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Hydraulic Modeling and Evaluation of The Water Supply Network of Egyptian Media Production City

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Abstract: Water demand increases rapidly because of numerous human activities, population growth, and changing lifestyles. Efficient water resources management techniques are necessary for sustainable development. This study aims to develop a reliable and effective hydraulic model to evaluate the hydraulic performance of the water distribution network of Egyptian Media Production City. WaterGEMS software was utilized to develop the hydraulic model based on numerical and operational data. The developed model allows for determining the pressures at network nodes and flows in pipes. The developed model was calibrated using 12 nodes' pressures, and then was validated using 8 other nodes. A series of simulations were performed to illustrate the operation of the network under variable water supply and demand conditions. The results showed that the network is currently operating erratically. In the case of average demand, water is supplied to all consumers, but some areas of the network experience good pressure (50%) and others low pressure (50%). In the case of maximum demand, there are water shortages that cannot be compensated for by the current pumping system. That is because of the limited supply of water from the reservoirs that feed most of the network. Proposed solutions were developed to achieve balanced pressures in the network, where the pressures increased, decreased, and still constant for 70%, 15%, and 15%, respectively. The proposed solutions will provide drinking water at the required pressure and quantity in each area without affecting the other areas despite the large differences in levels.

Keywords: water demand, water management, hydraulic model, WaterGEMS program, network operational analysis.

1. Introduction

Water management is essential for ensuring the sustainable availability of potable, sanitation, agricultural, and industrial water across various sectors. To meet current and future demands while protecting the environment, water resources must be strategically organized, expanded, allocated, and preserved. Water distribution networks (WDNs) are complex systems composed of pipelines, pumps, valves, and storage tanks that facilitate the movement of water from sources to consumers. Numerous studies have explored various aspects of WDN design to reduce costs [1], optimize energy use [2], and create adaptable designs through multi-objective optimization [3]. Water companies typically take several cost-related factors into account, including the energy required to transport water within the network, as well as expenses associated with network maintenance, leaks, and pipe failures. Research into these factors showed that network pressure significantly affects the operation of WDNs [4].

Hydraulic models are versatile tools that can be used both in the planning phase of new networks and during the operation of existing ones. The use of information technology and available software offers unlimited possibilities for solving problems related to water distribution that cannot be addressed with traditional methods (e.g., simulating the pressure and flow of water in a network). Computer simulations of network operations help make decisions regarding the ongoing operation of water companies [5-11].

Numerical analysis of networks enables the evaluation of networks from an operational perspective. It is particularly useful for optimizing the operation of existing networks. Modeling is very useful, for example, when it is planned to shut down parts of the water supply system for repairs and maintenance. In addition, analyzing the behavior of the network during periods of maximum water demand makes it possible to find the causes of problems in the operation of the network and test the designed solutions. By simulating the failure of a mainline, it is possible to achieve the right balance between the system efficiency and the water supply to consumers. The model can then be used to test alternative solutions to avoid the consequences of the interruption of water supply [12, 13]. The use of hydraulic models in the operation of water supply systems requires calibration and validation. These processes allow a reasonable agreement between actual measurements on site and calculated results. Only a correctly calibrated model can reproduce the actual operating conditions of the water supply system [14].

Aquis, WaterGEMS, and Water CAD are employed for the planning and study of WDNs. Selecting a software depends on various factors such as data availability, time constraints, budgetary limits, resource access, compatibility, and the overall scope of the project. The model's performance faces criticism due to its calibration with measured pressure levels [15-21].

This study aims to analyze the operation of the water supply system that supplies water to the Egyptian Media Production City. The analysis is based on a hydraulic model that allows checking the current network operation and identifying the locations where problems occur.

The scope of the study includes conducting a series of simulations of network operations for fluctuating conditions of supply and demand, analyzing the results, and providing solutions.

Bentley WaterGEMS was employed to analyze and enhance the water distribution system in the Egyptian Media Production City water supply system. The hydraulic modeling assumed a continuous water supply, and an extended-time simulation was utilized for the evaluation after calibration.

2. Materials and Methods

2.1 City of Egyptian Media Production

The city of Egyptian Media Production is in the 6th of October City, Giza Governorate, Egypt, and has diverse activities, as shown in Figure 1, where the number of employees and guests ranges from 3,000 to 5,000 people daily. The water network supplies water to the studio area, filming area, Movenpick Hotel, media club, and entertainment area (Magic Land), as well as the workshop area, public buildings, religious buildings, commercial buildings, and agricultural land. None of the buildings is more than three stories high. The buildings are fully connected to a sewage system, including a sewage treatment plant.

The water supply network of the Egyptian Media Production City was analyzed.

The analyzed areas are characterized by relatively large differences in altitudes, where contour lines are shown in Figure 2.

As shown in Figure 3, the water intakes 1 and 2 lie at 145.31 and 160.87 m above sea level (a.s.l.), respectively. An underground reservoir is located at 176.30 m a.s.l., and the highest point receiving water from the reservoir is 181.62 m a.s.l. The topography is, therefore, not suitable for the good operation of the water supply system.

The water supply network feeds an area of approximately 2.3 square kilometers, and water is supplied from two water intakes located in the northern and southeastern parts of the area. The southeastern intake discharges water directly into the network, while the northern intake supplies water to the network and three ground reservoirs (the master of them at the west of the city, Reservoir 1, and the other two reservoirs in the middle of the city) simultaneously.

The pumping system includes three pumps, two external pumps with two water intakes, and an internal pump in the middle of the city at 153.00 m a.s.l. to lift water from low to high levels. In addition to special pumps for the Mövenpick Hotel and the A&K Studios Complex.

Water is supplied to consumers directly from the intakes, and to the 3 ground reservoirs via 160 mm diameter water pipes. The total capacity of the main underground reservoir, Reservoir 1, is 2,000 cubic meters. Water is pumped from the two water intakes into the network, and at the same time, water is pumped from the ground reservoirs to the network.

The network consists of PVC and steel pipes, which account for 98% and 2% of the used pipes, respectively, with diameters and lengths illustrated in Table 1 and Figure 4.

Average consumption data from 2020 to 2024 obtained from meters were used, as shown in Figure 5. Note that some of the meters for which the average was taken had been repaired, and some had been replaced.

The average daily water demand for the entire network is 2,700 m3/day, considering customer privacy, as shown in Figure 6, which presents the hourly water consumption pattern throughout the day. Due to the nature of operations, there are four high-volume users: Movenpick Hotel, Media Club, Magic Land, and A&K Studios Complex. Their calculated average daily demand was 800, 500, 205, and 700 m^3/day, respectively.

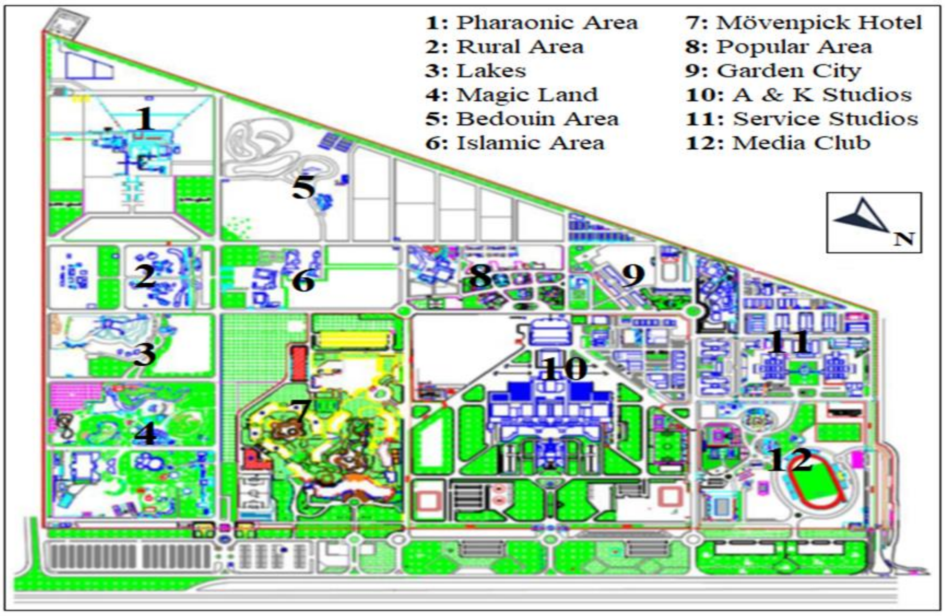

Figure 1. Egyptian Media Production City

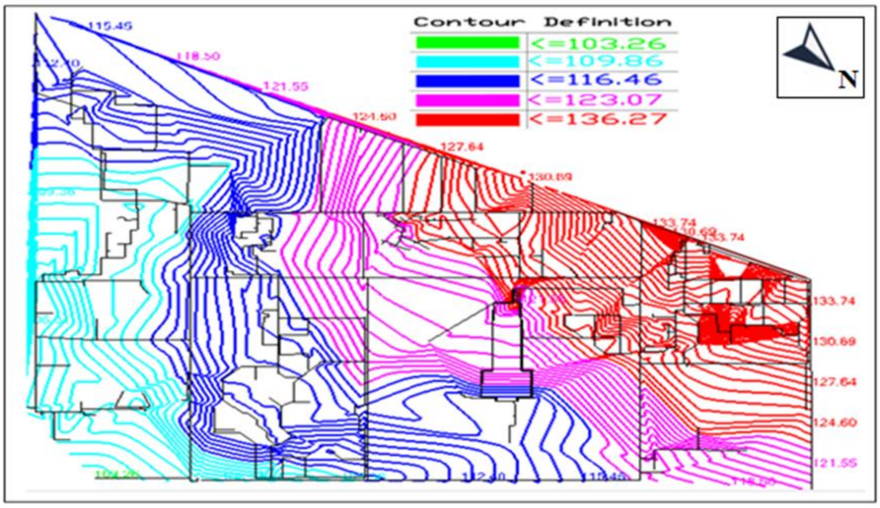

Figure 2. Altitude Profile of the Egyptian Media Production City

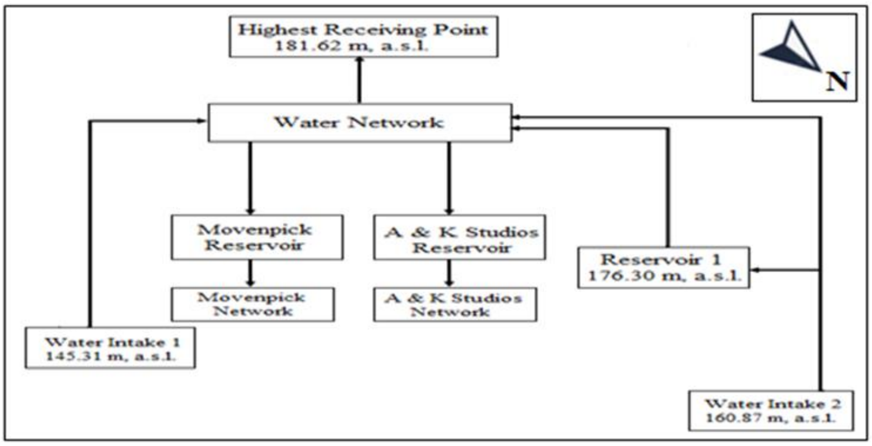

Figure 3. Egyptian Media Production City Water Supply Network Components

Table 1. Diameters and Lengths of the Network Pipes

Diameter,mm	Material	Length,m	Percentage to the total length
160	PVC	1888	10%
110	PVC	8804	45%
75	PVC	6093	32%
63	PVC	2332	12%
50	PVC	242	1%
75	Steel	207	58%
32	Steel	152	42%

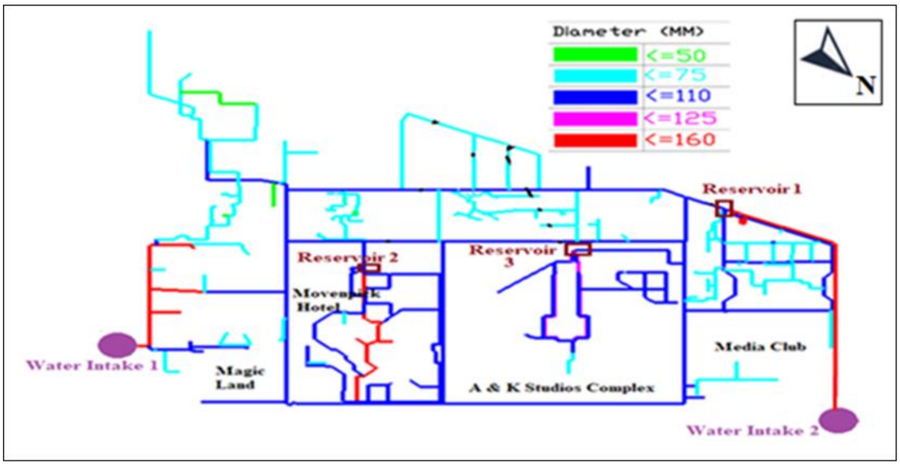

Figure 4. Water Supply Network Plan including Pipe Diameters, Main Users ,Ground Reservoirs, and Water Intakes

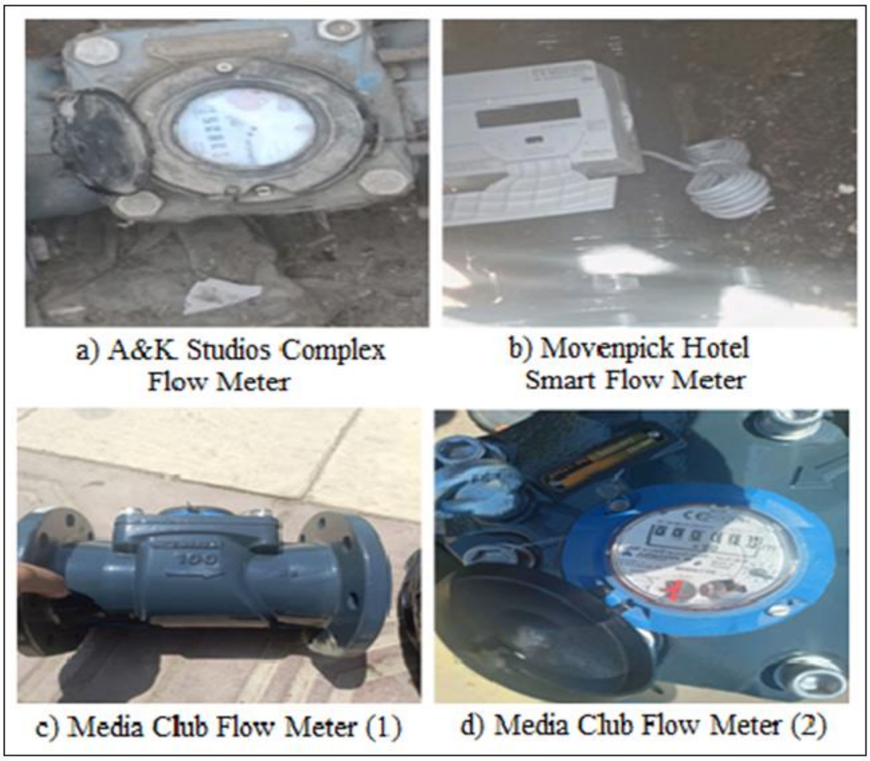

Figure 5. Flow Meters for Customers and Water Intakes

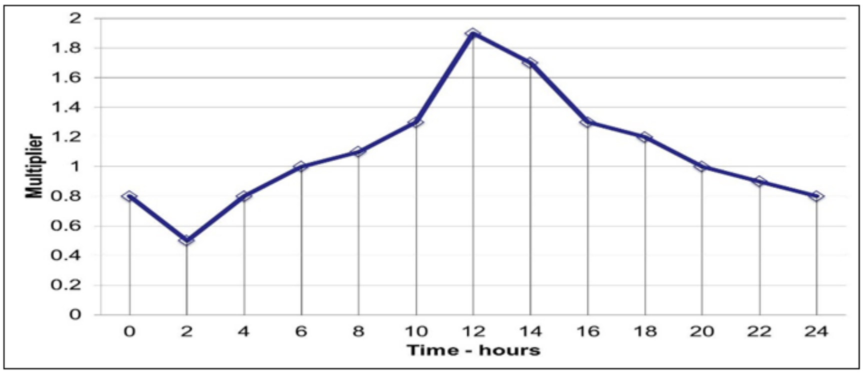

Figure 6. Hourly Water Consumption Pattern Throughout the Day

Water demand varies by area and use, where hotels and clubs have many swimming pools, Magic Land has recreational water plays, fountains, and extensive agricultural areas.

2.2 Hydraulic Model

The network was defined on the AutoCAD panels and WaterGEMS program, including levels, junctions, pipes, pumps, reservoirs, valves, peak usage, minimum usage, and consumption throughout the day, week, and year.

WaterGEMS (developed by Bentley Systems, USA) is an advanced application for building hydraulic models of water distribution systems.

To identify fluctuations in water consumption during the day and throughout the year, coefficients of hourly variation throughout the day, daily variation throughout the week, and monthly variation throughout the year were used, as obtained from meter monitoring. For temporal variations throughout the day, as an example, the values shown in Figure 6 were used, and the maximum hourly water demand (Qhmax) was calculated as 229 m^3/hour.

Modeling is especially important when evaluating, modifying, or expanding an existing network. Different variations concerning proposed solutions can be quickly analyzed to select the most beneficial solution. The impact of increasing the load on the existing system can be estimated, and errors can be detected during the design of new sections.

This study developed a hydraulic model using WaterGEMS software. A gradient algorithm - a hybrid loop and node iterative method - was used to simplify the cumbersome inter-computation procedure.

Based on the range of operational data collected, a single-period analysis was used to model the network. The Hazen-Williams equation was selected to calculate the pressure drop in the pipes and to calculate the turbulent water flow.

The network model developed consisted of 377 junctions connected by 413 pipe segments.

The model included two water intakes, a main ground reservoir (Reservoir 1) that supplies water to the network, two private ground reservoirs for individual regions, and a pumping system. The developed model was characterized by a high degree of detail.

Pumps' locations and capacities, and water supply methods for all areas were gathered from the network operator. A multi-point curve was used based on the operating range. The model considered the inner pipe diameter.

During the simulation of network operation, pressure values at the nodes were calculated for five different cases concerning pump or reservoir situations, as illustrated in Table 2, which shows these cases and their timing.

For Case A, the water consumption is low. So, the suction pumps from the main reservoir (Reservoir 1) are closed (off), and the rest of the pumps are operated (on) to fill the main reservoir at this time. For Case B, water consumption begins to increase. So, the main reservoir filling is off, and the reservoir pump is started (on) to compensate for the increase in consumption.

Case D was chosen as the basic case, as it does not depend on withdrawing water from the reservoirs. So, when self-sufficiency occurs with the water coming from the two water intakes, the water in the reservoirs will be available for use in the event of any malfunctions or water outage from one of the intakes, or to change the water and not stagnation in the tanks.

Case D was used in evaluating the simulation compared to the reality measures, and to apply virtual solutions until the best solutions are chosen to solve the existing problems.

2.3 Model Calibration

The model was calibrated using the measured points of the pump rooms and fire hydrant locations within the network, as shown in Figure 7. Concerning the level of detail in the model, the number of points required must be at least 2% of the nodes (7.54, ≈ 8 nodes). So, 12 data points, 3.2% of the nodes, were used in the calibration process. The site pressure readings were compared with the model pressure readings in Case D, as shown in Table 3, to assess the accuracy of the model pressure values. The site and model values of pressure are shown in Figure 8, indicating a great calibration result with a coefficient of correlation R^2 = 0.9979, indicating that the developed model is a good representation of the network.

The calibrated model was validated using 8 other nodes, as shown in Table 4. The site and model values of pressure are shown in Figure 9, indicating a great validation result with a coefficient of correlation R^2 = 0.9973, indicating that the developed model is a good representation of the network.

TABLE 2. Five Cases Concerning Network Operation (Pumps and Reservoirs)

Case	Time		Pump Condition					Filling Reservoirs		
	From	To	Intake 1	Intake 2	Bedouin	Suction from Reservoir 1	(K)	Reservoir 1	Reservoir 2	Reservoir 3
A	12 AM	8 AM	On	On	On	Off	Off	Open	Open	Open
B	8 AM	9.30 AM			On	On		Closed		
C	9.30 AM	5 PM			Off	On				
D	5 PM	12 PM			On	Off				
E	Friday	Saturday			Off	Off				

Figure 7. Pressure Gauges During Measurement in Fire Hydrants and Pump Rooms

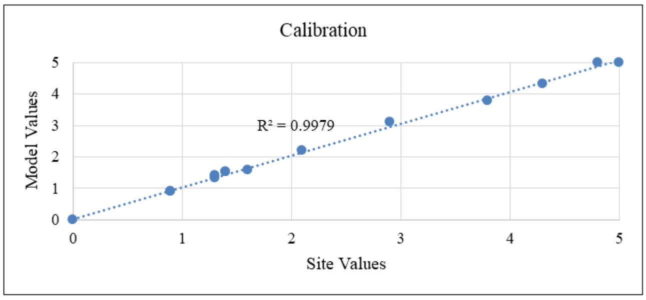

Figure 8. Model Calibration Results

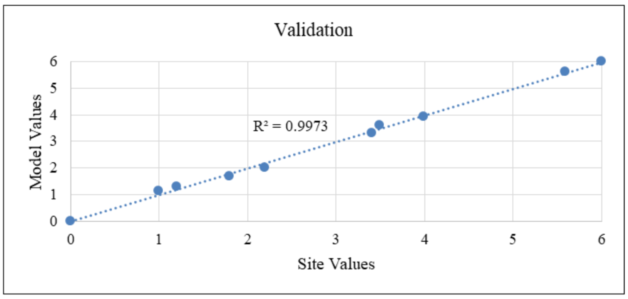

Figure 9. Model Validation Results

Table 3. Pressures of the Nodes, bar, for Calibration Process

Nodes	Hangars	Gate2	Bedouin	Service	Club, NE*	Club, SW*	Public	Admin.	Borsa	El-Reefy, NE*	El-Reefy, SW*	Pharaonic Area
Site	2.9	3.8	4.3	0.9	2.1	1.4	1.6	1.3	0.9	4.8	1.4	1.3
Model	3.1	3.8	4.3	0.9	2.2	1.5	1.6	1.4	0.9	5.0	1.5	1.3

.N: north, E: east, S: south, and W: west *

Table 4. Pressures of the Nodes, bar, for Validation Process

Nodes	A	Islamic		Magic Land			Movenpick Hotel	Toshka
		SW*	NE*	SE*	N*	W*		
Site	1.0	3.5	2.2	5.6	4	3.4	1.8	1.2
Model	1.1	3.6	2.0	5.6	3.9	3.3	1.7	1.3

3. Results and Discussions

Pressures below 2 bar are not acceptable as an auxiliary water source in case of fire. The maximum permissible pressure for the main supply and distribution pipes is 10 bar. However, due to their expected lifespan and to avoid any failure in the network, the maximum permissible pressure was assumed as 8 bar.

From the results in Tables 3 and 4, the maximum and minimum pressures were 5.6 and 0.9 bar, respectively. The mean value of the pressure was 2.51 bar, with a standard deviation of 1.44.

Figures 10 and 11 display pressures in the nodes and water flow results, respectively, within the network for the studied case D.

As shown in Figure 10, pressure levels exceeded 4.5 bars in several locations and surpassed 6 bars at certain nodes, particularly in the Magic Land area. Conversely, lower regions experienced significant pressure drops, reaching as low as 0.9 bars. This indicates that the pressures were low (< 2 bar) in 50% of the nodes representing areas with high levels (e.g., the Service Studios area) and areas with low levels (e.g., the Pharaonic, Islamic, and Garden City areas).

Figure 11 illustrates inefficiencies in flow distribution and water movement within the network. The Bedouin pump failed to operate effectively, as water was dispersed rather than delivered to higher-elevation areas like Service Studios. This was due to interconnected pipelines that redirected water downward through a parallel path, creating a recirculating loop and preventing proper upward flow.

It can be mentioned that evaluating the water supply distribution system in Sekota Town, Ethiopia, using Bentley WaterGEMS, [19], revealed high-pressure issues, negatively impacting the system's performance. For the existing system, results showed that pressure in all nodes was very high, above the maximum pressure. For the optimized system, results showed that pressure in all nodes became within the permissible limits.

Also, evaluating the hydraulic performance of the water distribution system in Tulu Bolo town, Ethiopia, employing WaterGEMS, [22], showed that 92.6% of the studied nodes had optimum pressure, about 1.27% were under permissible pressure, and the remaining nodes were above the allowable pressure.

In this study, however, to solve the network pressure problem, several solutions were tried based on cost and feasibility without affecting customers and avoiding any negative effects in some parts of the network. The final proposed solutions were identified as follows:

1. Planning the water path from the water intake on the low level to the highest level (service area) without dispersing the water in the rest of the network. This was

done by closing some valves and installing some non-return valves.

2. Adding some connections in the Islamic area to balance the pressure.
3. Operating the Bedouin pump (responsible for raising water from the low level to the high level) 24 hours a day instead of 12 hours. This was done by employing two pumps instead of only one pump.
4. Changing some pipe diameters with lengths not exceeding 100 meters in the rural area so that the neighborhoods with low levels are not affected by raising the water to the high level.

After performing the proposed solutions, the network showed significant improvements, as shown in Table 5 and Figures 12 and 13, which represent the pressures in the nodes and water flow results, respectively, within the network after employing the proposed solutions.

As depicted in Figure 12, pressures across all areas were stabilized, with no area recording less than 2 bars. Of the studied 20 nodes, the pressures were low (< 2 bar) in 10 nodes, representing 50% of the nodes. Applying the proposed solutions, the pressures increased in these nodes, in addition to 4 other nodes. Also, the pressures decreased in 3 other nodes, and were the same in 3 other nodes. Applying the proposed solutions guaranteed that the pressure in any node is ⩾ 2 bar, which is satisfied.

As illustrated in Figure 13, flow regulation was enhanced, with the Bedouin pump effectively supplying the required volume and supporting consistent distribution.

Figure 14 shows the pressures before and after implementing the proposed solutions. Figure 15 illustrates the percentage ratios of the changes in pressures before and after implementing the proposed solutions.

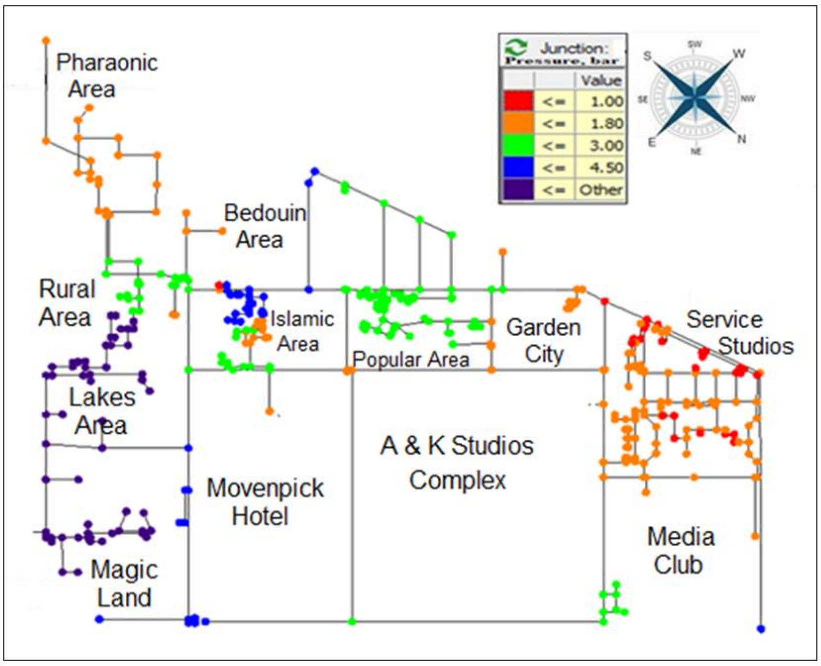

Figure 10. Pressures at the Nodes for Case D

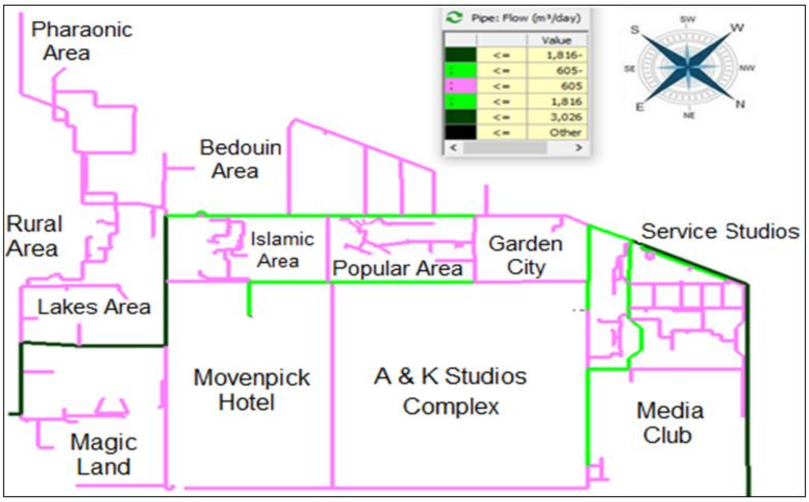

Figure 11. Flow in the Pipes for Case D

Table 5. Pressures of the Nodes, bar, Before and After Solutions

Nodes	Pressure Before Solutions	Notes	Pressure After Solutions
Hangars	3.1	---	4.6
Gate2	3.8	---	3.8
Bedouin	4.3	---	5.5
Service	0.9	Low	2.0
Club, NE	2.2	---	3.2
Club, SW	1.5	Low	2.7
Public	1.6	Low	3.0
Admin.	1.4	Low	2.6
Borsa	0.9	Low	2.0
A	1.1	Low	2.0
Islamic, SW	3.6	---	3.3
Islamic, NE	2.0	---	3.5
Magic Land, SE	5.6	---	5.6
Magic Land, N	3.9	---	2.3
Magic Land, W	3.3	---	2.0
Movenpick	1.7	Low	3.3
El-Reefy, NE	5.0	---	3.0
El-Reefy, SW	1.5	Low	2.7
Pharaonic Area	1.3	Low	2.0
Toshka	1.3	Low	2.0

* N: north, E: east, S: south, and W: west.

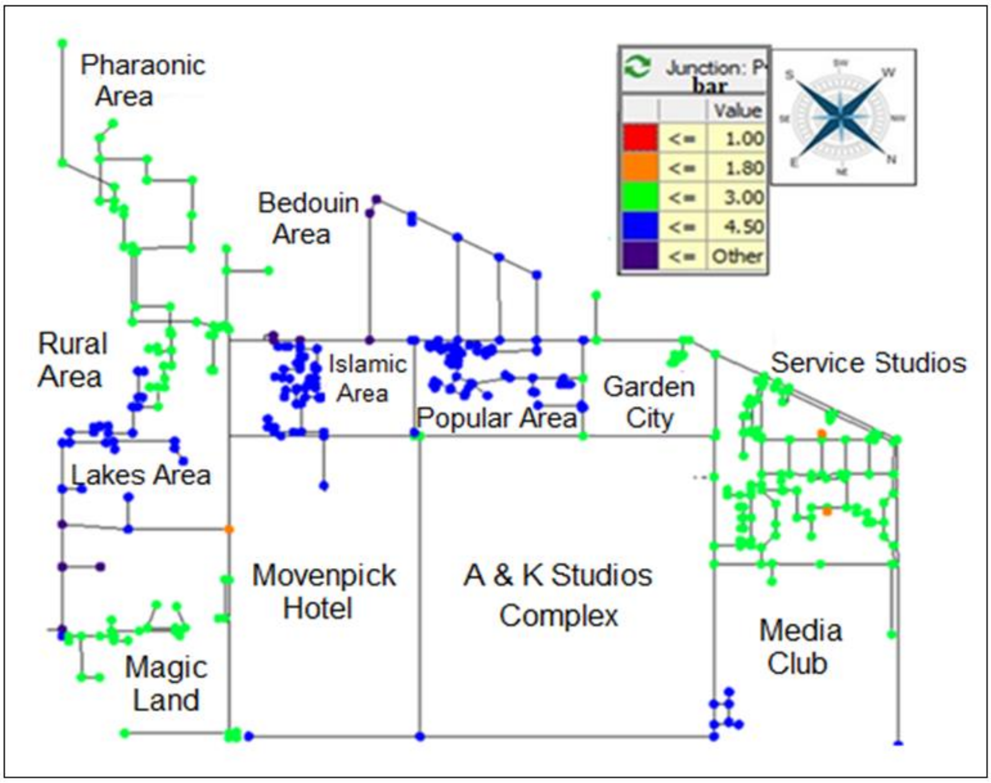

Figure 12. Pressures, bar, at the Nodes Employing the Proposed Solutions

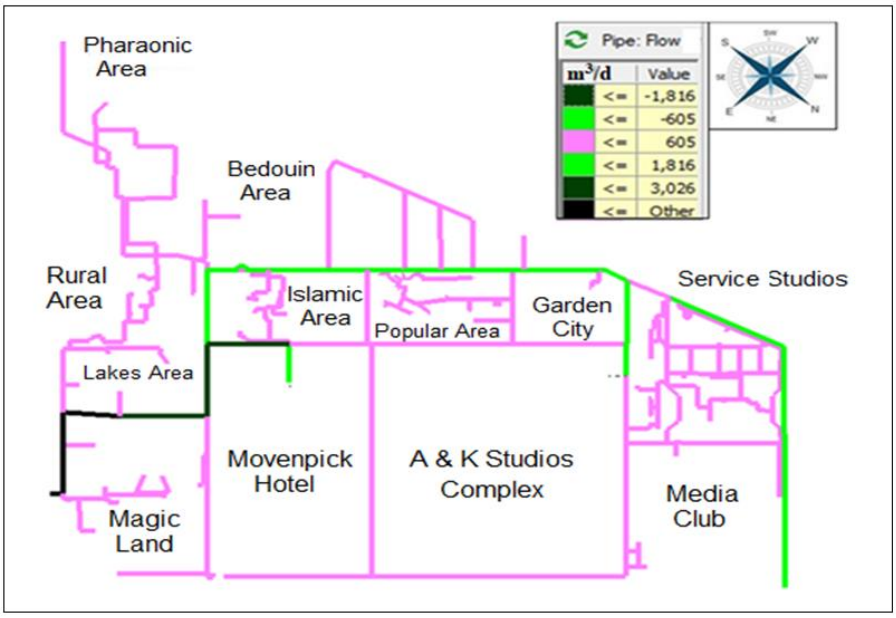

Figure 13. Flow in the Pipes, m3/d, Employing the Proposed Solutions

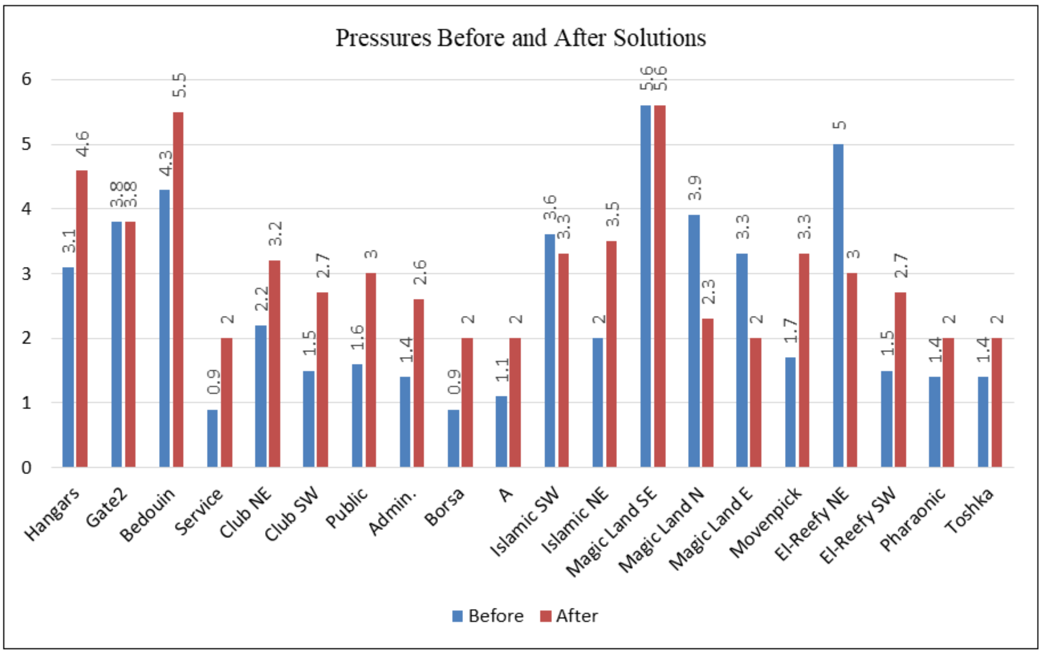

Figure 14. Pressures, bar, Before and After Implementing the Proposed Solutions

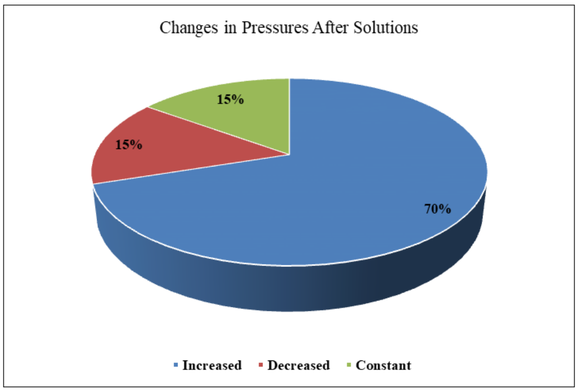

Figure 15. Percentage Ratios of the Changes in Pressures Applying the Proposed Solutions

4. Conclusions

The main objective of this study is to evaluate and examine various network operation variations and their impacts. A hydraulic model was developed employing the WaterGEMS program to simulate the water distribution network and the current pumping system, and identify all the problems that need to be addressed. The model was calibrated using real pressure measurements taken from pump stations, fire hydrants, and various points along the network. This allowed for the identification of critical areas with insufficient pressures.

The network is not operating stably at the moment. Because of the wide variations in levels, there are places in the network suffering low pressure (50%), sometimes falling below 0.9 bar during peak water demand hours. The weak pressure was most evident in the western part of the network due to its high elevation. This issue cannot be resolved with the current pumping system and network layout.

To improve the operation of the network, many solutions were performed until the least expensive and most effective solutions were proposed to solve the pressure problem. These proposed solutions included adding a new pump to lift water from low levels to high levels, changing some pipe diameters with lengths not exceeding 100 meters, and adding some pressure-regulating valves and non-return valves to avoid affecting the pressures in areas with low levels.

Applying these proposed solutions, the obtained results guaranteed that the pressure in any node is ⩾ 2 bar, which is satisfied.

Considering the importance of the city and the lack of tolerance for water shortages in any area, whether it is filming studios, open filming areas, the Movenpick Hotel, the Media Club, or entertainment areas, the proposed solutions will preserve the water in the reservoirs at full capacity and not to use it except if water does not enter from the main intakes or for periodic movement to change the water in the tanks to prevent it from stagnating.

It is recommended that the diameters of the water supply networks should be expanded gradually in the future, particularly between the current reservoirs and the water intakes, as well as between locations with low and high levels. The pipes should have a diameter of 160 mm because of the long distances and high flow rates. This enhancement will accommodate higher flow demands over longer distances and contribute to the long-term stability and efficiency of the network.

of writing the report as the radiologist does. We will collect 3D data and improve our model to handle these data and train on them. We will use more XAI methods to explain our model and make it trusted.

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