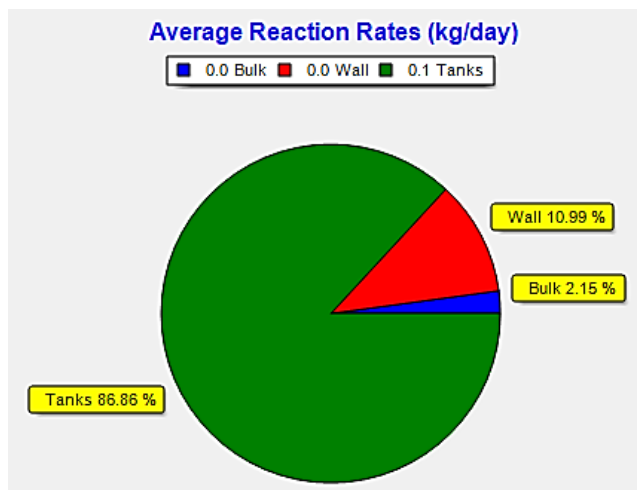


**(a)**
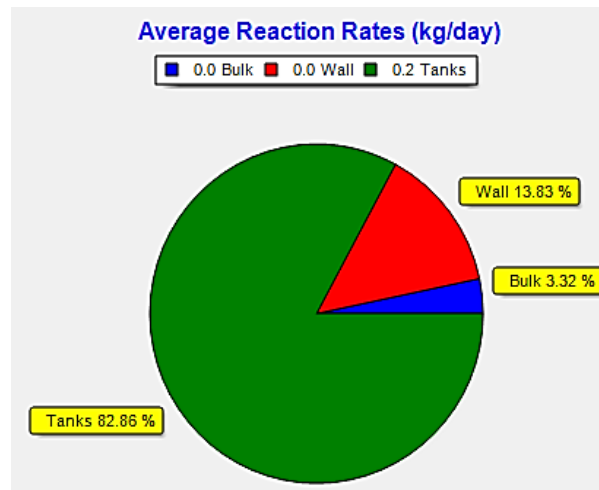


**(b)**

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

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

The increased age of water in a WDS is related to 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.
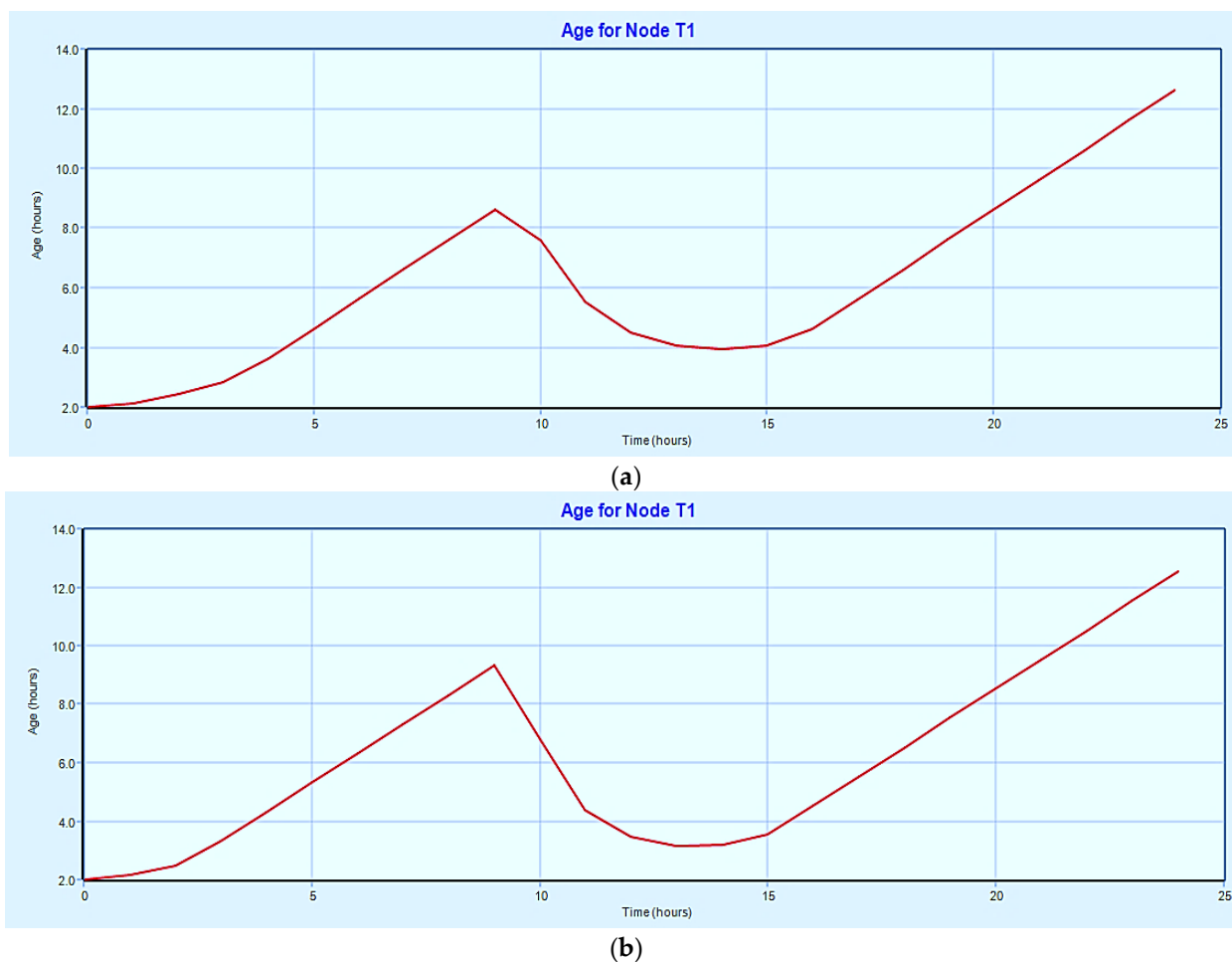
(**a**)



(**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.

*3.4. Leakage Modelling of the Network by EPANET Extension- WaterNetGen:*

The emitter discharge at the nodes, which is contributed due 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 2.2.3. 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 Table 1 and Table 2 indicating negligible leakage discharge in the WDS, 0.1% for WDS part I and 0.15% for WDS part II.

**Table 1.** Emitter flow at nodes 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, 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 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 is maintained at each node up to 11 h of the simulation. However, a re-addition of chlorine to the water in storage reservoir was required to maintain the standard residual chlorine at every point in the WDS, at 12 h. The maximum percentage decay of chlorine is taking 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 is 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 done by 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 for WDS part II is 0.029 L/s, 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, 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. Also the auto decomposition of chloramines to ammonia, formation of disinfection by products and biological regrowth can be modelled. EPANET-RTX (Real time extension); it allows to connect 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.

## References

1. Grayman, W.M. History of water quality modeling in distribution systems. In Proceedings of the 1st International WDSA/CCWI Joint Conference, Kingston, ON, Canada, 23–25 July, 2018.
2. Lipiwattanakarn, S.; Kaewsang, S.; Makpiboon, C.; Changklom, J.; Pornprommin, A. Water quality audit in drinking water distribution networks. *J. Water Resour. Plan. Manag.* **2021**, *147*, 04020113.
3. Siew, C.; Tanyimboh, T.T.; Seyoum, A.G. Penalty-Free Multi-Objective Evolutionary Approach to Optimization of Anytown Water Distribution Network. *Water Resour. Manag.* **2016**, *30*, 3671–3688.
4. Nono, D.; Odirile, P.T.; Basupi, I.; Parida, B.P. Assessment of probable causes of chlorine decay in water distribution systems of Gaborone city, Botswana. *Water SA* **2019**, *45*, 190–198.
5. Mostafa, N.G.; Matta, M.E.; Halim, H.A. Simulation of chlorine decay in water distribution networks using watercad—Case study. *J. Eng. Appl. Sci.* **2013**, *60*, 25–42.
6. Kourbasis, N.; Patelis, M.; Tsitsifli, S.; Kanakoudis, V. Optimizing Water Age and Pressure in Drinking Water Distribution Networks. *Environ. Sci. Proc.* **2020**, *2*, 51.
7. *IS 10500*; Indian Standard Drinking Water Specification. Bureau of Indian Standards: New Delhi, India, 2012.
8. Cobacho, R.; Arregui, F.; Soriano, J.; Cabrera, E. Including leakage in network models: An application to calibrate leak valves in EPANET. *J. Water Supply Res. Technol.—AQUA* **2015**, *64*, 130–138.
9. Muranho, J.; Ferreira, A.; Sousa, J.; Gomes, A.; Sá Marques, A. WaterNetGen: An EPANET extension for automatic water distribution network models generation and pipe sizing João Muranho, Ana Ferreira, Joaquim Sousa, Abel Gomes. *Water Sci. Technol. Water Supply* **2012**, *12*, 117–123.
10. Rossman, L. *EPANET 2.2 User Manual*; United States Environmental Protection Agency: Washington, DC, USA, 2020.
11. Muranho, J.; Ferreira, A.; Sousa, J.; Gomes, A.; Marques, A.S. Pressure dependent demand and leakage modelling with an EPANET Extension—WaterNetGen. *Procedia Eng.* **2014**, *89*, 632–639.
12. Avile, A.; Garcı, F. Pressure management for leakage reduction using pressure reducing valves. Case study in an Andean city. *Alexendria Eng. J.* **2019**, *58*, 1313–1326.
13. Walski, T.; Researcher, I.; Weir, M.H. Modeling leakage reduction. *Am. Water Work. Assoc.* **2006**, *98*, 147–155. https://doi.org/10.1002/j.1551-8833.2006.tb07642.x.