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Water Distribution Network Assessment for Future Needs and Insights to Climate Change

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ABSTRACT. Global and regional water resources systems will be impacted by climate change and the inflow to drinking water reservoirs is a significant issue. Urbanization increases water demand in cities, and deteriorating infrastructures lead to leaks in water distribution systems. The study aims to evaluate and create a new water distribution system for Surat City's North Zone in India. WATERGEMS which is a computer program used in hydraulic behavior simulation with the pressure pipe networks was used. The water distribution network has been analyzed for a 24 × 7 continuous water supply for the present population. Population forecasting is also carried out for 30 years by considering 2022 as the base year. The existing water distribution network was analyzed for future demand, in which it is observed that some portion of the water distribution network is not enough to deliver the necessary quantity with the least amount of pressure and head loss. The water distribution network is then redesigned as per the requirement to reduce head loss and maintain the minimum pressure as per Central Public Health & Environmental Engineering Organisation (CPHEEO). It was found that the pressure at all junctions and the flow with their velocities at all pipes are sufficient to supply the network of the study region with enough water. The study's conclusions will aid decision-makers in addressing the issue of water scarcity and meeting user needs.

Keywords: 24 × 7 water supply, climate change, New North Zone-Surat City, water distribution network

1. Introduction

Water is an absolute necessity in our daily lives. The need for water is increasing day by day as the population grows. Designing efficient water distribution networks can meet this requirement. Water distribution networks are critical infrastructures for delivering water from sources to end users. As the human population and economies grow, global freshwater demand has increased rapidly (Boretti and Rosa, 2019). This demand for water is met by establishing an appropriate water distribution network. The need for conservation and proper distribution of water is also important to achieve some of the Sustainable Development Goals (SDGs) of the United Nations and zero hunger (SDG2).

Water is distributed in two types of supply systems, intermittent and continuous supply systems. The hydraulics of the water supply system is negatively impacted by intermittent water supply, which degrades the network and raises the cost. Intermittent water supply water is distributed in less than 24 hours (Klingel, 2012; Weston et al., 2022). According to reports of indicator bacteria because they contain less free chlorine than the minimum amount (Kumpel and Nelson, 2013; Burt et al. 2018). By ensuring customer convenience, the advantages of a constant, pressurized water supply outweigh the disadvantages of intermittent supply (Jayaramu et al., 2015).

A continuous, high-quality water supply system lowers the level of contamination because the pipes are under positive pressure and the entry of contaminants into the pipes is limited. Smart metering and efficient leakage control enable better demand management of a water supply system (Britton et al., 2013). Additionally, it leads to less or no water storage, which lowers water waste. Distribution networks have a longer lifespan as steady pipe pressure results in less pipe damage (Tawalare and Balu, 2016).

Water Geospatial Engineering Modelling System (WaterGEMS) is a versatile hydraulic Modelling application for water distribution systems with advanced interoperability, optimization, and asset management tools (Awe et al., 2019). Due to the numerous drawbacks of the intermittent water delivery scheme, it is critical to convert to a traditional system that would deliver potable water to the consumer's faucet on demand, at high pres-

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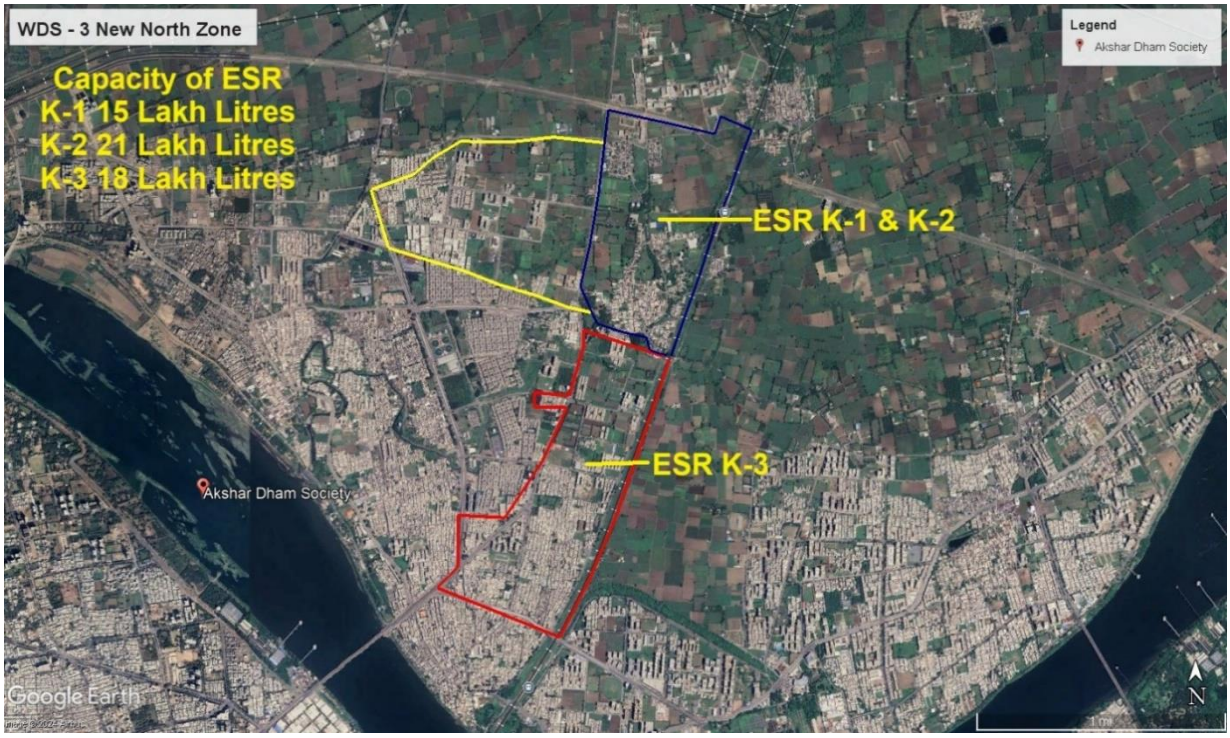

Figure 1. Study area (New North Zone of Surat City).

sure, and in a continuous flow. By implementing these systems, the risk of theft and leakage is reduced, the existing system's capability is increased, nonrevenue water is reduced, operation and maintenance costs are reduced, water quality and quantity are improved, consumers receive immediate and proper water, revenue is increased by converting illegal connections to legal connections, and the existing water supply scheme is optimized and controlled (Quadar et al., 2021). The objective of the study is to assess the water distribution network using WaterGEMS software for future needs in the changing climate. The future scenario would open the discussion among water authorities to target sustainable development goals. By implementing these systems, the risk of theft and leakage is reduced, the existing system capability is increased, nonrevenue water is reduced, the operation and maintenance costs are reduced, water quality and quantity are improved, consumers receive immediate and proper water, revenue is increased by converting illegal connections to legal connections, and the existing water supply scheme is optimized and controlled (Quadar et al., 2021). The objective of this study is to assess the water distribution network using WaterGEMS software for future needs in changing climate. The future scenario would open discussion among water authorities to target sustainable development goals.

2. Materials and Methods

2.1. Study Area

The westernmost city in the Indian state of Gujarat, Surat, is well-known for its textile and diamond industries. Surat, also known as the Silk City of India, will have an estimated population of 7.2 million in 2022, making it the eighth-largest city in India. Surat, a port city on the banks of the Tapi River, is one of the cities in India with the fastest population growth. Surat City has a total area of 326 km^2 and a population density of 14,000 inhabitants per km^2. Kosad is in the New North zone, one of Surat's seven divisions. The Kosad survey area has a population of 88,224. The new North Zone water distribution system is Water Distribution System (WDS): K point network systems Elevated Storage Reservoir (ESR) i.e., ESR K-1, ESR K-2, and ESR K-3. In this paper, an analysis of WDS ESR K-2 is carried out using the WaterGEMS model.

2.2. Data Collection

The field data such as the existing water distribution system map, length of pipe, diameter of pipes, junction report, pipe report, and demand at every node and junction of the West zone were collected from the hydraulic department of Surat Municipal Corporation (SMC).

2.3. Overview of WaterGEMS Software

An American company called Bentley Systems Incorporated creates, produces, sells under license, and supports computer software and serves for the planning, building, and maintenance of infrastructure. The building, plant, civil, and geospatial markets in the fields of architecture, engineering, construction (AEC), and operations are served by the company's software. Large, constructed assets like roads, railways, bridges, buildings, power plants, and utility networks are designed,

Table 1. Population Forecasting

No.	ESR	A	2022 (Immediate)			2036 (Intermediate)			2052 (Ultimate)		
			D	P	De	D	P	De	D	P	De
1	K-2	8	650	5,200	936,000	700	56,00	1,008,000	1,000	8,000	1,440,000
		65	260	16,900	3,042,000	415	26,975	4,855,500	510	33,150	5,967,000
		75	260	19,500	3,510,000	415	31,125	5,602,500	510	38,250	6,885,000

Note: where, A represents area in hectares, D represents density hectares, P represents population, and De represents demand (L/day)

engineered, constructed, and operated using software products. 20% of the company's revenue is reinvested in research and development. The model can be used to create, display, edit, run, and analyze hydraulic models from a geospatial environment because WaterGEMS offers full geo-database integration (Shiu et al. 2022). The Newton-Raphson method is the method used in this software for network analysis. The analysis of the existing water distribution system was carried out using WaterGEMS. The following steps were used in WaterGEMS software:

Step 1: Design period. The design period for this work has been adopted by the lag time that must pass between the design and execution of the project. It is divided into three stages, namely, immediate, intermediate, and ultimate stages.

Step 2: Population forecasting. Based on the collected data, population forecasting for the next 30 years was carried out using the density method. Detailed calculation is shown in Table 1.

Method of density. In this method, the trend in the rate at which a city's population is increasing in each sector is identified, and population forecasts are made for each sector using the methodology described above. The population of the city is calculated by adding population by sector.

Step 3: Water demand. Water demand projections were carried out as per standard 135 litres per capita per day (LPCD) for the users. In the present study, the water demand of 180 LPCD is taken by including all the losses as the study area has institutional, commercial, and industrial buildings. Values of the ESR's zone wise demand are computed by considering the probable population density in every zone concerning the development plan and previous data available. Individual demand for ESR K-2 is shown in Table 2.

Step 4: Thiessen polygon. The load builder facility was used to assign the water demand at each node of the water distribution network using the Thiessen polygon method. Each nodal was given a ward wise area. The Thiessen polygon method was used to distribute this demand among all the nodes, and a demand pattern was applied to it to make it fluctuate throughout the day.

Step 6: Once the Thiessen polygon process for the existing network area is completed, create a new hydraulic model file for analysis using WaterGEMS software.

Step 7: Import the network along with the details of the pipe and junction in WaterGEMS software. (Figure 2)

Step 8: Import the data like node, junction, and pipe diameter using the property editor.

Step 9: Import the demand pattern for the design of the water distribution networks.

Table 2. Demand for Each ESR K-2

Demand for ESR K-2			
K2	Total Demand	L/day	14,292,000
	Peak Demand	L/day	42,876,000
		MLD	42.876
	Demand	L/ha/d	289,702.70

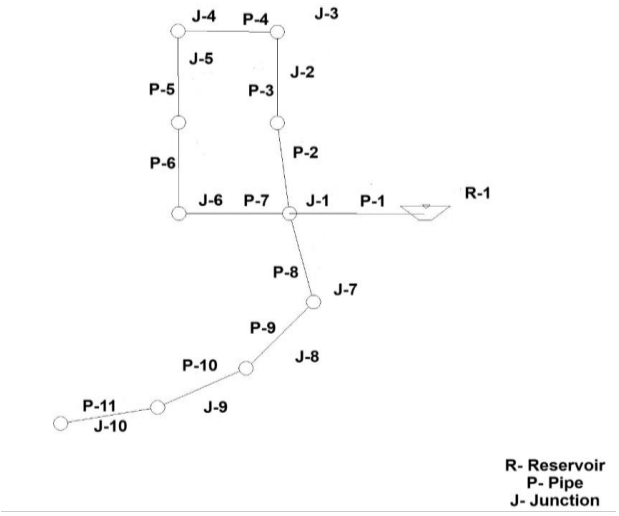

Figure 2. Import network.

Step 10: Set demand on each node.

Step 11: Run analysis and propose a design.

3. Results and Discussion

Analysis and design of the existing water distribution network were carried out using WaterGEMS. The WDS of ESR K-2 is simulated for both present demand scenarios and future demand scenarios.

3.1. Analysis of Existing Network Distribution using WaterGEMS

The pipe report of ESR K-2 includes 37 pipes. The result obtained using WaterGEMS software is presented in Table 3. There are a total 37 numbers of pipes. The flow computed using WaterGEMS is nearly equal to the actual flow. It is found that there are 17 pipes having a velocity less than the minimum velocity. As per Central Public Health & Environmental Engineering Organisation (CPHEEO) manual minimum velocity should be 0.6

Table 3. Pipe Report for ESR K-2

Label	Flow (L/s)		Velocity (m/s)		Head loss (m/km)	
	Actual	WaterGEMS	Actual	WaterGEMS	Actual	WaterGEMS
P-21	0.03	0.03	0.00	0.00	0.00	0.00
P-24	2.46	3.52	0.14	0.20	0.17	0.33
P-27	0.03	0.03	0.00	0.00	0.00	0.00
P-29	0.03	0.03	0.00	0.00	0.00	0.00
P-32	3.15	3.15	0.18	0.18	0.27	0.27
P-34	8.33	11.12	0.47	0.63	1.64	2.81
P-36	1.68	1.68	0.10	0.10	0.09	0.09
P-39	488.49	476.55	1.73	1.69	3.61	3.45
P-42	15.96	4.02	0.90	0.23	5.48	0.43
P-44	16.59	15.93	0.94	0.90	5.89	5.46
P-47	2.45	2.201	0.14	0.12	0.17	0.14
P-50	3.09	3.09	0.17	0.17	0.26	0.26
P-52	7.56	7.56	0.43	0.43	1.37	1.37
P-54	24.38	22.90	1.38	1.30	12.01	10.69
P-55	18.59	17.28	1.05	0.98	7.27	6.35
P-56	6.75	6.75	0.38	0.38	1.11	1.11
P-58	32.00	22.03	1.02	0.70	4.89	2.45
P-60	21.76	19.79	1.23	1.12	9.73	8.16
P-62	77.18	75.95	1.57	1.55	8.43	8.18
P-65	13.76	12.01	0.78	0.68	4.16	3.24
P-66	480.93	468.99	1.70	1.66	3.51	3.35
P-68	2.40	3.46	0.14	0.20	0.16	0.32
P-69	97.86	98.01	1.99	2.00	13.08	13.12
P-72	50.07	47.91	1.02	0.98	3.78	3.49
P-73	221.58	211.21	1.39	1.33	3.39	3.10
P-74	134.92	125.78	1.40	1.31	4.60	4.04
P-75	55.44	55.44	1.76	1.76	13.54	13.54
P-78	11.91	10.34	0.38	0.33	0.78	0.60
P-80	11.31	10.25	0.64	0.58	2.89	2.41
P-81	33.89	36.68	0.48	0.52	0.76	0.88
P-84	11.94	18.67	0.68	0.38	3.20	0.61
P-85	17.75	9.99	0.36	0.57	0.55	2.30
P-86	10.63	115.26	0.60	1.20	2.58	3.44
P-87	115.41	12.86	1.20	0.73	3.45	3.67
P-88	14.83	131.19	0.84	1.36	4.78	4.37
P-89	132.59	93.64	1.38	1.32	4.46	4.96
P-90	100.80	35.04	1.43	1.12	5.67	5.79

m/s in order to avoid depositions and consequent loss of carrying capacity. Pipes (i.e., P-21, P-24, P-27, P-29, P-32, P-36, P-42, P-43, P-50, P-52, P-56, P-68, P-78, P-80, P-81, P-84 and P-85) indicate that 18 pipes have a head loss gradient (m/km) greater than 3 m/km. The range of head loss above 3 m/km is 3.10 to 13.54 m/km. The errors between actual pressure and pressure obtained from WaterGEMS is shown in Table 4. The total number of the junction is 30. Based on the above study and analysis, it is found that there is fluctuation in the pressure head. The range of the pressure head is between 19.82 to 25.06 m.

3.2. Analysis and Design of Existing Network Distribution for Proposed Future Demand

In the present section, an analysis of the existing water distribution network is carried out for the next 30-year population. The base year is taken as 2022, total demand is calculated for the next 30 years and analyzed the existing water distribution network for future demand. As demand increases it is required to study whether the existing water distribution network is sufficient to provide an adequate quantity of water with minimum pressure. The results obtained by WaterGEMS software are discussed below. The analysis the of existing water distribution network of ESR K-2 is done with new demand. Demand was carried out based on the density method as discussed above which is 42.876 MLD and 2,89,702.70 LPCD. Using the Thiessen polygon tool, demand is distributed in each node. After that, all the input data entered such as elevation, length, existing diameters, and new demand, etc. run the software as Extended Period Simulation (EPS). The result obtained after the revised demand are as followed. Based on the above analysis it is observed that the newly proposed design is sufficient

Table 4. Junction Report for ESR K-2

Label	Elevation (m)	Demand (L/s)	Pressure (kg/cm^2)			Pressure Head (m)
			Actual	WaterGEMS	% Error	
J-1	10.3	0.03	2.3	2.4	-0.1%	24.3
J-2	10.3	0.03	2.3	2.4	-0.1%	24.3
J-3	12.7	19.60	2.0	2.2	-0.2%	22.0
J-4	12.2	0.03	2.1	2.2	-0.1%	22.5
J-5	12.0	0.03	2.1	2.3	-0.2%	22.7
J-6	13.7	6.90	2.1	2.3	-0.2%	22.6
J-7	13.7	0.03	2.1	2.3	-0.2%	22.6
J-8	11.9	10.60	2.1	2.3	-0.2%	22.7
J-9	11.7	18.80	2.1	2.3	-0.2%	23.1
J-10	12.3	2.30	2.0	2.2	-0.2%	22.4
J-11	12.3	1.70	2.0	2.2	-0.2%	22.4
J-13	14.7	0.00	2.4	2.5	-0.1%	25.0
J-14	12.3	30.90	2.0	2.2	-0.2%	22.4
J-15	14.6	9.10	2.0	2.2	-0.2%	21.9
J-16	14.6	8.60	2.0	2.1	-0.1%	21.5
J-17	14.6	4.80	1.9	2.1	-0.2%	20.7
J-18	14.6	13.10	1.9	2.1	-0.2%	20.6
J-19	11.9	3.10	2.1	2.3	-0.2%	22.7
J-20	16.0	7.60	2.2	2.4	-0.2%	23.6
J-21	11.9	6.80	2.1	2.3	-0.2%	22.8
J-22	14.9	34.90	1.8	2.0	-0.2%	20.2
J-23	14.6	12.40	2.2	2.3	-0.1%	23.0
J-24	14.0	9.50	2.3	2.5	-0.2%	24.5
J-25	14.3	9.30	2.1	2.3	-0.2%	22.9
J-26	14.2	11.30	2.4	2.5	-0.1%	24.9
J-27	14.1	22.80	2.2	2.3	-0.1%	23.0
J-28	14.0	133.0	1.9	2.1	-0.2%	20.7
J-29	14.7	24.80	2.2	2.3	-0.1%	23.1
J-30	15.0	55.40	1.8	2.0	-0.2%	19.8
J-31	14.0	19.00	2.2	2.3	-0.1%	23.0

to fulfil the future demand with minimum pressure and minimum head load.

3.3. Analysis of Existing Water Distribution Network for Proposed Future Demand

The pipe report of ESR K-2 includes 37 pipes. The result obtained using WaterGEMS software is presented in Table 5. Total numbers of pipes are 37. The flow in pipes increase as demand increases. As per above Table 5 the distribution of total flow is mentioned in each pipe. There was a slight increase in velocity after increasing flow. It is observed that the maximum velocity is at P-62 (2.58 m/s) compared to the similar pipe with existing which was 1.57 m/s, meaning that the velocity increase because of the flow is increase and diameter is less. This displays that the velocity of the existing pipes is less than that of the present flow. The range head loss is also higher as flow is greater diameter is not sufficient therefore existing pipe having more head loss due to increase flow.

It is observed that the whole network is not sufficient to provide adequate flow. There are 21 pipes having head loss more than 3 m/km namely P-34, P-36, P-39, P-42, P-44, P-54, P-55, P-58, P-60, P-62, P-65, P-66, P-72, P-73, P-74, P-75, P-78, P-80, P-85, P-87, and P-89. As flow increases in the pipe head loss also increases and due to this, the diameter of the pipe is required to increase. The junction report of ESR K-2 includes 30 pipes. The result obtained using WaterGEMS software is presented in Table S1. The pressure profile at each junction for proposed future.

After running the model, the result shows that the pressure head at all junctions ranges from 14.00 to 25.04 m for ESR-2. It is observed that 10 nodes have pressure heads less than 17 m. The junction having pressure heads less than 17 m are J-3, J-4, J-10, J-11, J-14, J-16, J-17, J-18, J-19, and J-22. The range of pressure is 1.4 to 2.5 kg/cm^2 which is less than existing pressure.

3.4. Proposed Design for Water Distribution Network of ESR K-2

The analysis of the EPS of the water supply distribution system for each of the hours during a water supply has been carried out in WaterGEMS software. The input parameters like demand, elevation and length, etc. based on the proposed design. An analysis of the existing water distribution network of

Table 5. Pipe Report for ESR K-2

Label	Length (m)	Diameter (mm)	Flow (L/s)		Velocity (m/s)		Head loss (m/km)	
			Proposed	Existing	Proposed	Existing	Proposed	Existing
P-21	23	150	0.50	0.03	0.03	0.00	0.01	0.00
P-24	28	150	5.88	2.46	0.33	0.14	0.86	0.17
P-27	39	150	0.50	0.03	0.03	0.00	0.01	0.00
P-29	35	150	0.50	0.03	0.03	0.00	0.01	0.00
P-32	37	150	5.05	3.15	0.29	0.18	0.65	0.27
P-34	41	150	17.92	8.33	1.01	0.47	6.79	1.64
P-36	52	150	17.36	1.68	0.98	0.10	6.40	0.09
P-39	70	600	496.84	488.49	1.76	1.73	3.73	3.61
P-42	70	150	34.72	15.96	1.96	0.90	23.11	5.48
P-44	80	150	23.19	16.59	1.31	0.94	10.95	5.89
P-47	100	150	0.95	2.45	0.05	0.14	0.03	0.17
P-50	103	150	4.05	3.09	0.23	0.17	0.43	0.26
P-52	115	150	0.58	7.56	0.03	0.43	0.01	1.37
P-54	120	150	28.20	24.38	1.60	1.38	15.72	12.01
P-55	131	150	19.17	18.59	1.08	1.05	7.69	7.27
P-56	131	150	8.85	6.75	0.50	0.38	1.84	1.11
P-58	149	200	46.77	32.00	1.49	1.02	9.88	4.89
P-60	159	150	25.72	21.76	1.46	1.23	13.26	9.73
P-62	163	250	126.78	77.18	2.58	1.57	21.13	8.43
P-65	169	150	14.00	13.76	0.79	0.78	4.30	4.16
P-66	177	600	496.03	480.93	1.75	1.70	3.72	3.51
P-68	184	150	4.88	2.40	0.28	0.14	0.61	0.16
P-69	187	250	3.57	97.86	0.07	1.99	0.03	13.08
P-72	191	250	97.69	50.07	1.99	1.02	13.04	3.78
P-73	194	450	344.07	221.58	2.16	1.39	7.67	3.39
P-74	226	350	176.78	134.92	1.84	1.40	7.60	4.60
P-75	225	200	42.25	55.44	1.34	1.76	8.19	13.54
P-78	236	200	64.06	11.91	2.04	0.38	17.70	0.78
P-80	261	150	12.17	11.31	0.69	0.64	3.32	2.89
P-81	292	300	46.77	33.89	0.66	0.48	1.37	0.76
P-84	329	250	16.63	11.94	0.34	0.68	0.49	3.20
P-85	392	150	20.86	17.75	1.18	0.36	8.99	0.55
P-86	379	350	77.96	10.63	0.81	0.60	1.67	2.58
P-87	439	150	24.99	115.41	1.41	1.20	12.57	3.45
P-88	456	350	68.21	14.83	0.71	0.84	1.30	4.78
P-89	513	300	150.83	132.59	2.13	1.38	11.99	4.46
P-90	543	200	102.99	100.80	0.10	1.43	0.06	5.69

ESR-K2 with a new forecast demand is discussed in the methodology section and it is found that some of the pipes are not enough to provide a sufficient amount of water without head loss. As a result, a very low velocity can be observed in some pipes since the piping system is old and the sizes are non-standard. However, a permanent solution to this problem is to redesign the network, which has been considered in this study. Due to economic reasons, we could not utilize the optimizing section of software in this study. To compensate for this limitation, only the current size of existing pipes was modeled, and it was also attempted to modify the system by focusing on the parts with pressure problems, taking into account the diameter possible for new pipelines, so that the pressure in the pipes can reach the stand and efficiency. As discussed earlier in some of the pipes head loss is more than 3 the head loss in the network. In the following table, the proposed diameter of the pipe is mentioned. A total of 37 pipes are connected in the network from that 22 pipes are redesigned. The pipes which are modified with their diameters are as per below Table S2. After redesigning the network results obtained from the WaterGEMS software are given in below Table S3. It is observed that the flow in a pipe is enough to provide adequate water for the next 30 years. The range of velocity is varied from 0.03 to 1.29 m/s. Maximum head loss in the network is 2.87 m/km which is under limitation. Also, as the diameter increases head loss decreases. The pressure head at the junction is above 17 m, which indicates that the proposed design is sufficient to provide the required amount of water under minimum pressure. The pipe and junction reports for a proposed design are as per below Tables S3 and S4. Pipe report table note indicates P as proposed pipe. The proposed pressure profile at each junction of ESR K-2 is shown in below Figure S1.

5. Conclusion

In this study, the existing water distribution network was analyzed and designed for ESR K-2 using WaterGEMS. In the existing WDS of ESR K-2, the total numbers of junction and pipes are 30 and 37 respectively, the average velocity in the pipes is 0.78 m/s, the head loss gradient varies from 0 to 13.54 m/km, and the pressure head on each node is above 17 m.

It is observed that 18 pipes have a head loss gradient above 3 m/km which is not tolerated so existing WDS is not enough to provide an adequate quantity of water to the users. A comparison of simulated and actual results shows that the simulated model seems to be reasonably close to the actual network. It was found that the resultant pressure at other junction and flows are not enough to provide water in the WDS of ESR K-2. According to the present population existing network is analyzed and designed for the prospective year 2052. According to the findings as the population grows from 2022 to 2052, parameters like demand, flow, head loss, and pressure increase. By checking the pressure and head loss in the existing water distribution network at its peak time, it shows that some potions have a deficiency, so the existing water distribution network is required to redesign.

To get efficient results, the variable parameter such as pressure, head-loss, and velocity should be controlled by keeping these parameters constant with the diameter that can changed to fulfill the requirements of an efficient existing water distribution network. Due to the economic viability of the plan, the least number of pipes was modified in case of necessity. As a result, by applying some changes in the existing water distribution network the problems of (a) pressure fluctuation, (b) head loss prevention, and (c) users' requirements are fulfilled.

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