LEC Journal 2022, 4(1): 23-27
ISSN: 2565-5205 (print)

Research Article

HYDRAULIC ANALYSIS OF LEKHNATH SMALL TOWN WATER SUPPLY DISTRIBUTION NETWORK, POKHARA METROPOLITAN CITY, NEPAL

[1]Kripa Ranjit, [2]Kishor Kumar Shrestha, [3]Amrita Gautam, [4]Amin Minaei*

[1]*Institute of Engineering, Tribhuvan University,* Pokhara, Nepal
[2]*Institute of Engineering, Tribhuvan University,*Pokhara, Nepal
[3]*Faculty of Spatial Development and Infrastructure Systems, Technical University of Cologne,* Cologne, Germany
[4]*Centro di Ricerca Sulle Acqua via, Ferrata, Pavia, Italy*
**Correponding author email: amin.minaei01@universitadipavia.it*

ABSTRACT

Water Distribution Network earlier will have challenge in fulfilling the growing need of water supply. Forecasting and monitoring the flow, pressure, demand, and quality of water in water distribution network are key requirement for sustainable and reliable water supply. Lekhnath city, due to the recent merger with the biggest metropolitan city of Nepal, Pokhara, has created the rapid growth of population resulting to haphazard pipeline extension in this area. For hydraulic analysis of Lekhnath Small Town Water Supply Distribution Network, one of the networks i.e., Shishuwakhudi distribution network was faced with problem analysis. This hydraulic analysis is a part of on-going doctoral research and Youth-led Initiative 'drinkPani' on 'Water Supply and Quality Monitoring using Emerging Technologies' where capacity building of Youth and Women through data-driven engagements (Water-informatics) is one of the core targets in the overall project-work package. The preliminary analysis of water quality was also derived from Young Water Volunteers (YWVs) under the research work on Youth-led Participatory Sensing (YPS) Model to enhance drinking water security of the study area. The Shishuwakhudi Water Distribution Network (WDN) supplies water to 1138 household at present and consisting of 41 junction nodes and 11.2km distribution pipeline distributing water from a reservoir. With field survey, households at each node of the network were determined. Demand driven analysis using EPANET was done to determine the pressure deficit at various nodes. Demand pattern based on design guideline was adopted for analysis. At present scenario, four nodes at end of the network showed negative pressure at peak hours (5 am- 7am). At other times, the pressure was above 10m head. Demand was forecasted for 10 years from now by projecting the household population based on growth rate of census 2011. When projected to future scenario, the existing pipeline showed only 17% reliability with a minimum pressure requirement of 10 m head as per norms of urban water supply project in Nepal. Genetic algorithm was used for optimization of the Shishuwakhudi Network with total cost of replacing pipes as an objective function with pressure constraint of minimum 10m head. With 500 generation of run, the optimal diameter for each pipe was obtained that gave optimal cost of NRs 4,21,50,917 (USD 359,690.64). This optimization helps in selecting the proper pipeline network for future expansion to fulfill the growing need of water demand.

Keywords— EPANET, Genetic Algorithm, Hydraulic Analysis, Water Distribution Network (WDN), Water Supply and Quality Monitoring, Reliability, Youth-led Initiative

1. INTRODUCTION

About 85% of global population accessed topipeline water supply system by 2010 [1]. Water supply network is the major concern for proper urbanization and management of smart cities. In Nepal, only around 25.4% of 61 piped water supply systems are well functioning [2]. Hydraulic analysis of water distribution network helps in pressure detection and management, efficient leakage control, optimal location for isolation of part of network in case of breakage or leakage, water distribution system reliability and response approaches to network failure events [3].Computer-aided models have brought significant advancements in efficient construction and monitoring of water supply systems. The provision of increasingly sophisticated and on hand laptop models allows these goals to be realized greater completely than ever before [4]. Manual Water Distribution Networks design done traditionally earlier are less efficient than computer-aided design ones in fulfilling the growing need of water supply. In this regard, there are a multitude of work in the literature which have employed information technology (IT) approaches for designing Water Supply systems [5, 6]. This is one of the most important public utilities as supply of safe and sufficient water is the basic need to human. This study follows this research trends and has some main objectives as follows:

- to determine the reliability of distribution network based on pressure constraint.
- to identify the potential changes in pipelines based on diameter and cost analysis.
- to perform cost optimization with single objective function of pressure values.

1.1 Study Area

Lekhnath area lies in Pokhara Metropolitan City, Kaski district of Gandaki Province in Nepal that extends over an area of 123.11 sq. km in the south-eastern portion of Pokhara Valley (28°6'N to 28°11'N latitude and 84°6' E to 84°16'E longitude). Lekhnath Small Town Water Supply project is second biggest project among First Small Town Water Supply project under Department of Water Supply and Sanitation in Nepal. This project covers Ward numbers 26, 27, 29, 30, 31 and 32 of Pokhara Metropolitan City with four distribution areas viz Lapsidanda, Arghaun, Dadakonakh and Sisuwakhudi. As per report of Lekhnath Small Town Water Supply Project, 2020 A.D, the total household connection in Sisuwa Khudi (Fig-2) is 1138, Lapsidanda is 3508, Arghaun is 829 and Dandako Nak is 7635 (Source: Lekhnath Small Town Water Supply and Sanitation User Committee Office,2020). Fig-1 below shows the study area of the research work in the map of Nepal.

This study is a part of doctoral research and Youth-led Initiative 'drinkPani' on 'Water Supply and Quality Monitoring using Emerging Technologies', where youth are the key actors as Young Water Volunteers (YWVs), assigned officially in 'water clubs' – called drinkPani Clubs – with intensive training and tools for water sampling, test, data collection, reporting and sharing under a 'Youth-led Participatory Sensing' (YPS) Model in progress, including regular verification and preparation initiatives for climate action as well, to enhance drinking water security using ICTs as the major component, including field kits, water quality sensors, mobile apps, data dissemination digital platforms like websites, which can also support for research based learning environment [7]. Shishuwakhudi distribution network covers 1138 household connection at present. This consists of total 41 junction nodes with total distribution pipe length of 11.32 km and a 300 m3 reservoir (Fig-3). The pipe material consists of mainly HDPE (High Density Polyethylene) and GI (Galvanized pipe) pipe of various pressure density.

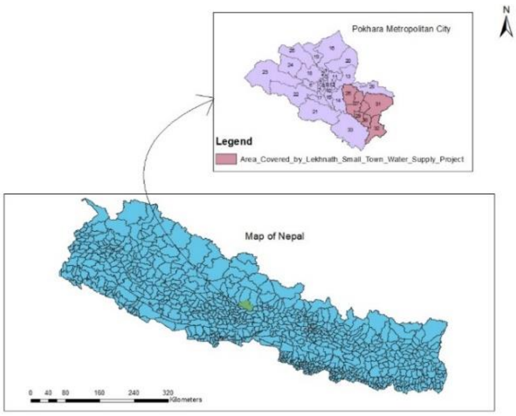

Fig-1: Study Area Showing Map of Lekhnath

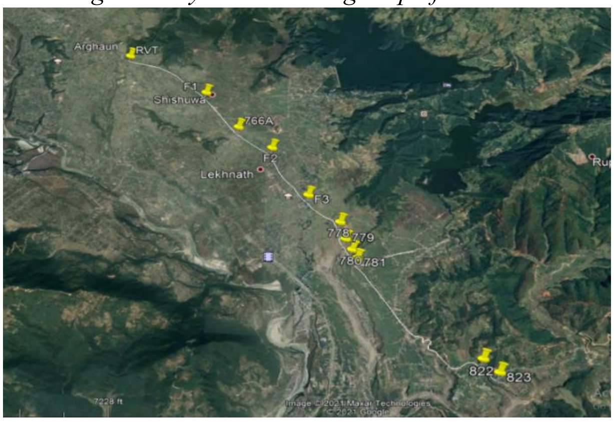

Fig-2: Shishuwakhudi Distribution Network (Source: Google Earth, 2020)

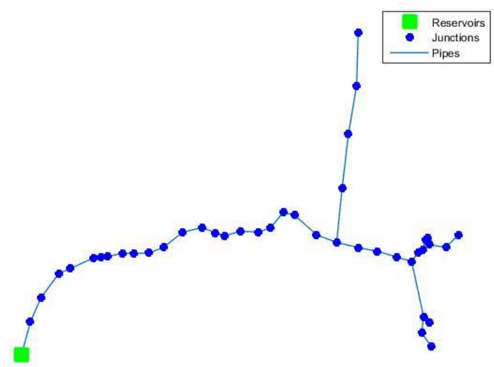

Fig-3: Topology of ShishuwaKhudi Distribution Network

2. METHODOLOGY

2.1 Hydraulic Analysis

The hydraulic analysis of Shishuwakhudi distribution network, one of distribution network of Lekhnath Small Town Water Supply was taken as a problem analysis. The primary data was household data from each node of the network collected by site visit to determine the present demand of the area. The secondary data included the layout of network with detail information of position and elevation of physical component, diameter, length, and pipe roughness coefficient of existing pipes collected from utility documents of Lekhnath Small Town Water Supply Project. Thus, obtained data were inserted in EPANET 2.2 VERSION as input parameters. The Hazen William's energy loss was used for head loss calculation in pipeline given by following formula:

$$h_f = 10.69 \times \left(\frac{Q}{C_{HW}}\right)^{1.852} \times D^{-4.87} \times L \qquad (1)$$

hf = head loss (m), L= pipe length, D = pipe diameter, Q = flow rate in the pipe (m3/s)

CHW = Hazen – William Coefficient

The extended period hydraulic analysis for present scenario was performed considering the demand pattern for that area suggested by Urban Water Supply and Sanitation (Sector) Project Design Guidelines, 2020. For future demand forecasting, population was projected to 2031 with population growth rate of 3% as per National Population and Housing Census (2011). Peak demand with peak factor of 3 was adopted and steady state hydraulic analysis was performed to analyze the network at peak demand. Minimum of 0.15 lps in each node was suggested to maintain flow in the pipeline ("Urban Water Supply and Sanitation (Sector) Project Design Guidelines," 2020).

2.2 Reliability

Water distribution system is the complex network of water supply that conveys water to the consumer with adequate pressure and acceptable quality. The main components of WDN consists of pipe systems, pumping stations, storage facilities, fire hydrants, house service connections and various appurtenances. The performance of water distribution depends upon the reliability of system supplying water to the sufficient demand with minimal loss [8]. Reliability based on pressure requirement was calculated in present as well as future scenario. Minimum of 10m head at each node was taken as constraint as per design guideline provided by Urban water supply and sanitation project, 2020.

$$\text{Reliability} = 1 - \frac{\text{No of failure nodes}}{\text{Total no of nodes}} \qquad (2)$$

No of failure nodes = No of nodes having pressure < 10m head

2.3 Optimization

Genetic Algorithm is a powerful technique for optimization design of pipe network [9]. In recent years many researchers have used genetic algorithm as an optimization tool for design of pipeline systems. Genetic algorithm is a heuristic search technique based on Darwin's Theory of Evolution that believes that the fittest individual produces the offspring with fittest character. This process iterates until the best offspring is produced at certain generation [10]. Genetic Algorithm was used for cost optimization of Shishuwakhudi distribution network for sustainability of network to meet the future demand. A single objective function of total cost of replacing pipes (CT) with pressure constraint was done for analysis.

Objective Function

$C_T = L_j \times C(D)_j$ (2)

C_T = Total Cost L_j= Length of link j

$C(D)_j$ = Unit Cost for diameter of link j

Constraint

Pressure head at node (H_n) > 10m (H_{min})

The following chart (Fig-4) shows the step-by-step procedure to perform genetic algorithm in optimization of water supply network.

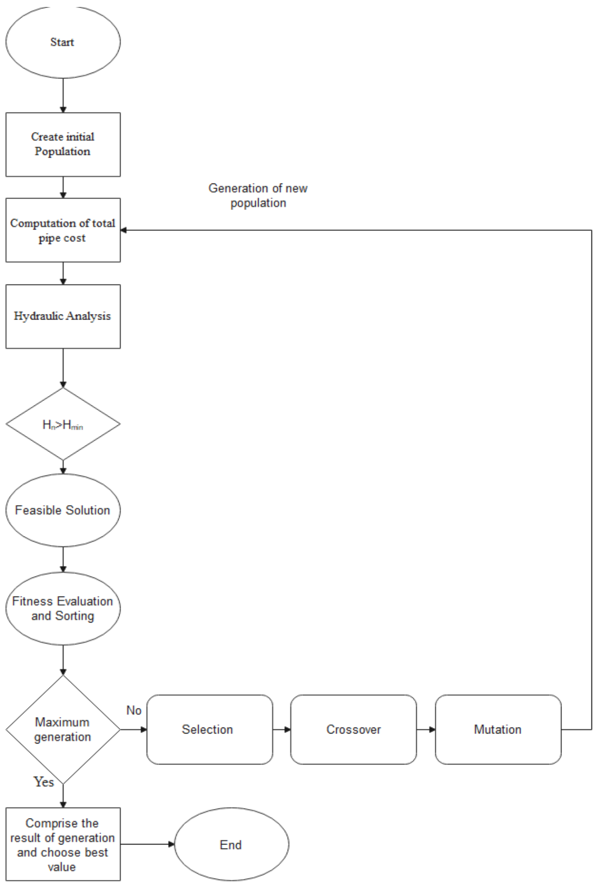

*Fig-4: **Flowchart of Optimization using Genetic Algorithm***

3. RESULTS AND DISCUSSIONS

3.1 Hydraulic Analysis

During Extended Period Analysis for present scenario, demand pattern was assigned as per design guideline provided by Small Town Water Supply and Sanitation Project for determining the real scenario of network. During peak hours, when 30% of total demand was consumed, some nodes at the end of network didn't receive water at sufficient pressure. Nodes 797,798,799,800 and 792 showed negative pressure which indicated the pipe size in this area is not sufficient to supply required quantity of water at peak demand. The reliability of network based on pressure requirement of 10m was 75% which need to be increased to 100%. Optimization of pipeline network in these critical areas is needed. The pipeline in the end of network are not getting adequate quantity of water at peak hours. Pressure irregularities are caused due to inadequate pipe size to fulfill the peak demand. Fig-5 and Fig-6 showed the pressure distribution at various nodes during peak hours.

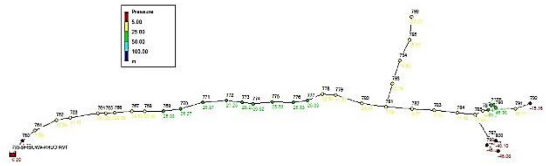

*Fig-5: **Pressure Distribution at different nodes during peak hours***

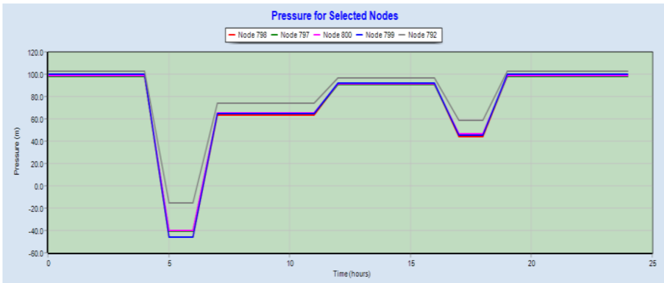

Fig-6: Pressure distribution at nodes having negative pressure during peak hours

The existing household of Shishuwakhudi distribution network was projected to forecast the population after 10 years with growth rate 3% using geometric increment. Thus, projected population was computed to determine the average demand at each node. Peak factor of 3 suggested by guideline of water supply and sanitation project was used to forecast the future base demand. Again the network was analyzed using EPANET to determine the hydraulic feasibility of the network. The analysis of Shishuwakhudi future forecasting showed negative pressure in most of pipes that indicated the existing network required rehabilitation and strengthening for future sustainability. Fig-7 showed only junction nodes from 760 to 772 had positive pressure and all other had negative pressure. The reliability of this network was obtained just 17% based on pressure in 2031. This is very low and should be increased for sustainability. The existing pipeline network requires rehabilitation for fulfilling future demand.

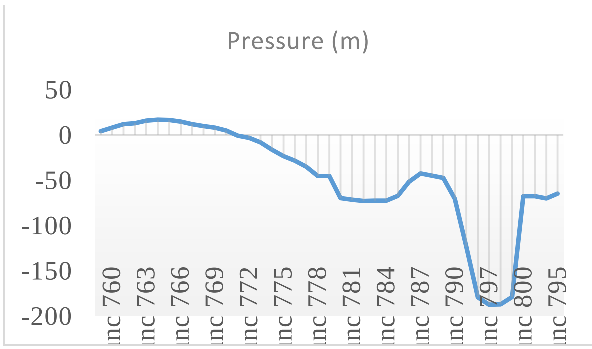

Fig-7: Pressure at nodes in projected year 2031 A.D

Thus, this network was optimized using genetic algorithm to get minimum cost of replacing pipes with optimal diameter.

3.2 Cost Optimization using genetic Algorithm

For sustainability of water distribution network to fulfill future growing demand, cost optimization with pressure constraint was done using genetic algorithm. The total cost of replacing 41 numbers of pipes in Shishuwakhudi distribution network was proposed with optimal diameter of commercial pipes. The following commercial pipes were selected for optimization.

Table-1: Commercial Pipes and Their Rates in Local Market (HDPE)

Outer Diameter of Pipe	Inner Diameter	Cost (Rs)/m
32	23.4	91.18
40	29.6	140.32
50	37.2	217.31
63	46.8	346.44
75	56	486.49
90	67.2	701.06
110	82.2	1037.67
125	93.6	1354.63
140	104.8	1629.86
160	120	2120.74
180	134.8	2692.2
200	150	3312.75
225	168.6	4203.68
250	187.4	5186.21
280	211	6485.85
315	236.6	8506.68

Source: Kaski Jilla da Rate 2078/079

Single objective function of pressure constraint of minimum 10m head suggested by Design Guidelines Urban Water Supply and Sanitation Project, 2020 with optimum cost for replacement was performed. For performing genetic algorithm, MATLAB 2015a was used for coding. Initial population of N= 100 was used as initial seeding for different number of iteration (generation). Number of generations 50, 100 and 500 were used as variables of tuning for finding the optimum solution. The following table showed best solution obtained in 50, 100 and 500 iterations.

Link ID	Optimal Diameter (mm)	Node ID	Optimal Pressure (mm)
Pipe 761	236.6	Junc 760	2.93
Pipe 762	211	Junc 761	6.79
Pipe 763	187.4	Junc 762	10.64
Pipe 764	187.4	Junc 763	11.6
Pipe 765	168.6	Junc 764	14.58
Pipe 766	134.8	Junc 765	14.64
Pipe 771	211	Junc 766	13.46
Pipe 770	168.6	Junc 767	16.23
Pipe 769	168.6	Junc 768	14.33
Pipe 768	168.6	Junc 769	13.61
Pipe 767	187.4	Junc 770	13.22
Pipe 776	187.4	Junc 771	15.47
Pipe 775	168.6	Junc 772	12.46
Pipe 774	168.6	Junc 773	13.85
Pipe 773	168.6	Junc 774	14.23
Pipe 772	150	Junc 775	16.26
Pipe 780	168.6	Junc 776	21.07
Pipe 779	150	Junc 777	18.1
Pipe 778	168.6	Junc 778	18.13
Pipe 777	134.8	Junc 779	13.69
Pipe 781	168.6	Junc 780	24.13
Pipe 793	104.8	Junc 781	11.26
Pipe 782	150	Junc 782	12.62
Pipe 783	134.8	Junc 783	12.21
Pipe 784	150	Junc 784	14.11
Pipe 785	134.8	Junc 785	16.64
Pipe 794	82.2	Junc 786	22.07
Pipe 792	120	Junc 787	37.5
Pipe 791	104.8	Junc 788	51.26
Pipe 790	82.2	Junc 789	50.09
Pipe 789	67.2	Junc 790	50.29
Pipe 788	120	Junc 791	27.91
Pipe 787	104.8	Junc 792	13.47
Pipe 786	104.8	Junc 797	15.94
Pipe 797	134.8	Junc 798	16.48
Pipe 800	82.2	Junc 799	17.81
Pipe 798	93.6	Junc 800	16.57
Pipe 799	120	Junc 793	14.67
Pipe 796	134.8	Junc 794	12.52
Pipe 795	134.8	Junc 795	14.11
Pipe 760	236.6	Junc 796	19.36

Thus, obtained optimal cost from different run i.e 50, 100 and 500 is given below:

Tc(50 gen) = Rs 4,95,5,7505
Tc(100 gen) = Rs 4,54,88,493
Tc(500 gen) = Rs 4,21,50,917

Thus, after run of 500 generation, the optimal cost was obtained with minimum pressure head sum violation of 10.8m at each run. This violation at pressure was obtained at the starting nodes that have no water demand and all other nodes showed optimum pressure. Therefore, this can be considered as the optimal solution. The diagram below (Fig-8) shows the cost obtained at various iteration. At 500 iteration, the cost remain almost constant so, it was taken as a limiting point for optimal solution.

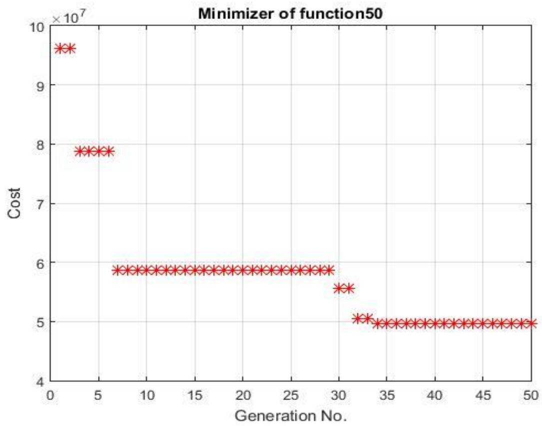

Fig-8: Cost Optimization with generation 50

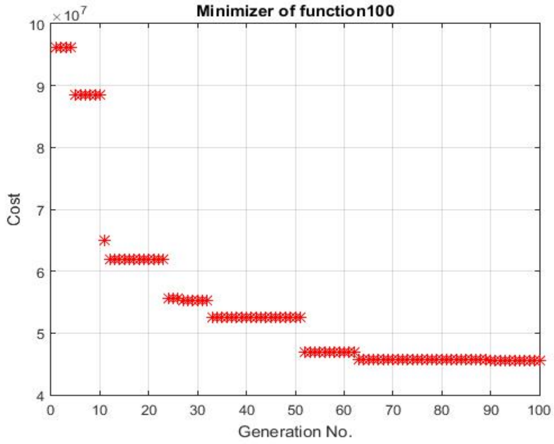

Fig-9: Cost Optimization with generation 100

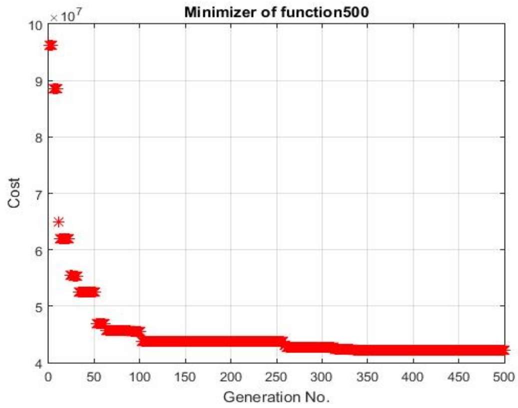

Fig-10: Cost Optimization with generation 500

4. CONCLUSIONS

This hydraulic analysis of water supply network in Lekhnath water supply was done to determine the existing network condition in terms of quantity. Inadequate water supply at each point of nodes has been a great issue in this area due to unplanned extension of pipelines. Shishuwakhudi is one of the networks supplying water to 1138 household. At present scenario, the household at the end of network are lacking adequate water supply during peak demand. Pressure at nodes 797,798,799,800 and 792 showed negative pressure that implied insufficient pressure head of water in these nodes even in the present scenario. When projected to future scenario, the existing pipeline showed only 17% reliability with minimum pressure requirement of 10 m head as per norms of urban water supply project in Nepal. For cost optimization with single objective constraint of minimum pressure head of 10m as suggested by Urban Water Supply and Sanitation (Sector) Project Design Guidelines, 2020 was performed using genetic algorithm technique for Shishuwakhudi Distribution Network for peak demand of 2031. After 500 generation optimizations gave the optimal solution with sum of pressure violation of 10.8m and cost of NRs 4, 21, 50,917 (USD 359,690.64). This violation has been obtained due to starting nodes with no water demand. The obtained optimal diameters could be precious for replacing the existing pipes with minimum cost for sustainable supply of water for next 10 years.

This hydraulic analysis can be considered to support in locating the nodes and links with less reliability and might assist in future planning for sustainable analysis of water supply network. The genetic algorithm might assist in optimization of any network with less time consumption and more reliability.

ACKNOWLEDGEMENT

This study was supported by Technical University of Cologne, Germany with doctoral research grant from German Academic Exchange Service and supervision from Prof. Dr. Lars Ribbe, including the support of Prof. Dr. Karl Schneider from University of Cologne, Germany, Dr. Sudan Panthi from WHO, Nepal, Asst. Prof. Dr. Raziyeh Farmani from University of Exeter, UK. Authors' team also would like to express gratitude to Er. Nirjal Dhakal sir and Er. Namraj Khatri from Ministry of Water Supply, Nepal for their valuable guidance in during analysis and detail investigation of the acquired data. Last, but not least, authors would like to thanks Er. Shiva Amatya the Chief of Office, Lekhnath Small Town Water Supply and Sanitation Project for his continuous help during data collection phase.

REFERENCES

[1] Adeniran, A.E &Oyelowo, M.A. (2013). An EPANET Analysis of Water Distribution Network of the University of Lagos, Nigeria. Journal of Engineering Research, 18(2).

[2] Agunwamba, J.C., Ekwule, O.R., & Nnaji, C.C. (2018). Performance evaluation of a municipal water distribution system using waterCAD and Epanet. Journal of Water Sanitation and Hygiene for Development, 8(3), 459–467.

[3] Anisha, G., Kumar, A., Kumar, J., & Raju, P. (2016). Analysis and Design of Water Distribution Network Using EPANET for Chirala Municipality in Prakasam District of Andhra Pradesh. International Journal of Engineering and Applied Sciences, 3(4).

[4] Awe, O.M., Okolie, S.T.A, & Fayomi, O.S.I. (2020). Analysis and optimization of water distribution systems: A case study of Kurudu post service housing estate, Abuja, Nigeria. Results in Engineering.

[5] Corso, L. L., Gasparin, A. L., & Gomes, H. M. (2016). Reliability based design optimization using a Genetic Algorithm: Application to bonded thin films areas of copper / polypropylene. 24, 510–519.

[6] Gautam A., Ramirez J., Ribbe L., Schneider K., Panthi S., Bhattarai M. (2021)a. Role of Citizen Science in Safe Drinking Water in Nepal: Lessons on Water Quality Monitoring from Brazil. In: Babel M., Haarstrick A., Ribbe L., Shinde V.R., Dichtl N. (eds) Water Security in Asia. Springer Water. Springer, Cham. https://doi.org/10.1007/978-3-319-54612-4_57

[7] Gautam et. al, 2021. Research Brief on Innovation for Water @World Youth Parliament for Water. Special Issue on 5th General Assembly. March 2021 Available at: https://youthforwater.org/action/research-group-briefs-on-general-assembly-themes/

[8] Goldberg, D. E. and J. H. Holland (1988). "Genetic algorithms and machine learning."

[9] Jeppson, R. (1974). Steady Flow Analysis of Pipe Networks: An Instructional Manual. Reports. Paper 300.

[10] Letting, L. K., Hamam, Y., & Abu-Mahfouz, A. M. (2017). Estimation of water demand in water distribution systems using particle swarm optimization. Water (Switzerland), 9(8).