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Pressure Performance Assessment of Juja water Distribution Network using EPANET model

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Abstract: ***The current study was carried out to analyse the pressure performance within the existing Juja water distribution network. The study used EPANET as a simulation tool, and the nodal demand was calibrated using an inversion approach. The nodal demand was first calculated using population projection and secondly adjusted to feet field pressure collected with gauges at some point in the network. The analysis was run for an extended period using demand pattern multiplier collected from the water company in charge of the network. The analysis shows that the network is not able to meet the required pressure at the maximum hour of consumption. This results by slight pressure precisely around Gate C (Joyland and Greenfield); however, the pressure seems to be reasonable at the regular hour of consumption. In addition, the network during the night faces high pressure because of the decrease in consumption. This may explain the frequency of leakages occurs mostly during the night in the Juja distribution system. The study recommended the capacity building of the network, which will provide better services to Juja consumers.***

Keywords : Distribution System, EPANET, Low hourly consumption, Regular hourly consumption, Peak hourly consumption, Pressure.

I. INTRODUCTION

The availability of fresh and clean drinking water is vital for the socio-economic development in contemporary society. Besides, it is estimated that 785 million people lacked basic drinking water service[1] . Therefore, water predicament is one of the most significant challenges facing both developed and developing countries and really needs a significant concern to address it. Interestingly, it is one of the targets being undertaken under SDG 6, according to the United Nations report 2019.

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Water is an essential commodity for life. Indeed, water is an indispensable constituent for any creature living on earth. Man needs water not only for hygienic conditions and proper sanitation, but also for drinking, animal watering, a source of energy, transportation, and irrigation. Its control, its availability in terms of quantity and quality, must be of the great concern of any government.

In most of the developing countries, the water distribution network failed to satisfy the demand in term of flow and pressure during daily consumption. Especially in Juja water distribution network, a semi-urban town located in central Kenya, water does not reach all users, and some districts are facing daily water stress.

Several models have been applied in the analysis of water distribution systems such us WaterCAD, HydrauliCAD, WATSYS, Aquis, H2O map, KYPipe, WaterCAD, WaterGEMS, including the EPANET model [1]. EPANET, developed by the United States Environmental Protection Agency's Water Supply and Water Resources Division, is the widely-used. It is a free open source software and easy to use. EPANET can perform single or extended-period hydraulic simulation within a pressurised pipe network[2].

EPANET has been applied in various studies[3][4][5][6][7][8][9][7][10][11]. The studies conclude that the EPANET model is reliable and can be used as a useful tool by water utilities for the prediction.

EPANET allows various extensions [12], [13], [14]etc. and can also be interfaced with GIS[15], with the latest interfaced software known as GISpipe[2]. EPANET ability in simulating hydraulic and water quality parameters can be used as a tool for measuring and controlling a water distribution system [16].

EPANET model needs to be calibrated to predict accurate values. The calibration process is performed by adjusting some of the input data in order that the simulated pressure and flow results of the model are close to the actual results obtained through field measurement. Water distribution network models are calibrated by adjusting the network parameters (pipe roughness coefficients and nodal demands) so that the network performance closely mimics the field condition [17]. Model calibration can be categorized into two steps consisting of: (1) comparison of pipe flows, nodal pressures, and tank water levels, predicted by the model with those observed in the field for known operating conditions; and (2) adjustment of network input data to decrease the differences between the predicted and observed values[18]. This process can be performed manually and automatically,as well.

[1] https://sustainabledevelopment.un.org/sdg6

[2] https://en.gispipe.com

From the above, this study investigated the pressure performance of the Juja distribution network at differents hours during a daily consumption. The study assesses the pressure performance over the peak ,low ,and the regular consumption hour using EPANET model.

II. MATERIALS AND METHODS

2.1 Case study

Juja is a town in Kiambu County central. The town is located about 30 km east of Nairobi, with an estimated population of 118,793 in 2009. The town is semi-arid with an annual average rainfall of 1,200 mm with a mean temperature of 26ºC. The town lies between 1,300-1,500 meters above the sea level, and the landscape comprises of middle-level volcanic uplands[19]. The town is subdivided into six districts based on population density. The six districts each of a homogenous population density in the distribution system are shown in figure 1 and include Gachororo, Greenfield, Joyland, Ithuri, Gatagama, and Highpoint.

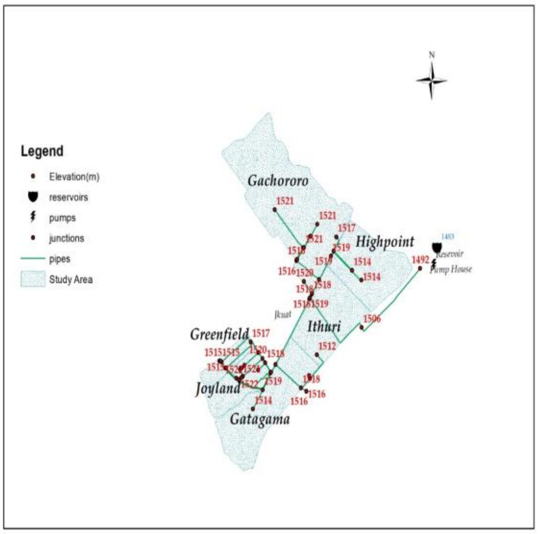

Figure 1 Juja Town distribution main

The area of the districts is given in Table 1

District	Area(ha)
Gachororo	197.33
Highpoint	81.99
Ithuri	78.24
Greenfield	21.52
Joyland	44.27
Gatagama	100.69

Table 1 The Juja town districts area

2.2 Pressure distribution Using EPANET

2.2.1 Data collection

2..2.1.1 Population forecasting

The actual population was calculated with the Arithmetic progressive method due to the few data available. The method used the past census reports to calculate the average increase in population per decade. The population of the next decade is found by adding to the previous population the increase. The population increase is assumed to be constant[20]. The population after an n^{th} decade will be:

$P_n = P + n.C$ (1)

Where P_n : the population after n decades, P: past population and C = dP/dt constant change in population. The present study used the Kenya national census for 1999 and 2009 to predict the actual population.

2.2.1.2 Existing network data collection

The data were collected from the field between January to March 2019 with GPS and remote sensing. The network layout data collected consists of all the physical components of the water distribution network and its characteristics.The data were collected in collaboration with the water company. The developed network layout used for hydraulic analysis was developed in the GIS format.

2.2.1.3 Model skeleton in EPANET

The model skeleton in EPANET was done by extracting data from the GIS format shapes files to create input network files for EPANET by selecting demand nodes at junctions with specific elevation, pipe characteristics (length, diameter, material) and pumps location using GISpipe. The pumps manufacturer`s performance characteristic curves were used as an input for the pumps flow and head in Epanet (see table 2 below). The Darcy-Weisbach formula was used as the head loss equation. The pipes roughness was assumed to be 0.0015 as recommended for plastics pipes [3] (pipes age were neglected).

Table 2. Supply characteristics

Pumps number	Rpm	Flow Q(l/s)	Head H(m)
A3/65	2960	22.22	85
DE100/26	2971	55.56	100

2.2.1.4 Nodal demand estimation

The average flow carried by the distribution system was estimated using the following formula:

Qavg = Specific demand X P_n (2) with P_n, the current population. The specific demand was assumed to be 50 L/person/day (Juja is semi-urban).

The water use rate per length (unit flow rate) of distribution pipes was estimated by :

$q = Q_{avg} / \Sigma L_i$, (3) where L_i is the length of each pipe in the distribution system.

By multiplying the length of each pipe by the unit flow rate gives the tentative demand along the pipe. Then splitting the pipe demand between the corresponding nodes yields to estimate the nodal demands.

2.2.1.5 Nodal demand calibration

The nodal demand was calibrated using an inversion approach by adjusting the nodal demand in EPANET model to make pressure predictions accurate. Field pressure data (see figure below) collected at peak demand hour between 7 am to 9 am under were compared to the model result during the calibration process. The nodal demands as excel batch were used as input into EPANET.

[3] https://www.pipeflow.com/sitemap/pipe-roughness

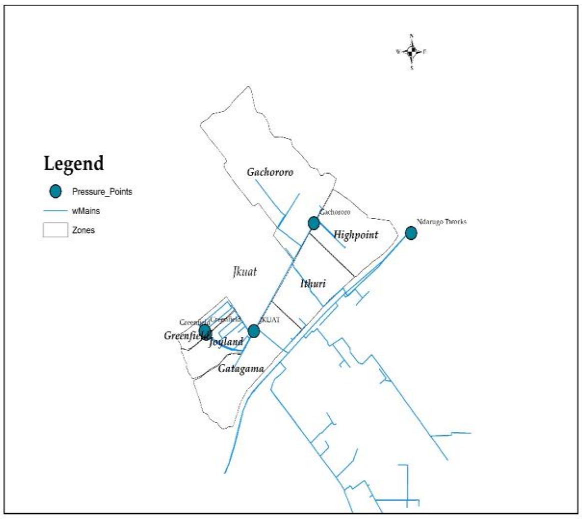

Figure 2. Calibration pressure points map

2.2.1.6 Demand pattern

The consumption in Juja distribution network may vary in three phases during a daily supply. The consumption is regular between 10am and 4 pm and slightly increased to the peak between 5pm to 7pm. From 8pm to 6 am the network experiment a low consumption in the distribution system. The consumption increased again to a peak between 7 am to 9 am. The demand pattern inserted into the software in term of multiplier 0.8, 1 and 1.65 respectively in low, regular, and peak consumption hour.

2.2.2 Data analysis

Once the model was build and the nodal demand calibrated, an extended hydraulic analysis was run. The various results representing the three phases of consumptions in the distribution system are presented as pressure distribution maps from EPANET and are discussed.

III. Results and discussion

3.1 Pressure performance

3.1.1 Population forecasting and Nodal demand estimation

The actual population of Juja city 2019 was estimated to 231577 peoples base on 1999 and 2009 census. The estimated average demand carried by the distribution system is found to be equal to 134 l/s.

3.1.2 Nodal demand calibration

With the inversion approach, the nodal demand was adjusted to make the model close to the field value, as shown in the graph below (see figure 3). The calibrated nodal demand are presented in table 3. The total calibrated average demand is 40.50 l/s. The higher deviation between the estimated demand and the calibrated demand may be due to the nature of Juja population, which may not have increased from the 2009 census as predicted. The population is composed mainly of students. New students come when others have been graduated, and have left the city.

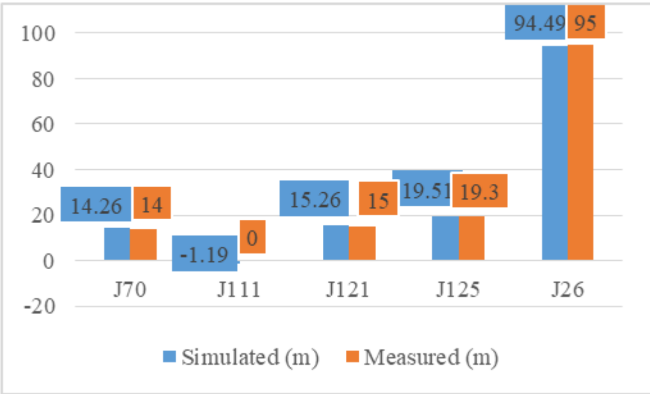

Figure 3. Nodal calibration chart

Table 2. Calibrated nodal demands

Junction ID	Elevation (m)	Base Demand (l/s)
70	1518	2.098022
44	1516	0.26869
90	1517	0.771696
59	1515	1.171647
65	1519	0.232676
45	1517	0.208085
26	1492	1.645639
111	1515	1.046665
110	1516	7.19E-05
8	1516	0.596967
28	1516	0.87863
36	1517	1.293318
29	1517	2.089662
115	1520	0.587824
98	1506	3.234741
93	1518	0.08115
20	1516	0.059428
60	1522	0.249967
15	1519	0.19089
91	1520	0.260811
79	1524	0.185123
75	1512	0.569625
3	1521	0.713526
41	1519	1.313256
97	1514	0.866267
22	1524	0.42887
80	1517	0.283383
76	1520	0.691045
112	1522	0.06069
64	1514	0.370446
99	1517	0.437624
102	1522	0.106765
119	1521	1.032972
120	1516	0.127837
122	1516	0.989977
92	1518	1.68771
87	1517	0.504372

54	1521	0.868507
33	1519	0.885969
25	1515	0.705918
49	1519	1.759168
121	1515	0.433458
37	1521	1.364717
74	1517	1.734781
113	1522	1.3368
125	1519	1.426601
88	1518	0.541328
107	1518	0.474087
104	1514	0.497939
117	1518	1.02866
85	1521	0.101663
Total		40.50 l/s

3.1.3 Pressure simulation within the network

a) The pressure at peak consumption hour

The model is shown slight pressure at the maximum consumption hour, as shown in figure 4 below. The pressure drop below the minimum allowable pressure. However the minimum allowable pressure varies from each country regulation and the nature of the city (urban, semi-urban etc.), The minimum pressure for a semi-urban town like Juja can be fixed to 10 m [21]. Joyland and greenfield commonly called Gate C, are zones the most affected. This is a consequence of the demand growth illustrated by the increase of the consumption. Also, it is illustrated the weakness of the existing pumps to deliver the increased flow at sufficient head at the maximum consumption hour and, the flow increase causes a substantial increase of the head-loss in some pipes due to how far the gate C is from the pumping station. The regular daily amount supplied of 3000 m^3/day is close to the estimated demand obtains from the calibration process, which is found equal to 3500 m^3/day.

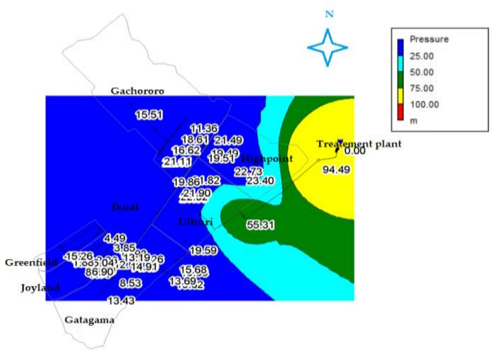

Figure 4. The pressure at the junctions between 7 am to 9 am and 5 pm to 7 pm when the consumption is maximal.

b) The pressure at regular consumption hour

Water mains may be sized based on water flow demands and pressure requirements. The model is shown normal pressure within the distribution network system. The standard working pressure in the distribution system range between 24 m to 63 m at users junctions. The network is under excellent performance, and users are able to enjoy excellent services.

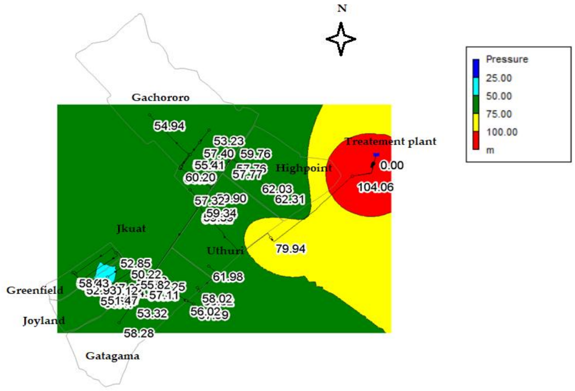

Figure 5. The pressure at the junction between 10 am to 4 pm when the consumption is regular.

c) The pressure at low consumption hour

The network modelled shows excessive pressure when the consumption is minimal. Excessive water pressure may cause pipe damage, leaks and wasted water. High water pressure caused costly annual water waste between 113.56 m^3 and 151.41 m^3 when home connection can't operate at a maximum recommended water pressure [4]. Water travelling at high pressure consistently through pipes can cause pipes damages. Excessive water pressure may lead to pipes eroding or leaking, while also causing other plumbing equipment damages. Additionally, the water hammer effect can also cause damage to the plumbing.

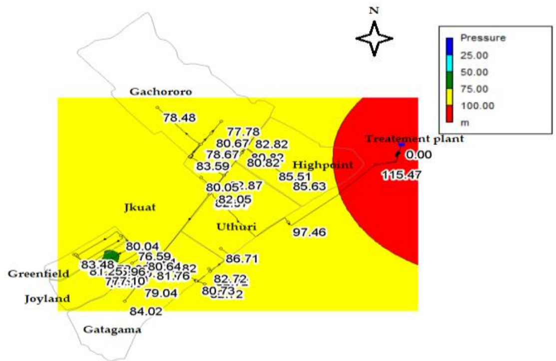

Figure 6. The pressure at the junctions between 8 pm to 6 am when the consumption is regular.

IV. CONCLUSIONS

From the study, it is evident to notify that pressure in the distribution system may vary in term of the consumptions. Peak consumption in Juja network occurs during 7am to 9 am, and 5 pm to 7pm reduced pressure in the distribution system and the network failed to deliver sufficient head at users points. During the night and earlier in the morning, (8pm to 6 am) when the consumption is reduced, high-pressure occur

[4] https://www.emergencyplumber.uk.com/plumbing/the-dangers-posed-by-high-water-pressure

and is sources of leakages within the distribution network. At the average consumption hours typically from 10 am to 4 pm, the network is able to deliver a sufficient head at all the points within the network. Therefor for maintaining adequate pressure at any hour during a daily supply, Juja network capacity building is required as a new investment to maintain an adequate supply throughout the entire network. The optimisation could include:

- The extension of the existing pumping stations using a booster pump (the pumping flows have to be adjusted to meet the calculated demand),
- The change of critical pipes with the appropriated ones, and
- Water tank for balancing the supply in the entire network.

The future work will focus on optimising the network for an efficient supply.

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