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Evaluation of Municipal Water Distribution Network Using Watercard and Watergems

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ABSTRACT

The pressure exerted on a water distribution system due to population increase and aging of the system amounts to routine assessment of its functionality. waterCAD and waterGEMS software was used comparatively in evaluating the serviceability of the water distribution system of Federal University of Agriculture Makurdi. A steady state analysis was also carried out to determine hydraulic parameters such as pressure, velocity, head loss, and flow rate. The result of the statistical analysis revealed that both simulators can be used interchangeably since there were no statistical differences. The pressure result indicated low head within the system which resulted to (100 %) of the nodes operating below the adopted system pressure of 10 meters. Also, (85 %) of the system velocity was within the range of 0.2 – 3 m/s adopted while 15% of the velocity exceeded the adopted velocity. The resultant effect of very high velocities in the system accounted for the pipe burst and leakages detected within the system. Hence, the system requires strengthen for optimum performance.

ÖZ

Anahtar Kelimeler:
ANOVA,
Karşılaştırmalı analiz,
Hidrolik Parametreler,
WaterCAD,
WaterGEMS.

Nüfus artışına ve sistemin yaşlanmasına bağlı olarak bir su dağıtım sistemine uygulanan baskı, işlevselliğinin rutin değerlendirmesine eşittir. WaterCAD ve waterGEMS yazılımı, Federal Tarım Üniversitesi Makurdi'nin su dağıtım sisteminin servis edilebilirliğinin değerlendirilmesinde karşılaştırmalı olarak kullanılmıştır. Basınç, hız, kafa kaybı ve akış hızı gibi hidrolik parametreleri belirlemek için bir kararlı durum analizi de gerçekleştirilmiştir. İstatistiksel analizin sonucu, her iki simülatörün birbirinin yerine kullanılabileceğini, çünkü istatistiksel farklılık olmadığını ortaya koymuştur. Basınç sonucu, sistemdeki düşük basma yüksekliğini gösterdi, bu da kabul edilen 10 metrelik sistem basıncının altında çalışan düğümlerin (% 100) sonucunu verdi. Ayrıca, sistem hızının (% 85) kabul edilen 0.2 - 3 m / s aralığındayken, hızın% 15'i kabul edilen hızı aşmıştır. Sistemdeki çok yüksek hızların sonuçta ortaya çıkan etkisi, sistemde tespit edilen boru patlaması ve kaçakları açıklamıştır. Bu nedenle, sistem optimum performans için güçlendirmeyi gerektirir.

1. Introduction

Drinking water serves as an essential element for life's sustenance and is also a required fundamental element with which almost all biotic components carry out their different activities of life [1]. As such, it is needful to pay close attention to the means via which this water is conveyed to consumers at their various stop taps. One of the most predominant factors affecting the performance of an existing network is the increase in population and its associated demand requirements which may call for complete reticulation or rehabilitation of the existing system. In evaluating the efficiency of a water distribution system, the design forms an integral part of the water supply setup which contributes enormously to curbing expenditures incurred during procurement and construction [2]. Hence, the need for a systematic design to achieve optimum system performance. Effective water supply in this instance is of major importance in the design of a new water distribution network, expanding of the existing network or strengthening it. The objectives attributed to a distribution system are to supply water to every household, industrial plants, and public places by means of a piping system at sufficient quantity and adequate pressure, without compromising its quality [3].

Agunwamba et al. [4] defined a water distribution system as ‘a system that supplies water with good quality, adequate quantities and at sufficient pressure to meet system requirements to the users’. Water distribution systems are required to supply water at a stipulated pressure based on the consumer’s demands which varies throughout the day, week, month and year. According to AWWA [5], the minimum pressure that should be observed at junctions throughout the system varies, and this depends on the type of water consuming sector and regulations that govern the system which typically operates between 275800 - 689500 N/m². However, the design of a water distribution system (WDS) and how it supplies water to users and its layout is related to their performance. A water distribution system (WDS) can be designed to supply water to its users through gravity flow, mechanical pumping or both. A system of water supply during its entire life should be able to provide the required quantity of water for the expected loading conditions with the desired residual pressures at all nodes. With the installation of distribution reservoirs and elevated tanks within different supply zones, some consumers are still left with little or no water supply [5]. Since water distribution systems are mostly designed and constructed to function for a long period of time, factors that affect the future performance of the system must be taken into cognizance. Some of these factors are population increase, the need for system expansion, pipe length, diameter, and pump capacity etc.

Water pollution, which has a negative impact on the quality of life of the society, is increasingly reaching to threatening dimensions [7]. One amongst the most disturbing issues faced by consumers of water in some part of the world is the unavailability of quality water and also the quantity of water that reach consumers at various supply outlets. According to Neelakantan et al [8] the problems generally faced with a water distribution system (WDS) arise from the following categories; (i) designing a new network (ii) modifying or expanding an existing network, (iii) operating an existing system.

Other problems faced with a water distribution system (WDS) are: increased service connections than estimated, expansion of service areas, breakage of network distribution components and increased roughness of pipe surface as a result of ageing. This study is aimed at evaluating the functionality of the water distribution network of Federal University of Agriculture, Makurdi using WaterCAD and WaterGEMS simulators. This will help to understand the needs of the system and also assist in the improvement of the long term planning of its utilities.

2. Material and Method

Study Area

The study was carried out at Federal University of Agriculture, Makurdi (FUAM). This University is a higher education institution that is located in Makurdi, Benue State, Nigeria. The University lies at latitude 7° 44´ North and Longitude 8° 35´ East of the Middle Belt region of Nigeria and it covers a land mass of 7,978 km². It is bounded on the North East by Guma Local Government Area and by River Benue in the South. Topographically, it is located in the Middle belt region of Nigeria and is characterized by gentle hills, clay soils, and tropical climate with two main seasons (rainy and dry seasons).

Figure 1. Google Earth Map of Federal University of Agriculture Makurdi

Data Collection

To assign demand to each node, the following components were taken into consideration; population demand, minor losses, fire demand and unaccounted for water. Population demand refers to the amount of water that is extracted from a particular node by that population served by that node [4]. Unaccounted for water consists basically of two components: water lost from the system and water used but not sufficiently documented [9]. Linkungan [10] stated that a provision of 10% of the population demand is added as fire demand in the case of fire outbreak. A 5% provision for minor losses is given. This accounts for losses where there are bends, valves, and fittings. Some other details required for the hydraulic simulation are Population served, Total pipe length, Demand per capita and Daily peak factor given as 29,121, 8,779 m, 120 l/c/d and 1.5, respectively. Table 1 shows the analysis of nodal demands at each node.

Table 1. Analysis of Demands at the Distribution Network Nodes

Node ID	Name	Population	Lcpd	Daily Demand (l/day)	Demand (l/s)	Fire Demand 10%	Minor Losses 5%	UFW 15%	Total Nodal Drawoff (l/s)
1	Meg Icheen Hall.	616	120	73920	0.86	0.09	0.04	0.13	1.12
	Block B	616	120	73920	0.86	0.09	0.04	0.13	1.12
	DTH Hall	616	120	73920	0.86	0.09	0.04	0.13	1.12
	Block C	180	120	19200	0.22	0.02	0.01	0.03	0.28
2	Gauis IgboeliBldg	5342	120	641040	7.42	0.74	0.37	1.11	9.64
3	Block A	5221	120	626520	7.25	0.73	0.36	1.09	9.43
4	Senior Staff Qtrs	840	120	100800	1.17	0.12	0.06	0.18	1.53
7	FST Cmplx	3028	120	363360	4.21	0.42	0.21	0.63	5.47

8	Engr'ring Cmplx	2420	120	290400	3.36	0.34	0.17	0.50	4.37
9	Zamfara Hostel	616	120	73920	0.86	0.09	0.04	0.13	1.12
	Block E	616	120	73920	0.86	0.09	0.04	0.13	1.12
	Block F	616	120	73920	0.86	0.09	0.04	0.13	1.12
10	Mgt. Sc.	1300	120	156000	1.81	0.18	0.09	0.27	2.35
11	Agronomy	1986	120	238320	2.76	0.28	0.14	0.41	3.59
	Agric. Ext	1988	120	238560	2.76	0.28	0.14	0.41	3.59
12	PG Sch	340	120	40800	0.47	0.05	0.02	0.07	0.61
14	Animal Sciences	1915	120	229800	2.66	0.27	0.13	0.40	3.46

KEY: UFW = Unaccounted-for-water

WaterGEMS and WaterCAD Simulators

WaterGEMS V8i provides a friendly interface for engineers to analyze, design and optimize water distribution systems. This software manages the water system data, time-series hydraulic result, current and future scenarios and other core infrastructure data all within the same GIS environment [11]. Also, according to [12] network variables such as; flow, pressure, and velocity along with their optimization can be controlled because waterGEMS V8i has strong design algorithm for accurate design of the network.

WaterCAD is a hydraulic software and water quality modeling application for water distribution systems. waterCAD helps engineers and users to analyze, design and optimize water distribution systems. It is developed by the Bentley company and has the following capabilities; Building a network and performing a steady state analysis, Extended period simulations (EPS), Interface and graphical editing, Streamlined model building, Water quality analysis, Automated Fire flow analysis, Reporting results, Pressure dependent demand, Darwin designer to optimize a pipe network, Critical and segmentation and Comprehensive scenario management.

3. Results

Table 2 shows the result of flow rate (l/s), velocity (m/s), and headloss (m) for both waterCAD and waterGEMS simulators. While Table 3 shows the result of pressure fluctuation within the distribution system.

Table 2. Pipe information/Pipe output data

Pipe	Start Node	Stop Node	Diameter (mm)	Length (m)	Flow (l/s)	Velocity (m/s)	Head loss (m)
1	R-1	Pmp-1	250	67.00	30	0.62	0.09
2	Pmp-1	CV-1	250	447.33	30	0.62	0.59
3	J-1	T-2	110	210.00	22	2.29	8.17
4	T-2	T-3	110	88.00	-36	3.79	8.66
5	J-1	J-2	250	305.00	6	0.12	0.02
6	J-2	T-4	110	71.00	-25	2.60	3.49
7	J-2	CV-2	250	61.14	23	0.47	0.05
8	J-3	T-5	110	83.24	-29	3.08	5.58
9	CV-2	J-3	250	50.40	23	0.47	0.04
10	J-3	J-4	250	1,301.00	45	0.92	3.56
11	J-4	CV-3	225	0.03	-25	0.64	0.00
12	CV-3	T-1	225	730.00	-25	0.64	1.16
13	J-4	J-5	250	636.26	69	1.41	3.88

14	J-5	CV-4	250	689.24	69	1.41	4.20
15	CV-4	J-6	250	62.45	69	1.41	0.38
16	J-6	CV-5	250	670.69	69	1.41	4.09
17	CV-5	J-7	250	32.05	69	1.41	0.20
18	J-7	T-6	225	149.00	48	1.20	0.76
19	J-7	J-8	225	350.00	-6	0.15	0.04
20	J-8	T-7	63	49.00	-10	3.05	6.20
21	T-7	CV-6	63	5.40	0	0.00	0.00
22	CV-6	T-8	63	4.60	0	0.00	0.00
23	J-8	CV-7	225	718.52	0	0.00	0.00
24	J-9	T-9	110	43.00	-29	3.08	2.89
25	CV-7	J-9	225	26.77	0	0.00	0.00
26	J-9	T-10	110	93.46	29	3.08	6.27
27	J-7	J-10	250	195.00	24	0.48	0.16
28	J-10	T-11	110	41.00	22	2.29	1.60
29	J-10	CV-8	250	540.06	0	0.00	0.00
30	CV-8	J-11	250	29.94	0	0.00	0.00
31	J-11	T-12	110	49.00	11	1.13	0.52
32	J-11	T-13	110	116.00	19	2.00	3.52
33	J-11	J-12	250	182.00	-35	0.72	0.32
34	J-12	T-14	110	53.00	-36	3.77	5.17
35	CV-1	J-1	250	18.67	30	0.62	0.02
36	J-12	CV-10	250	237.16	0	0.00	0.00
37	CV-10	J-13	250	27.84	0	0.00	0.00
38	J-13	T-15	110	54.00	16	1.67	1.16
39	J-13	J-14	250	773.00	-17	0.35	0.35
40	J-14	T-16	110	108.00	-20	2.07	3.49

KEY: CV= Check Valve; P = Pipe; J = Junction; T = Tank; Pmp = Pump; R = Reservoir

Table 3. Nodal elevation and Pressures result in waterCAD/waterGEMS

Junction	Elevation (m)	Pressure (m)
1	110.00	7.65
2	112.00	5.53
3	113.00	4.56
4	105.00	8.99
5	101.00	9.02
6	103.00	2.41
7	100.00	1.21
8	101.00	0.23
9	115.00	7.24
10	99.00	2.06
11	102.00	1.99
12	100.00	4.27
13	111.00	1.63
14	110.00	2.96

4. Discussion

Output of Nodal Demand (l/s) in waterCAD and waterGEMS

Figure 3 shows the result of nodal demand at various nodes for waterCAD and waterGEMS simulators. Nodes 2, 3, 7 and 11 are areas with particularly high draw-outs with nodes 2 and 3 having the highest demands. Nodal demands are mainly based on the population served by that particular node [4]. Nodes 2 and 3 happen to have the highest population which is evident in the amount of draw-outs at those nodes.

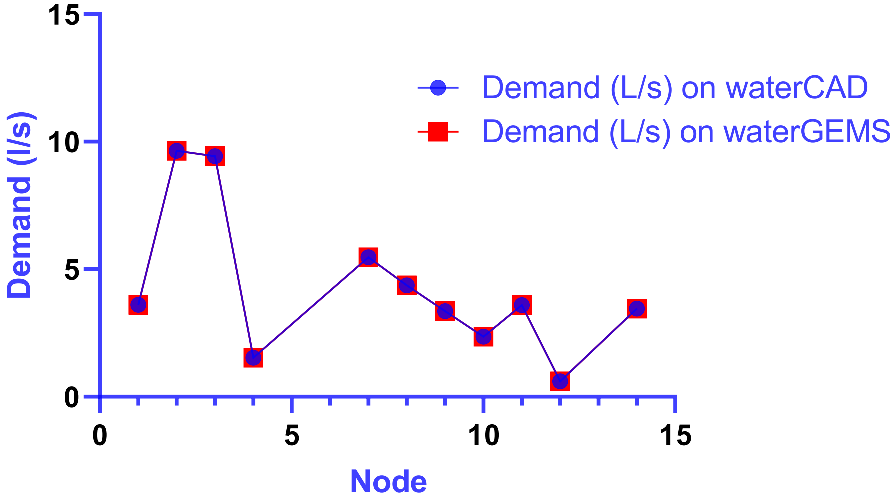

Figure 3. Nodal Demand Output in WaterCAD/WaterGEMS

Output of Flow Rate and Velocity Fluctuations in WaterCAD/WaterGEMS Simulators

The output result of velocity and flow rate at various pipes is presented in Figure 4 and 5, respectively. The velocity of flow including those greater than 3m/s were depicted with 6 out of the 40 pipes having velocities greater than 3.0m/s while others have their velocities within the range of 0.2m/s to 3.0m/s and some less. Very high velocities occurred in pipes 4, 8, 20, 24, 26 and 34 within the system. One of the parameters that should be considered when quality of water in a distribution system is altered is velocity [13]. For the distribution system under study, the most eminent causes of velocity fluctuation are: (i) Changes in demand (nodal draw-off), (ii) Changes in transmission conditions. Very high velocity changes in a distribution system can cause leakage, when there are pipe burst and subsequent entering of water into the system [14]. In other to maintain an adequate flow velocity in the system, the step-down approach should be employed. This will require a progressive decrease in the size of the pipes so that a higher flow velocity can be achieved in the entire loop or system. This would also help to maintain a consistent pressure throughout the system.

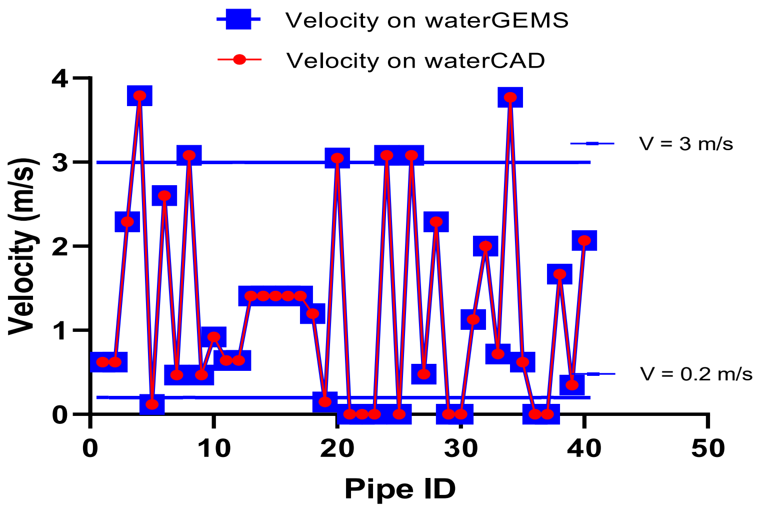

Figure 4. Results of Velocities in WaterCAD/WaterGEMS

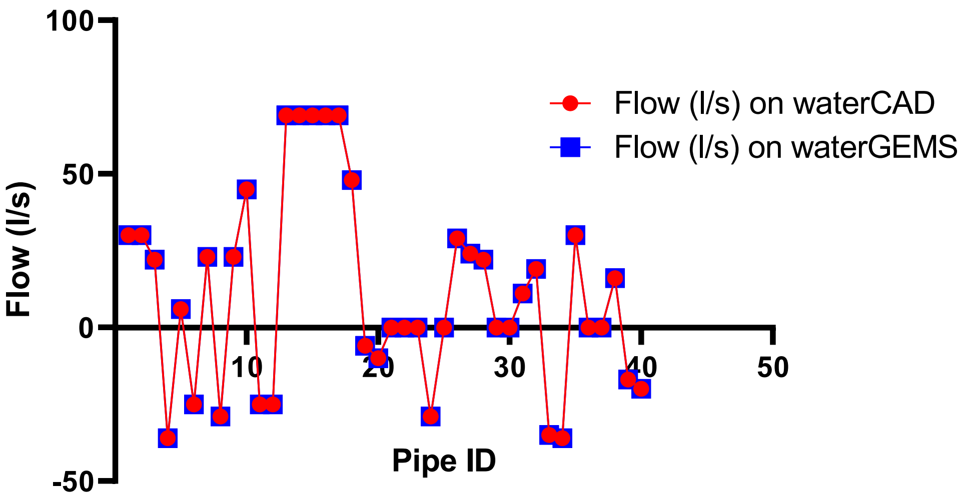

Figure 5. Results of Flow rate of waterCAD/waterGEMS Simulators

Pressure Fluctuations and Node Elevations in the System

Figure 6 shows the result of pressure distribution at various nodes and the elevation of the nodes within the distribution system for waterCAD/waterGEMS simulators while Figure 7 shows the contour plot of pressure distribution. The minimum pressure adopted for this study is 10m. Nodes J1 - J14 all fell below the minimum adopted system pressure. This indicates that the pressure within the distribution system is low and not sufficient enough for effective system performance. This can be attributed to a number of factors which include: (i) pipe roughness, (ii) leakages (iii) equipment failure, (iv) elevation.

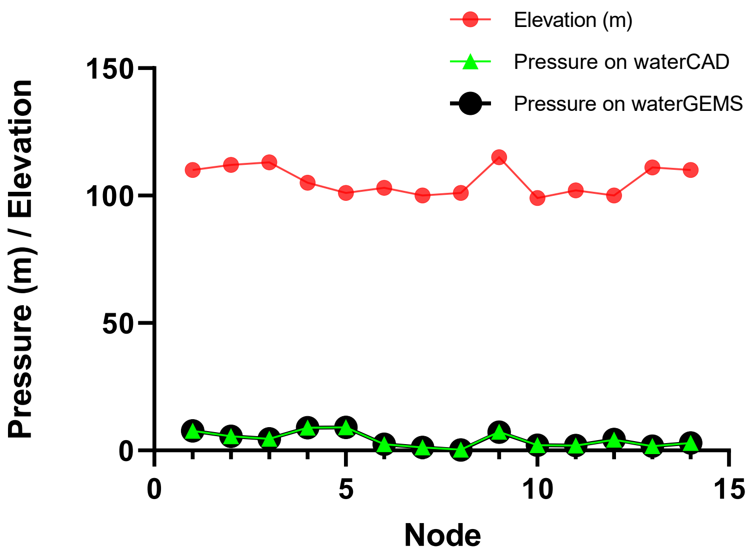

Figure 6. Result of Pressure and elevation at various nodes within the distribution system for waterCAD/waterGEMS simulators

Statistical Comparison of Results

Single Factor ANOVA test was used in comparing the level of significant difference in results obtained from both simulators. This test was carried out on pressure, velocity, and nodal demand results. Table 4 shows the summary of ANOVA test for results of pressure, nodal demand, velocity, and headloss obtained using waterCAD and waterGEMS simulators.

Table 4. Summary of ANOVA Result for waterCAD and waterGEMS Simulator

Parameter	Fcritical	F	P-value	Remark
Pressure	4.23	1.4xE-5	0.998	No significant difference in waterCAD and waterGEMS pressure output
Nodal demand	4.3	7.8xE-5	0.993	No significant difference in waterCAD and waterGEMS demand output
Velocity	3.96	2.4xE-4	0.988	No significant difference in waterCAD and waterGEMS velocity output
Headloss	3.96	1.9xE-4	0.99	No significant difference in waterCAD and waterGEMS headloss output

The results all showed that there was no statistically significant difference between velocity ($p = 0.988$), pressure ($p = 0.998$), nodal demand ($p = 0.993$) and headloss ($p = 0.990$) values obtained from both waterCAD and waterGEMS simulators at $\alpha = 0.05$. The system recorded an average value of 1.22 m/s for velocity, 3.38 m for pressure, 1.91 for headloss and 3.38 l/s for nodal demand. Eighty-five percent (85 %) of both waterCAD and waterGEMS velocity results were within the adopted range of 0.2 – 3 m/s while fifteen percent (15 %) of the velocity results violated the adopted velocity range. Pressure results for both waterCAD and waterGEMS recorded a hundred percent (100 %) value below the adopted system pressure of 10 m. The adopted system pressure was influenced by the height of buildings (10 m) within the location of study.

5. Conclusions

The focus of this study is to analyze the water distribution system of Federal University of Agriculture, Makurdi and to identify deficiencies (if any) that may be present in the system using waterCAD and waterGEMS simulators. There was pressure fluctuation in the system and this is as a result of elevation changes and draws out at the nodes. The system recorded insufficient pressure to meet the required demand at all the junctions. A number of pipes within the system recorded velocities within the adopted velocity; however, very high velocities were recorded at some points. Leakages and pipe burst were also noticed, hence requiring strengthening of the system for improved system performance.

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