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Simulation of Chlorine Decay in Al-Gukook Water Distribution Networks Using EPANET

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tcartsbA: ***The approach of the research is to simulate residual chlorine decay through potable water distribution networks of Gukook city. EPANET software was used for estimating and predicting chlorine concentration at different water network points . Data required as program inputs (pipe properties) were taken from the Baghdad Municipality, factors that affect residual chlorine concentration including (pH ,Temperature, pressure ,flow rate) were measured .Twenty five samples were tested from November 2016 to July 2017. The residual chlorine values varied between (0.2-2mg/L) , and pH values varied between (7.6 -8.2) and the pressure was very weak in this region. Statistical analyses were used to evaluated errors. The calculated concentrations by the calibrated model were very close to the actual concentrations measured in field at different sampling points for different sampling days.***

Keywords: Chlorine decay, Water quality, Water distribution network, EPANET software

1. Introduction

Chlorination became the most expanded disinfection method which is used to disinfect drinking water, due to its efficiency, germicidal potency, and economy. Chlorine disinfectants leave a residual that prevent re-growth of microorganisms that able to escaping from treatment process or entering the water distribution system causing external pollution [1]. Chlorination incorporates the addition of chlorine gas or salts to a fluid stream inoperative microorganisms, some of that might be pathogenic. Many factors were used to control the efficiency of the chlorine disinfection process including chlorine chemistry, reactor hydraulics and microbial inactivation kinetics.[2]. Chlorine is a heavy oxidizer, it is react with an extensive variety of chemicals and naturally occurring organic (and/or inorganic) matter (NOM) in the treated and/or distributed water to form harmful disinfection by-products (DBPs). A small number of these DBPs were suspected cancer-causing agents and having adverse reproductive and developmental wellbeing impacts,[2]. The reduction of residual chlorine in water distribution network because of it was bulk reaction with the water’s natural organic matter (NOM) (bulk decay) and with the material of the network element (wall decay). Thus , it was imperative for any water supply authority to arrange the chlorine disinfection inside upper and lower point of confinement of residual chlorine to creation then customers from water-borne sicknesses and harmful DBPs. [3].

The water quality models were integrated in virtual all new network simulators were created to simulate the movement mixing and transformation of chemical or biochemical water quality parameter which might be counted to be fully diluted in the water conveyed by the system, [3].

AL –Qaisey studied the concentrations of residual chlorine in the water networks from seven water treatment plants in Baghdad city during study period between February and July of the year 2004, where residual chlorine temperature and pH value were measured. Results indicated that the residual chlorine concentration was within the limits of the Iraqi standard except for some points. pH values varied between 7 to 8.2, the study showed that there is no clear relationship between these values. The relationship between temperature and residual chlorine was an inverse relationship. [4]

Nagatani made a research for controlling free chlorine in water distribution system of Osaka Water. Free chlorine decay simulation using EPANET2 developed water quality simulation algorithm using data collected in field testing study. The study showed the relationship between wall reaction coefficients and water temperature, and prediction method for wall reaction coefficients and C-factors with pipe age and pipe lining material obtained from GIS database could be predicted. [5]

Mostafa studied the performance of the drinking water supply system serving sixth of October City . They simulated free chlorine decay in this system, using water-age investigations, to assess the feasibility of using it as a measuring and controlling tool for estimating chlorine concentration at different points in the network . Field information were used as program inputs from day by day records . The system model was calibrated to minimize error in the program results. [6]

Al-Suhaili and Al-Azzawi found that the characterized GIS maps demonstrated that the zones for a way from the treatment plants have always low chlorine concentration . The area's having low concentration are Al-sadir,Al-Kadhimya, and Al-Amiria .Also low chlorine concentrations were observed in summer months than those in winter months. The Amiria district (636) was chosen as a case study to test the capacity of using the quantitative- qualitative model in the EPANET software, to locate the required onsite chlorine injection point number, areas and dosage, in order to raise the chlorine to acceptable limits in the other nodes of the network. The EPANET model can be utilized successfully to acquire the required injection program for this purpose. [7]

A goal of water treatment for giving water safe from microbiologically pollutant . The water that conveyed to the customer is affected by various procedures. Displays the aspects regarding chlorine decay in drinking-water distribution networks, also the residual chlorine decay simulation using EPANET2 in Ramnicu Valcea water distribution system. Their conclusion is to control the free chlorine concentration in drinking water, the reduction of chlorine concentration beneath the minimal level lead to secondary development of microorganisms. The excessive of chlorine concentration lead to forming of dangerous disinfection by-products, water quality models can be used by drinking water utilities in order to efficiently plan. But, in applying water quality models to actual water distribution system it is critical that a well-calibrated hydraulic model to be used along with site-specific reaction rate data. [8]

A study for chlorine residual simulation in Duhok's water distribution network for Ashti district. The field measurements were used for simulate using EPANET 2.0.

The developed hydraulic model is a combination of gravity and pumped distribution systems, it consists of a reservoir, a pump, a tank, 152 pipes, and 114 nodes. Chlorine dose of 1.0 mg/L was injected to the reservoir constantly. The first-order decay equations were used for modeling both the bulk flows and wall reaction. The result found highly water consumption at a period of peak consumption, 10 a.m. to 12 p.m., having a residual chlorine concentration of 0.31 to 0.59 mg/l, and 44% of the reaction rates of the chlorine were happened in the high elevated tank .That impose addition of adequate dosage of chlorine with appropriate mixing in the tank. [9]. The objectives of this research are to study chlorine concentrations, evaluate the drinking water quality in water supply network and to simulate the decay of chlorine using EPANET program.

2. Materials and methods

2.1 The Site Description

Al Chikook is a district (district 440) in Municipality of Shuala in the karkh side of Baghdad City, the district is located at longitude 44°18'30.77"E, and latitude 33°22'33.92"N. This district includes 560 House, 1,150,000 person, 30 street, 3 school, and 124 shop, also includes Gas Plant, Electricity station, Petrol station (Anwar Al Kadhimiya), Trade stores , Repair garage .The water network is of plastic pipes with diameter 200 mm in the main line , delivery branches ranging from 110 mm to 160 mm. It has many defects such as leaks and interference with sewerage water which cause water contamination in these networks. fo ytilapicinuM .“1 .giF” ni nwohs sa margaid krowteN aluhS.

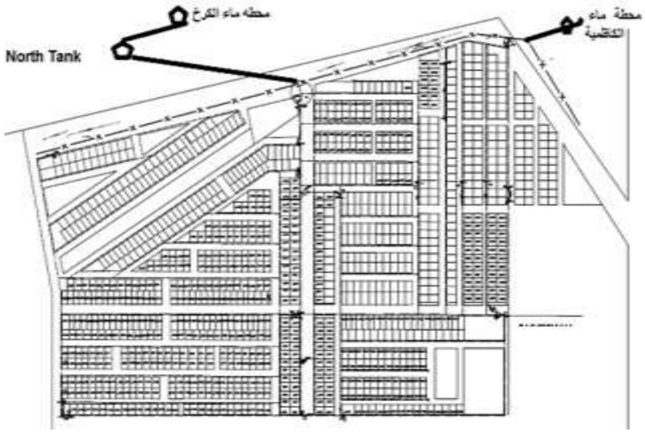


Figure 1: Water distribution network for the study area

2.2 Samples Collection

The field samples were collected for six months from November 2016 to July 2017. The water samples were collected from fixed points in distribution network once a week. 25 water samples with a total no. of fixed point at a constant interval as shown in “Fig. 2” .

The free chlorine concentration, PH, pressure , temperature, and flow rate were measured .Chlorine and pH measurements were according to the standard methods.

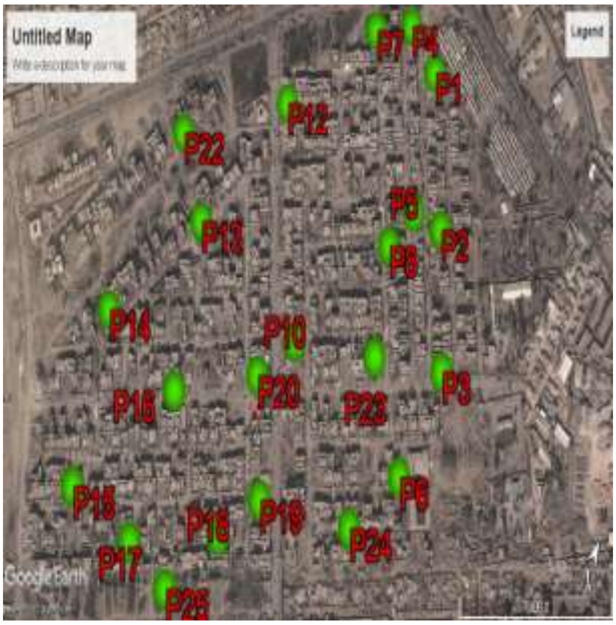


Figure 2: The study area

3. Chlorine Decay

Disinfectants are highly reactive and do not continue for long periods, and most waters appear a rapid and immediate consumption of chlorine when the substance is first added in primary disinfection. As the water goes through the distribution system, chemical, physical, or microbiological transformations may happen within the water bulk and in addition through interaction with the pipe wall which leads to chlorine consumption or decay. Hypothetically, chlorine consumption can be in general classified as bulk or wall decay, [10].

EPANET is a program for modeling water distribution systems (including storage tanks, pipes, nodes, pumps, reservoirs, and valves). The EPANET program calculates water quality, pressure and hydraulic head at every junction; Also, it calculates velocity, flow rate, water quality, and head loss though every pipe in the system. This program is distributed by the USEPA, [12]. The EPANET model deals with the bulk decay of chlorine using first-order kinetics. Bulk decay (kb) is a function of initial chlorine concentration and water temperature.

R1 = KbCn (1)

At the limiting chlorine concentration CL, the expression becomes:

R1 = Kb(CL – C)C(n – 1) ; CL = 0, Kb < 0, n = 1 (2)

Where R1 = bulk rate of reaction, mass/ volume /time.
C = chlorine concentration ,mass/volume.
n= is the order of reaction.

In this study, Kb was determined assuming first-order kinetics, with the use of a colorimeter, in the laboratory, [11].

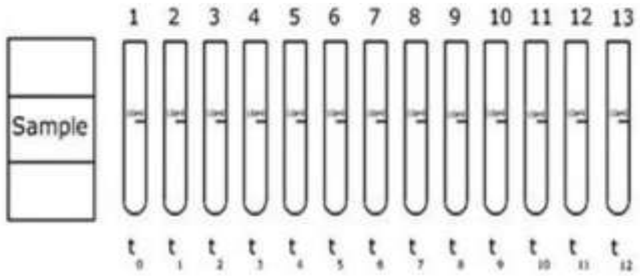
For the wall decay coefficient, it was set to zero because of the network pipes made of PLASTIC material which characterizes with a smooth surface of the internal pipe's wall.

4. Determination of decay coefficients

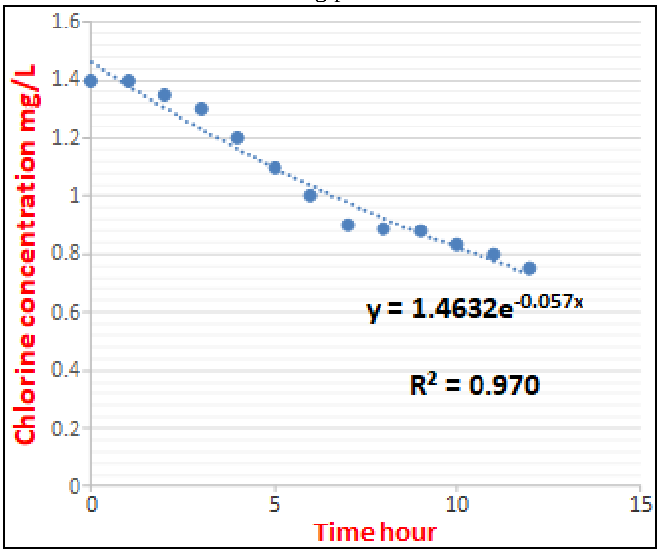
The Bulk decay was approved to be affected by chemical substances in the distribution system. The following steps to calculate the first order decay coefficient for bulk decay (Kb) [6]:

a) Eight water samples were selected from the distribution network on the same street.
b) One water sample was divided in to 13 sub samples each of 10 mL.
c) Free chlorine concentration was measured using LOVIBOND device.

The first sample was measured free chlorine at time zero followed by another sample was measured after one hour and so for the rest of the samples with time gap one hour between each sample as shown in "Fig. 3A". The free chlorine measured were plotted against the time. The same procedure applied on 7 random water samples. The bulk decay coefficient K_b = -0.057 h^{-1} which has the highest determination coefficient (R^2 =0.9704) and corresponds to -1.368 day^{-1}as shown in "Fig. 3B" The negative sign refers to reduction of chlorine residuals with time.



A: Testing procedure.



B: First-order adjustment of the testing results for a certain sample

Figure 3: Determination of bulk decay coefficient in laboratory.

5. Result and discussion

5.1 Analysis of Field Measurements

Temperature was measured on site at the time of collection of water samples. where temperatures ranged between (10-30 c°). To evaluate how much the chlorine measurements are dispersed, the standard deviation(σ) and the coefficient of variation (C.V) were calculated for chlorine concentrations measured at each point as shown in Table 1 in winter, and Table 2 in summer.

Table 1: Standard deviation and coefficient of variation values for different sampling points in winter

Sampling point	1	2	3	4	5	6	7	8	9	10	11	12	13
σ	0.432	0.404	0.521	0.533	0.456	0.321	0.390	0.328	0.416	0.414	0.183	0.156	0.507
C.V	0.450	0.398	0.443	0.640	0.412	0.272	0.263	0.224	0.354	0.309	0.132	0.109	0.487
Sampling point	14	15	16	17	18	19	20	21	22	23	24	25	
σ	0.219	0.471	0.376	0.353	0.250	0.473	0.563	0.609	0.585	0.488	0.269	0.430	
C.V	0.173	0.479	0.286	0.274	0.178	0.481	0.549	0.554	0.553	0.542	0.196	0.606	

Table 2: Standard deviation and coefficient of variation values for different sampling points in summer

Sampling point	1	2	3	4	5	6	7	8	9	10	11	12	13
σ	0.147	0.220	0.202	0.192	0.244	0.293	0.267	0.279	0.262	0.297	0.294	0.279	0.287
C.V	0.113	0.161	0.149	0.148	0.182	0.231	0.208	0.227	0.202	0.242	0.230	0.210	0.216
Sampling point	14	15	16	17	18	19	20	21	22	23	24	25	
σ	0.220	0.135	0.155	0.151	0.158	0.153	0.141	0.233	0.290	0.306	0.221	0.123	
C.V	0.182	0.111	0.134	0.128	0.134	0.130	0.492	0.190	0.233	0.245	0.192	0.111	

The maximum value of standard deviation is 0.6 mg/L with a corresponding coefficient of variation (C.V) of 0.55 and occurs at sampling point (21) in winter, 0.29 mg/L with a corresponding coefficient of variation (C.V) of 0.22 and occurs at sampling point (11) in summer. The standard deviation analysis indicates that the data points tend to be very close to the mean (because the standard deviation is closer to zero than to unity) and hence concluded that chlorine concentrations measured in field are centralized for all sampling points and accordingly for the entire network .The output of the simulated results are shown in "Fig. 4"showed that concentration of residual chlorine in the nodes (junctions) at the 24th hrs , is equal to zero and trace concentration respectively ,as it was expected because of prevailing of the low flow velocity in the pipes ,and the relatively high residence time in the network's nodes ,privately at dead ends within the period (12 P.M – 5 A.M),where demand pattern was set to zero.

Percentages distribution of the average reaction rates in distribution system were shown in "Fig. 5", the 91% of these reactions occurred in the high elevated tank (feeding source) .Essentially, this result may refers to the high age of water ,the factor that has the greatest overall effect on water quality, the cumulative sediment in the tank basement and the lack of maintenance work.

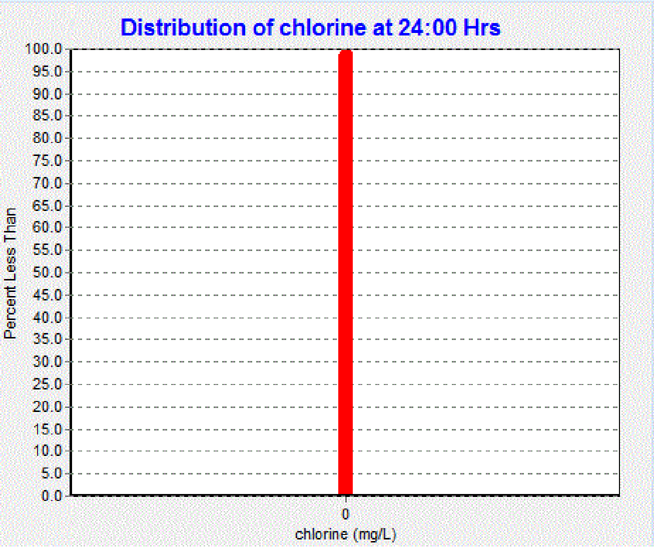


Figure 4: Frequency distribution curves of residual chlorine concentration in the nodes at 24th

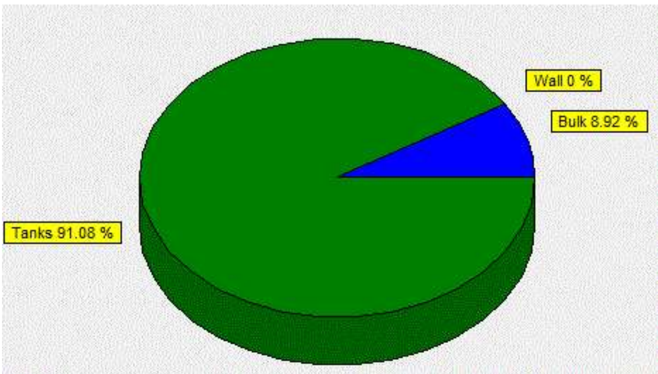


Figure 5: Percentages distribution of the average reaction rates in distribution system

6. Comparison of EPANET result and field measurement

Fig. 6-12 shows the comparison of simulated (computed) and measured (observed) data of main values of chlorine concentration, there are variances in these results and that may be showed in three figures. This variance between model results and field measurements due to:

a) No systematic operation schedule of the pump station has a guideline role in stream regime within network pipes.
b) Variations in every day water demand pattern while a steady pattern was adopted when utilizing EPANET.
c) Difference in devices that were used in measurement and accuracy between the study's devices and water treatment plants' devices.
d) Consistent estimations of kb were adopted in EPANET neglecting temperature effect on kb (due that the study was performed during winter) and pipe material effect on kw (due that 100% of the network is plastic). The reason for the fluctuation in Chlorine values in the field measurements is the difficulty of checking and entering houses, especially in the early days, so we have to take the sample from the owner of the house. The owner had taken the sample directly from the tap without allowing it to get rid of the water in the pipes, so we get non-accurate results. The second reason is the consumption of water by citizens and the water temperature. After period of time we able to enter the houses and take samples ourselves, so we observe the results become more accurate and homogenous.

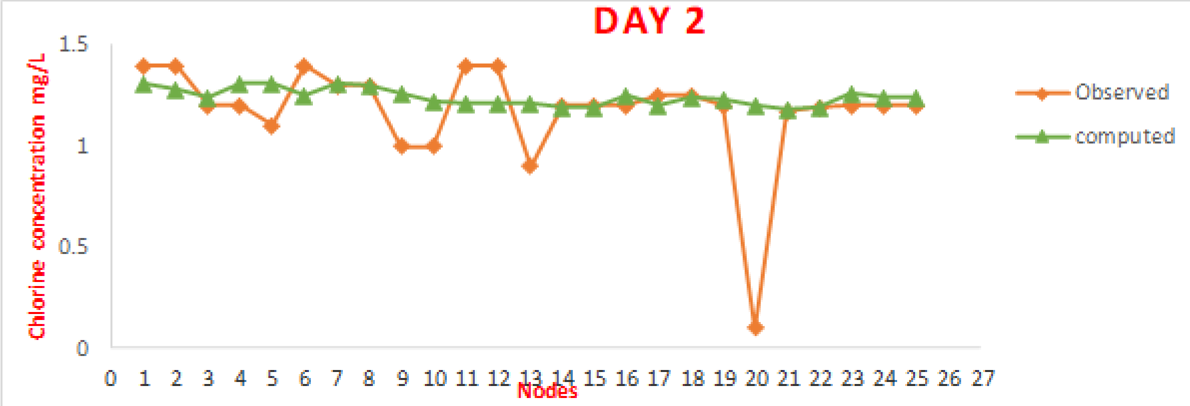


Figure 6: Field measurements and EPANET results of free chlorine concentration and resulted errors at 2nd day

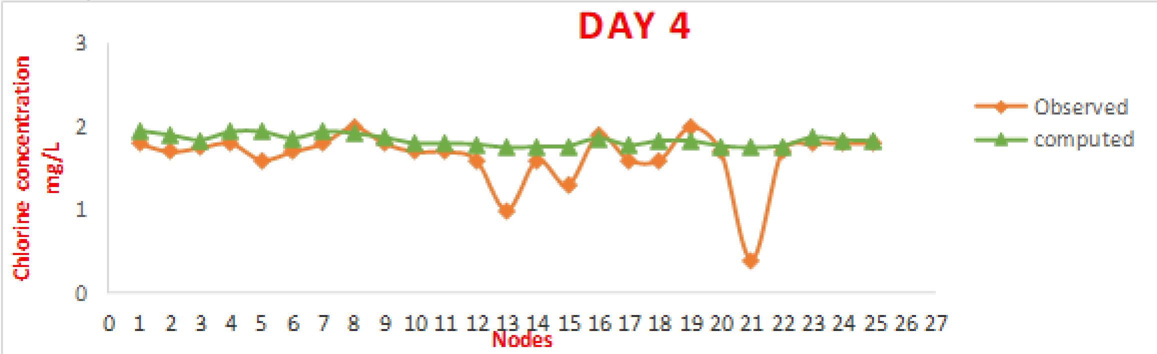


Figure 7: Field measurements and EPANET results of free chlorine concentration and resulted errors at4th day

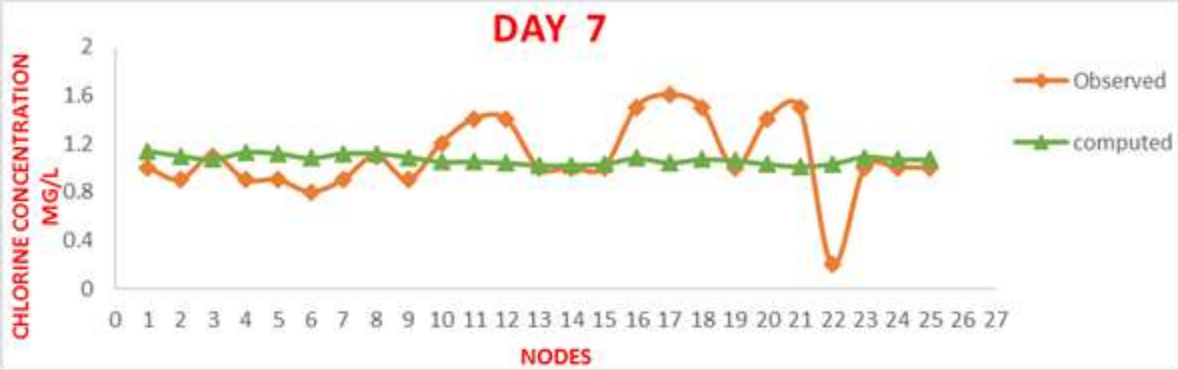


Figure 8: Field measurements and EPANET results of free chlorine concentration and resulted errors at 7th day

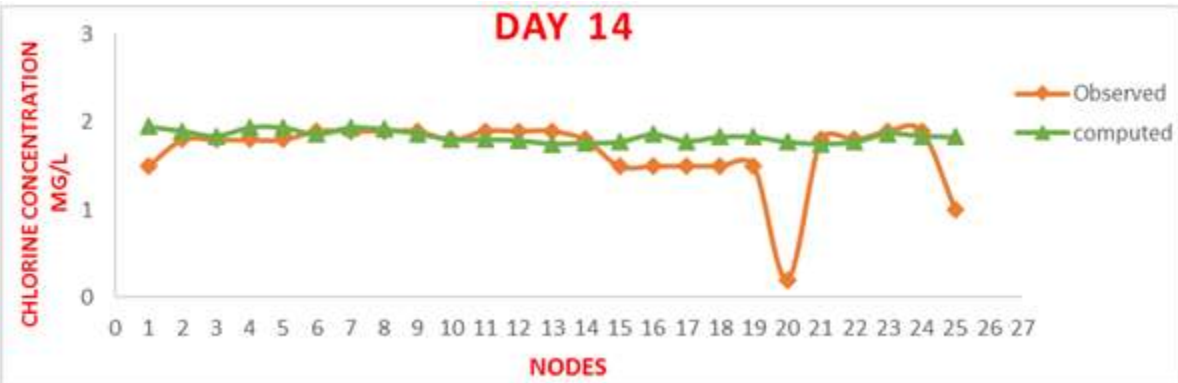


Figure 9: Field measurements and EPANET results of free chlorine concentration and resulted errors at 14 th day.

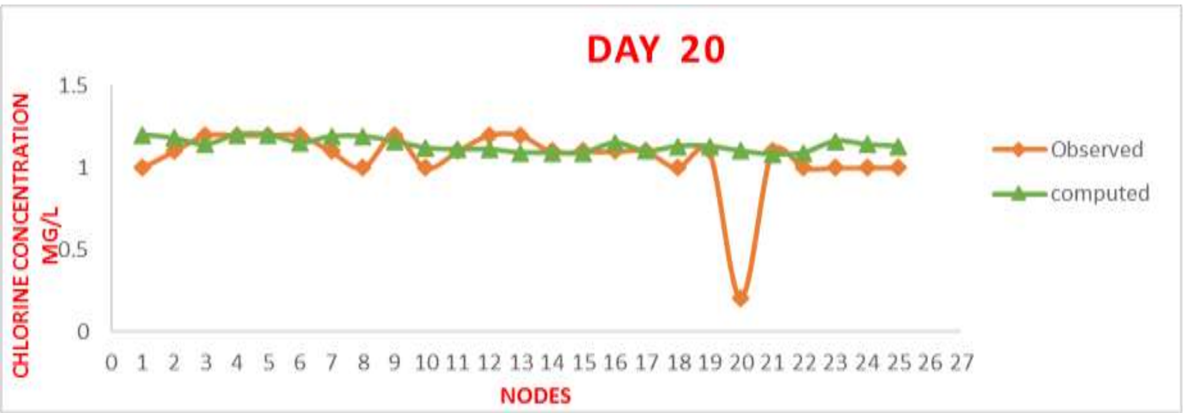


Figure 10: Field measurements and EPANET results of free chlorine concentration and resulted errors at 20th day

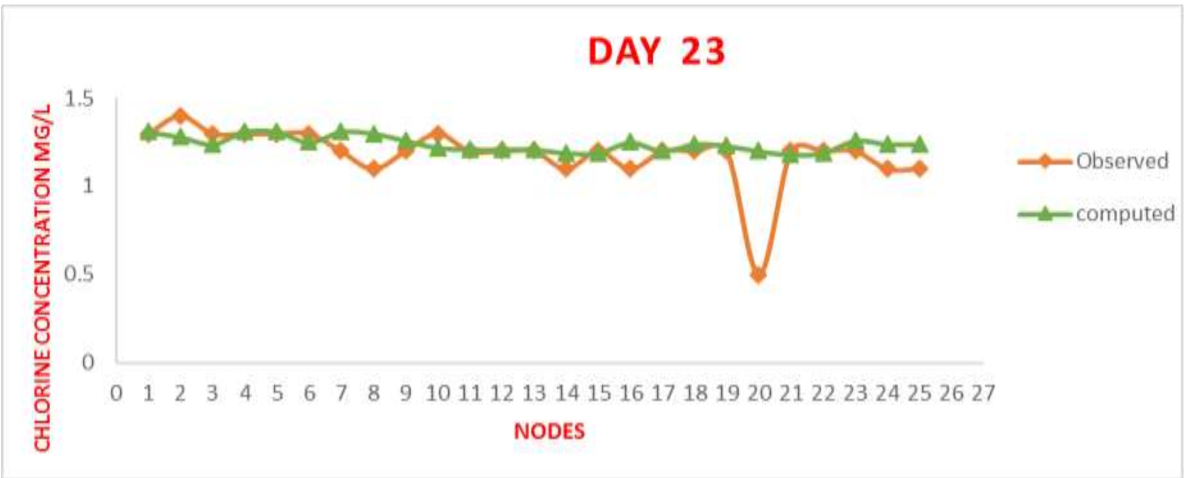


Figure 11: Field measurements and EPANET results of free chlorine concentration and resulted errors at 23th day.

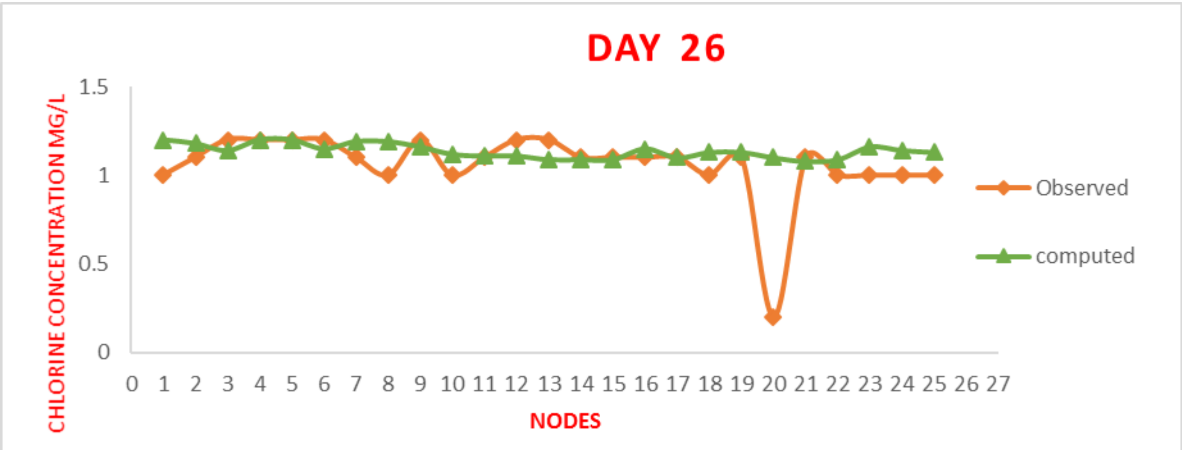


Figure 12: Field measurements and EPANET results of free chlorine concentration and resulted errors at 26th day

7. Conclusion

1) The chlorine concentration in the area of study were within the permissible limits expect some points , that is because the over take on the network and ruptures in the pipe ,in some pipes
2) Point ,these ruptures help to enter polluted water in to the network, especially during houses pumps operation .
3) Values of coefficient of variation in some points were less than others because the readings were
4) Different during pumps operation, also there are no maintenance for ruptures leads to more pollutants to enter the network. The other reason is it must open the valve for a time in order to discharge the water and to have a fresh water.
5) The study comes out with most of highly water consumption nodes at peak consumption period (10 A.M – 12 P.M). The residual chlorine concentration is (0.2 – 2 mg/l).
6) The result showed that About 91% of the reaction rates of the chlorine were happened in the high elevated tank. That impose addition of adequate dosage of chlorine with appropriate mixing in the tank which requires an extra amount of chlorine dosage with an appropriate mixing in the tank.

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