CHLORINE EVOLUTION SIMULATION AND TEMPERATURE EFFECT ON RESIDUAL CHLORINE

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Abstract

The research is on chlorine evolution simulation and temperature effect on residual chlorine in Sokoto water distribution network using EPANET Multi-Species Extension (MSX). Two input files were prepared, the first one, is a standard Epanet 2.0 input file that describes the hydraulic characteristics of the network being analyzed. The second file is the special EPANET-Multi-Species Extension file that describes the species being simulated and the chemical reaction/equilibrium model that governs their dynamics. I.e. residual chlorine and temperaturedecay species. First order reaction chlorine decay model was used (-Kb*CL2) for EPANET-MSX chlorine simulation at an assumed temperature of 25°C, with detailed chlorine settling results per hour for 6 hours to be 0.2 mg/l, 0.17 mg/l, 0.15 mg/l, 0.13 mg/l, 0.1 mg/l, 0.06 mg/l, respectively and for temperature implementation in Sokoto water distribution network using EPANET-MSX water quality command line approach the following equation was used:(-Kb*CL2*EXP(-25.211*(25-T_w)/(273+T_w).at varying temperatures of 26, 28, 30, 32, 34, 36, 38, 40, 42, and 44°C. The results indicate temperature influence on residual chlorine per hour respectively as 0.2 mg/l, 0.19 mg/l, 0.18 mg/l, 0.18 mg/l, 0.17 mg/l, 0.16 mg/l, 0.15 mg/l, 0.14 mg/l, 0.13 mg/l, 0.12 mg/l.

Keywords:Chlorine Evolution Simulation, Temperature, Residual Chlorine, Bulk and Wall decay coefficients.

1.0 INTRODUCTION

Chlorine is the most popular disinfectant used in drinking water distribution systems. In order to make the prediction of chlorine decay more true, biofilm growth and substrate utilisation more confident, numerical models have been developed. Typically, the source water is cleared and disinfected in treatment plant before being discharged into a drinking water distribution system. Disinfection is the most crucial stage in the treatment of drinking water, and chlorine (or other disinfectant) is applied in the clarified water, as the final stage of treatment before distribution (Beata *et' al*, 2018).

Behavior and transport of chemical species in water distribution system have taken center stage in the management of the world services. Advancements in computer technology, beginning in the mid-eighties, allows for the addition of water quality to hydraulic models. This is due to the fact that water quality can greatly deteriorate from the water treatment plant, through the distribution system, and to the consumer's tap. With developments in dynamic hydraulic simulations, the projected simulation of water quality within a distribution system became possible.(Rossman, 2000).

EPANET 2.0 is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. Epanet tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated.EPANET is designed to be a research tool for improving our understanding of the movement and fate of drinking water constituents within distribution systems. It is applicable for many kinds of applications in distribution systems analysis. Sampling program design, hydraulic model calibration, chlorine residual analysis, and consumer exposure assessment are some examples. Epanet can also help assess alternative management strategies for improving water quality throughout a system.

Temperature is one of the most important parameters affecting the quality of drinking water, among all domestic water supply factors. The significance of drinking water temperature is based upon its role in physical, chemical and biological processes. Viscosity of drinking water, tends to fall as temperature increases. A temperature rise from 5 to 25 °C prompt the viscosity to drop by almost 40% resulting in a decrease in flow resistance, which directly affects the transport phenomena in distribution pipes (Blokker and Pieterse-Quirijns 2015).

Blokker et al. examined chlorine decay concentrations and water temperatures at the network extremities of a distribution system under different demand models. Residual disinfectant concentrations was found to be more sensitive to the choice of chlorine model than demand model and that temperature played a key role in the process of decaying. (Ljiljana et al, 2017)

Deterioration of water quality in distribution networks has a great impact on human health and public acceptance of tap water reaching them. Residual chlorine should be maintained through network pipes to prevent contamination and microbial regrowth. (Nagwan, *et'al*, 2013).

2.0 MATERIALS AND METHODS

2.1 EPANET Multi-Species Extension Procedures

To determine chlorine evolution simulation of Sokoto water distribution network using EPANET Multi-Species Extension (MSX), which allows more detailed settings of species decay model structure.Many water quality problems in distribution systems can only be analyzed by using a multi-species approach. Chlorine evolution simulations have been performed with EPANET-MSX, which is in relation to the water quality simulations and it allows more detailed settings of species decay model structure, than the classical EPANET water quality solver. Standard approaches used in running MSX is by either command line or toolkit versions of EPANET-MSX, regardless of which approach is used, the user must prepare two input files to run a multi-species analysis. One of these is a standard EPANET 2.0 input file that describes the hydraulic characteristics of the network being analyzed (EPANET-MSX will ignore any water quality information that might be in this file).

Any network file that was created, edited and then exported from the Windows version of EPANET 2.0 can serve as the Epanet 2.0 input file for the multi-species extension. The second file that must be prepared is a special EPANET-MSX file that describes the species being simulated and the chemical reaction/equilibrium model that governs their dynamics. This study uses command line/prompt approach. The standard EPANET input file, the special EPANET-MSX file, the EPANET-MSX more detailed chlorine setting report file and the Epanet-MSX temperature effect report files were presented at the appendices.

2.2 Implementing Sokoto Temperature Effect into EPANET-MSX Chlorine Values

The most commonly used chlorine decay model is a first order reaction (Vasconcelos et al, 1997) and decay rate of residual chlorine due to reactions with materials in the bulk phase is also represented;

$$\frac{dC_{cl}}{dt} = -k_T C_{cl}; \qquad (2.1)$$

In Eqn. 3.1 K_T is the reaction rate coefficient (L/mgCl/h) which depends on the temperature of the water T_{water} (°C).

Where

$$K_T = K_{25}\exp\left(\frac{-\frac{E}{R}.(25-T_{water})}{(273+25).(273+T_{water})}\right)(2.11)$$

Substituting K_T in to eqn * we have

$$\frac{dC_{cl}}{dt} = -\{K_{25}\mathbf{exp} \quad \left(\frac{-\frac{E}{R}.(25-T_{water})}{(273+25).\,(273+T_{water})} \right\} C_{cl} \quad (2.2)$$

-E/R the activation coefficient (K_b) where an E/R Is calculated to be 7513 at varying water temperature starting from T = 25°C to any $T_{\text{above 25}}$

Clark et al (2012) have derived a chlorine wall decay equation;

$$\frac{dC_{cl}}{dt} = -k_r C_w - \mathbf{d}.k^e_{mt} C_w \qquad (2.3)$$

With C_w the chlorine concentration taking into account wall decay only(mg/l), K_r the stagnant decay rate(l/s), k_{mt} the coefficient of mass transfer to the pipe wall (m/s) and *d* and *e* in the net wall decay function. In this case the chlorine wall decay equation is negligible as the eqn. 3.1 does not take account of chlorine wall decay.

The combine model of Vasconcelos et al, 1997 and Clark et al (2012) is implemented in Epanet Multi- Species Extension as

$$\frac{dC_{cl}}{dt} = -\{K_{25}\mathbf{exp} \quad \left(\frac{-\frac{E}{R}.(25-T_{water})}{(273+25).\,(273+T_{water})} \right\} C_{cl} \ + \ -k_r C_w - \mathbf{d}.k^e_{mt} C_w$$

Since eqn. 3.3 is zero, combined equation for temperature model in MSX will be transformed into;

$$\frac{dC_{cl}}{dt} = -\{K_b\ C_{cl}\mathbf{exp} \quad \left(\frac{-\frac{E}{R}.(25-T_{water})}{(273+25).\,(273+T_{water})} \right\} \quad (2.4)$$

Eqn. 3.4 is used to model and implement the influence of temperature in Epanet Multi-Species Extension.

K= K_T= the reaction rate coefficient which depends on the temperature of the water T_{water}.

E = Ea = Activation Energy
R= Ideal gas constant = 8.3145J/K. mol

T= Temperature in kelvin.

Activation Energy (E_a) is calculated for the study using the formula

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{E_a}{R} \times \left(\frac{1}{T_1} - \frac{1}{T_2}\right)(2.4.1)$$

K1 and K2 are the reaction rate constants at T1 and T2 (0.005 and 0.0067)

T1 and T2 are the absolute temperatures (in Kelvin) (29°C + 273.15) and (32.6°C + 273.15)

R is the Ideal gas constant = 8.3145J/K. mol. Substituting the values we have; In (0.0067/0.005) = Ea/8.3145 x (1/302.15 – 1/305.75),

So, In (1.34) = Ea /8.3145(0.0000956)

Ea= 2.433401505/0.000038954= 62,468.59129,

Ea/R= 62,468.59129/8.3145=7513

Todd Helmenstine (2019)

First order reaction chlorine decay model used in eqn. 2.1 (-Kb*CL2) is the equation for the determination of residual chlorine using Epanet-MSX at an assumed temperature of 25°C and equation 2.4 ($-Kb*CL2*EXP(-25.211*(25-T_w)/(273+T_w))$) is used to implement temperature influence in a water distribution network using EPANET-MSX water quality command line approach at varying temperature starting from 25°C to any possible temperature within a particular network and to verify the temperature model equation in relation to more detailed EPANET-MSX residual chorine equation at assumed temperature of 25°C; thus if, water temperature (T_w) of 25°C is substituted into the implementation equation the equation will return to the initial equation of residual chlorine using EPANET-MSX at an assumed temperature of 25°C and thereby serving as a validation for the study.

3.0 RESULTS AND DISCUSSIONS

3.1 EPANET-MsxChlorine Evolution Simulation For Sokoto Water Distribution Network

EPANET 2 (Rossman, 2000) is a widely used program for modeling the hydraulic and water quality behavior of drinking water distribution systems. Its water quality component is limited to tracking the transport and fate of just a single chemical species, such as fluoride used in a tracer study or free chlorine used in a disinfectant decay study and current single-species models, however, must model free chlorine loss under the assumption that all other reactants are in excess and thus their concentrations can be considered constant. This limitation is responsible for the widespread observation that the water-specific decay rate constant of the common first-order model is not a constant at all, but rather varies significantly with chlorine dose. An extension to EPANET2 that allows it to model any system of multiple, interacting chemical species in the network is developed. This set of software tools is referred to as EPANET-MSX, where MSX stands for Multi-Species Extension. Many water quality problems in distribution systems can only be analyzed by using a multi-species approach. Both models (EPANET 2.0 & EPANET MSX) have been used and the results of calibration and validation have been compared with the real data. In order to simulate the hydraulic model, public domain EPANET solver has been used while the chlorine evolution simulations have been performed with EPANET MSX, which is in relation to the water quality simulations and it allows more detailed settings of species decay model structure, than the classical EPANET water quality solver.

Standard approaches used in running MSX is by either command line or toolkit versions of EPANET-MSX, regardless of which approach is used, the user must prepare two input files to run a multi-species analysis. One of these is a standard EPANET Input file that describes the hydraulic characteristics of the network being analyzed (EPANEt-MSX will ignore any water quality information that might be in this file). Any network file that was created, edited and then exported from the Windows version of Epanet can serve as the Epanet input file for the multi-species extension. The second file that must be prepared is a special EPANEt-MSX file that describes the species being simulated and the chemical reaction/equilibrium model that governs their dynamics. This study uses command line/prompt approach. The standard EPANET input file, the special EPANET-MSX file and the report file for the research is presented at the appendices.

3.2: EPANET-MSX Results and Analysis:- The Epanet Sokoto multi-species command line analysis was successfully achieved and the more detailed setting of chlorine results at each node during each time interval is reported in the report file, extracted in table 3.6 for some nodes and plotted in comparison with each other, Figures 3.0, 3.1, 3.2, and 3.3.

Table 3.0: EPANET Chlorine Multispecies Results for Some Critical Nodes

Hours	Node 8	Node 9	Node 19	Node 20	Node 22	Node 24	Node 27	Node 29	Node 31	Node 34
0.00	0	0	0	0	0	0	0	0	0	0

1.00	0.2	0	0	0	0	0.2	0	0	0	0
2.00	0.17	0	0	0.17	0.17	0.17	0	0.2	0	0
3.00	0.15	0.09	0	0.15	0.15	0.15	0.02	0.17	0.15	0.17
4.00	0.13	0.13	0.08	0.13	0.13	0.13	0.13	0.15	0.13	0.15
5.00	0.1	0.11	0.11	0.11	0.11	0.11	0.11	0.13	0.11	0.13
6.00	0.06	0.09	0.1	0.08	0.08	0.07	0.09	0.1	0.08	0.11
7.00	0.07	0.05	0.06	0.06	0.06	0.06	0.07	0.08	0.07	0.08
8.00	0.08	0.06	0.05	0.07	0.03	0.08	0.04	0.06	0.04	0.06
9.00	0.1	0.07	0.06	0.08	0.05	0.09	0.02	0.03	0.02	0.03
10.00	0.13	0.08	0.07	0.11	0.05	0.12	0.05	0.06	0.05	0.05
11.00	0.13	0.1	0.08	0.12	0.06	0.13	0.05	0.07	0.06	0.05
12.00	0.12	0.11	0.09	0.12	0.05	0.12	0.06	0.06	0.05	0.07
13.00	0.12	0.1	0.09	0.11	0.07	0.12	0.04	0.07	0.05	0.06
14.00	0.12	0.09	0.08	0.11	0.07	0.12	0.05	0.08	0.06	0.08
15.00	0.11	0.09	0.08	0.1	0.08	0.11	0.06	0.09	0.06	0.08
16.00	0.11	0.09	0.08	0.11	0.08	0.11	0.07	0.09	0.08	0.08
17.00	0.11	0.1	0.09	0.1	0.08	0.11	0.07	0.09	0.08	0.09
18.00	0.11	0.1	0.09	0.1	0.09	0.11	0.08	0.09	0.08	0.09
19.00	0.11	0.09	0.09	0.1	0.09	0.11	0.08	0.09	0.08	0.09
20.00	0.11	0.09	0.09	0.1	0.09	0.11	0.08	0.1	0.09	0.09
21.00	0.11	0.09	0.09	0.1	0.07	0.11	0.08	0.09	0.07	0.09
22.00	0.11	0.09	0.08	0.1	0.06	0.11	0.06	0.07	0.06	0.07
23.00	0.11	0.08	0.08	0.09	0.05	0.1	0.05	0.06	0.05	0.06
24.00	0.1	0.08	0.07	0.09	0.04	0.1	0.04	0.05	0.04	0.05
25.00	0.09	0.07	0.06	0.08	0.04	0.09	0.04	0.05	0.04	0.04
26.00	0.08	0.07	0.06	0.08	0.05	0.08	0.03	0.05	0.04	0.05
27.00	0.07	0.07	0.06	0.07	0.06	0.07	0.04	0.06	0.04	0.05
28.00	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.07	0.05	0.06
29.00	0.07	0.05	0.05	0.06	0.07	0.07	0.06	0.07	0.06	0.07
30.00	0.07	0.06	0.05	0.06	0.06	0.07	0.06	0.07	0.06	0.07

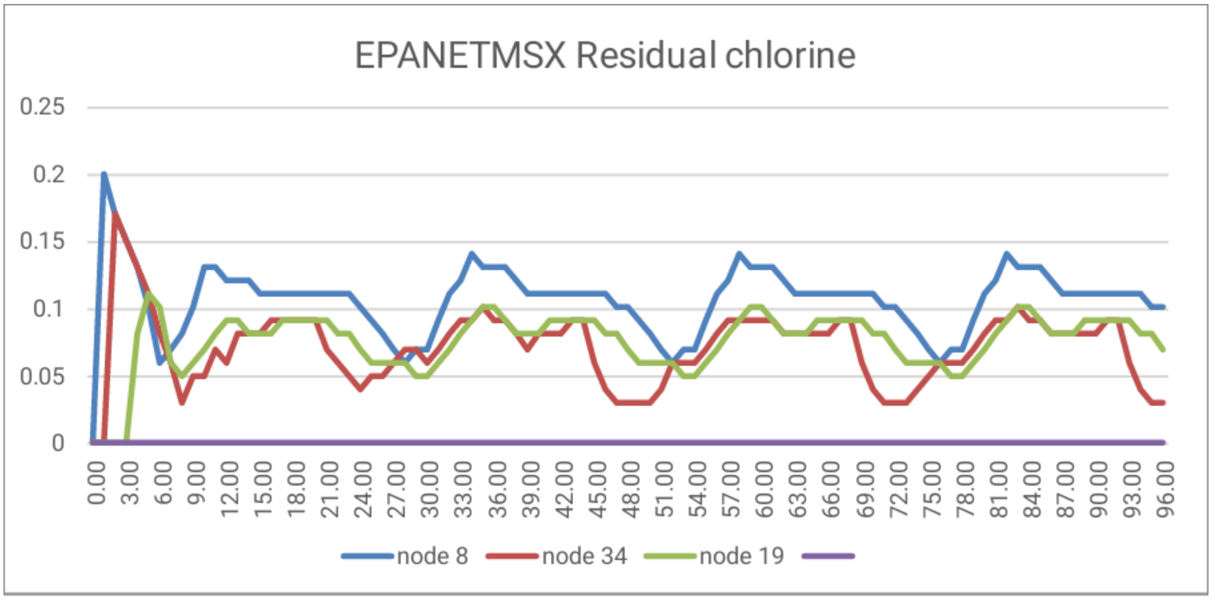

Figure 3.0: Plot of Epanet-MSX Sokoto chlorine results comparison at nodes 8, 34 and node extremity 19.

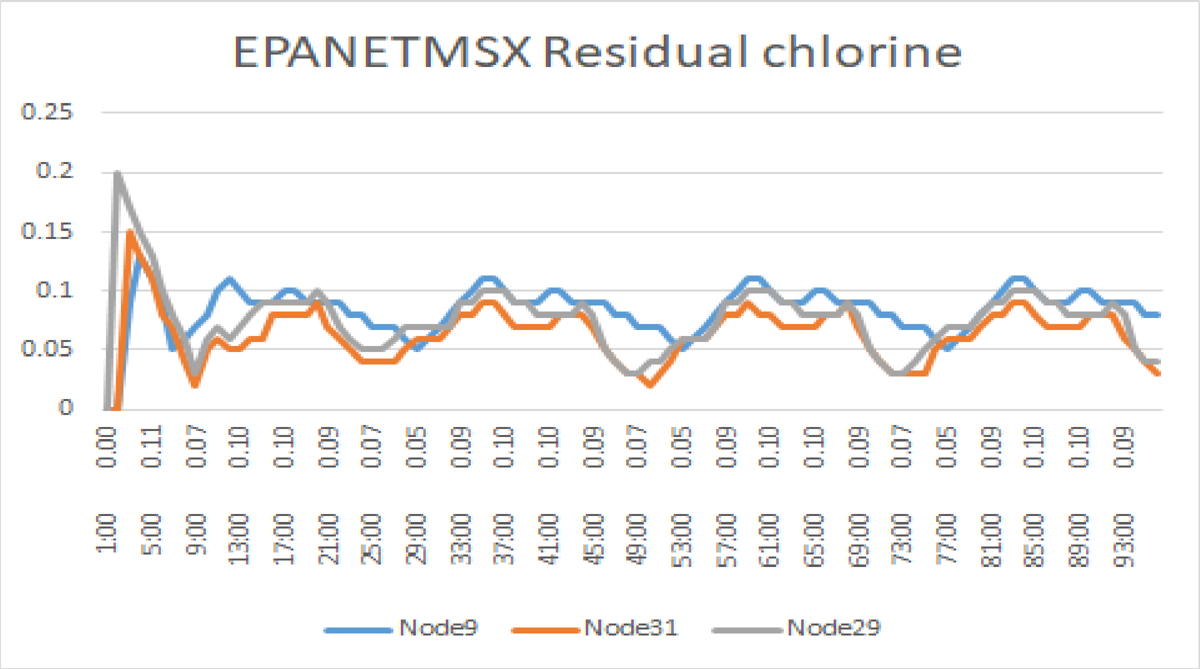

Figure 3.1: Plot of Epanet-MSX Sokoto chlorine results comparison at node extremities 9, 31 and node29.

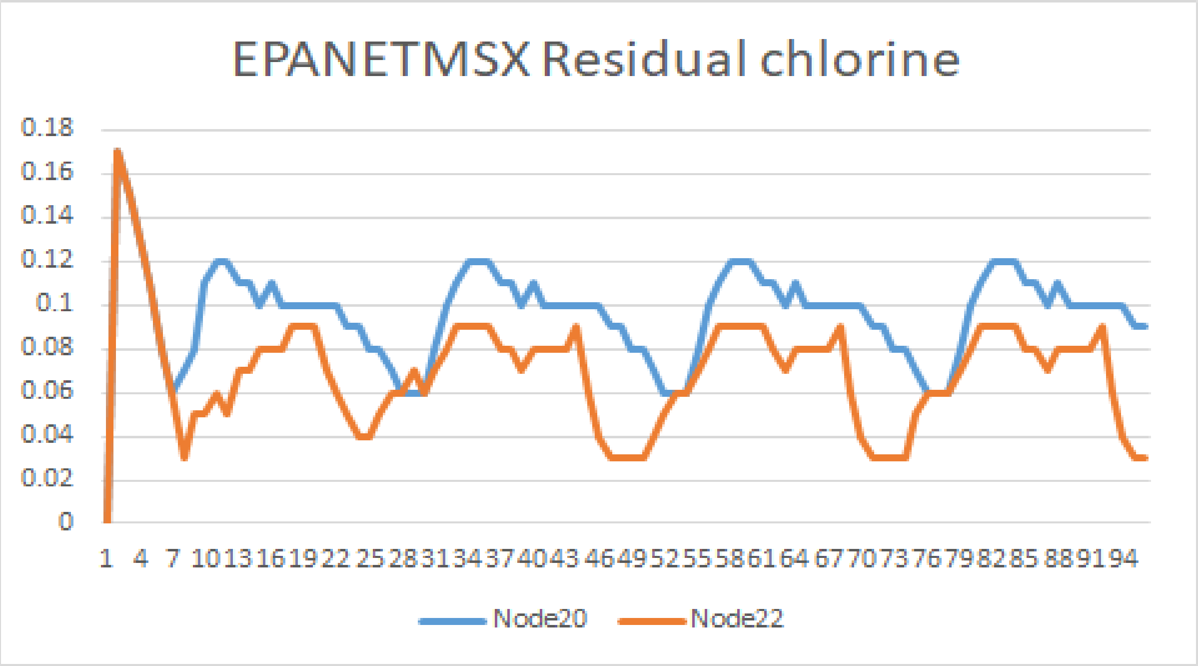

Figure 3.2: Plot of Epanet-MSX Sokoto chlorine results comparison at node extremities 20 and 22.

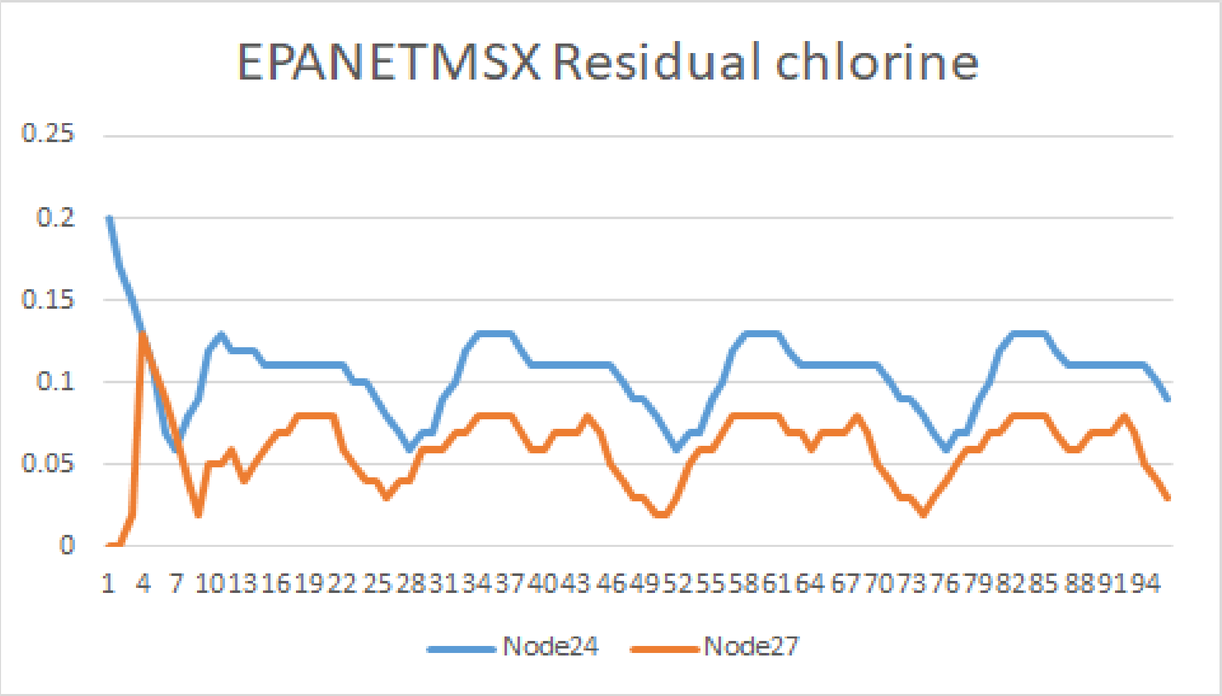

Figure 3.3: Plot of EPANET-MSX Sokoto chlorine results comparison at node 24 and node extremity 27.

3.3: EPANET-MSX and EPANET 2.0 Sokoto Water Distribution Network Outputs Correlation

The output of EPANET2 node chlorine time series results was compared with EPANET-Multispecies chlorine results to ascertain the extent and degree of detailed species evolution and the effect of other factors on the chlorine decay in Sokoto water distribution system.

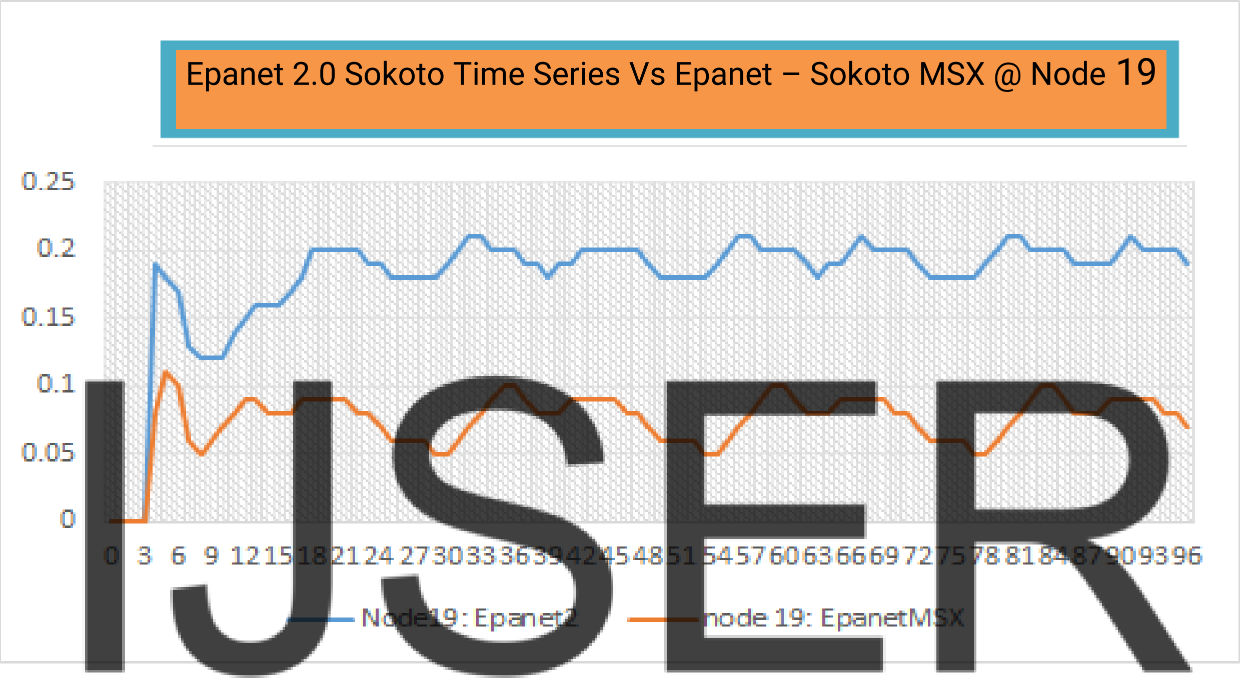

Figure 3.4: Plot of EPANEt-MSX Sokoto chlorine results: depicting the extent of detailed

chlorine species evolution at node 19.

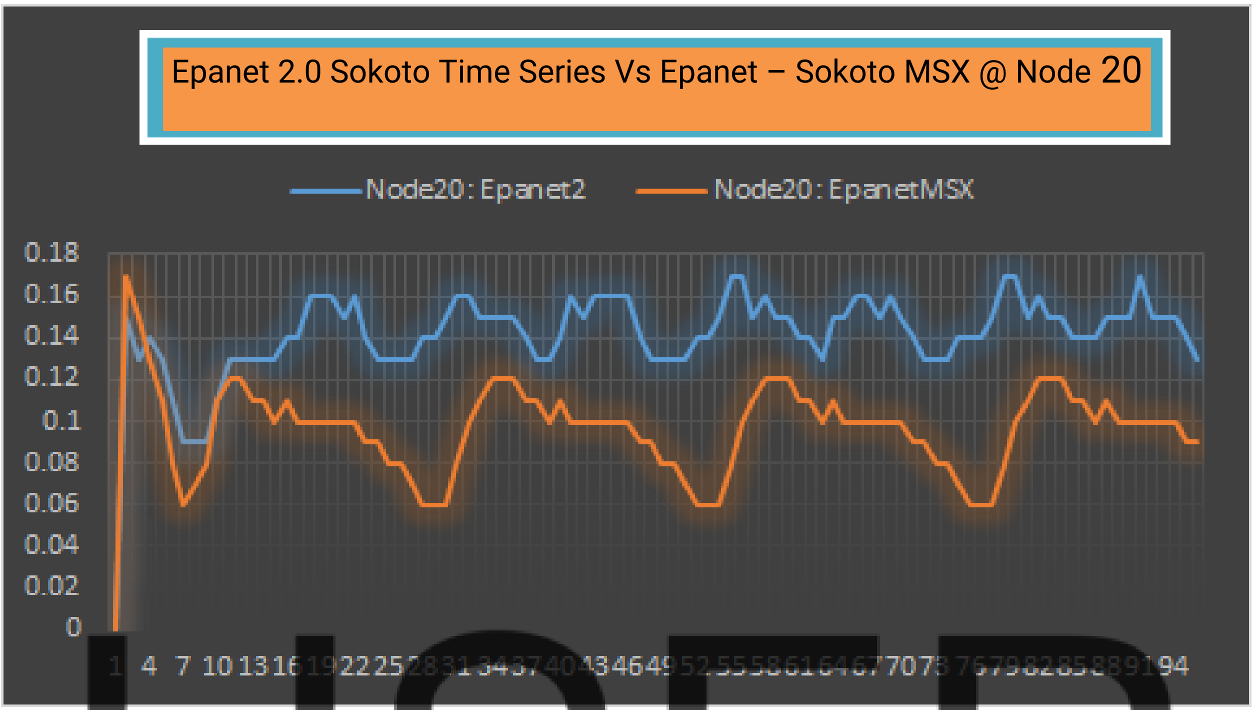

Figure 3.5: Plot of EPANET-MSX Sokoto chlorine results: depicting the extent of detailed chlorine species evolution at node 20.

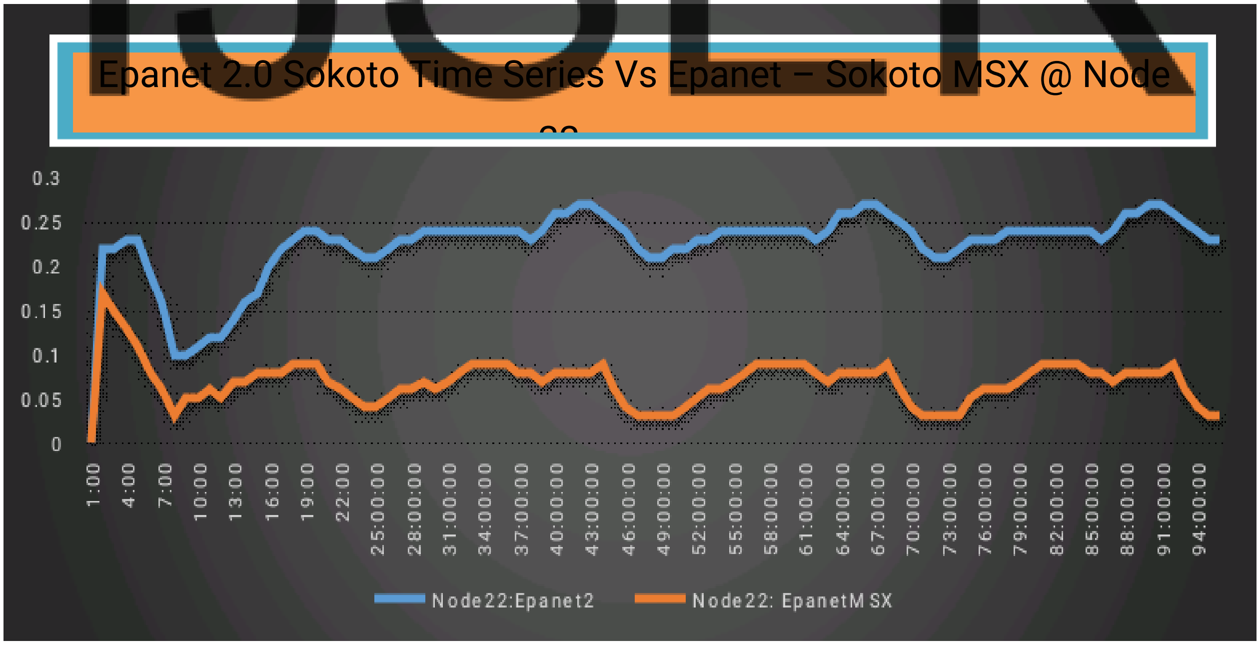

Figure 3.6: Plot of EPANET-MSX Sokoto chlorine results: depicting the extent of detailed chlorine species evolution at node 22.

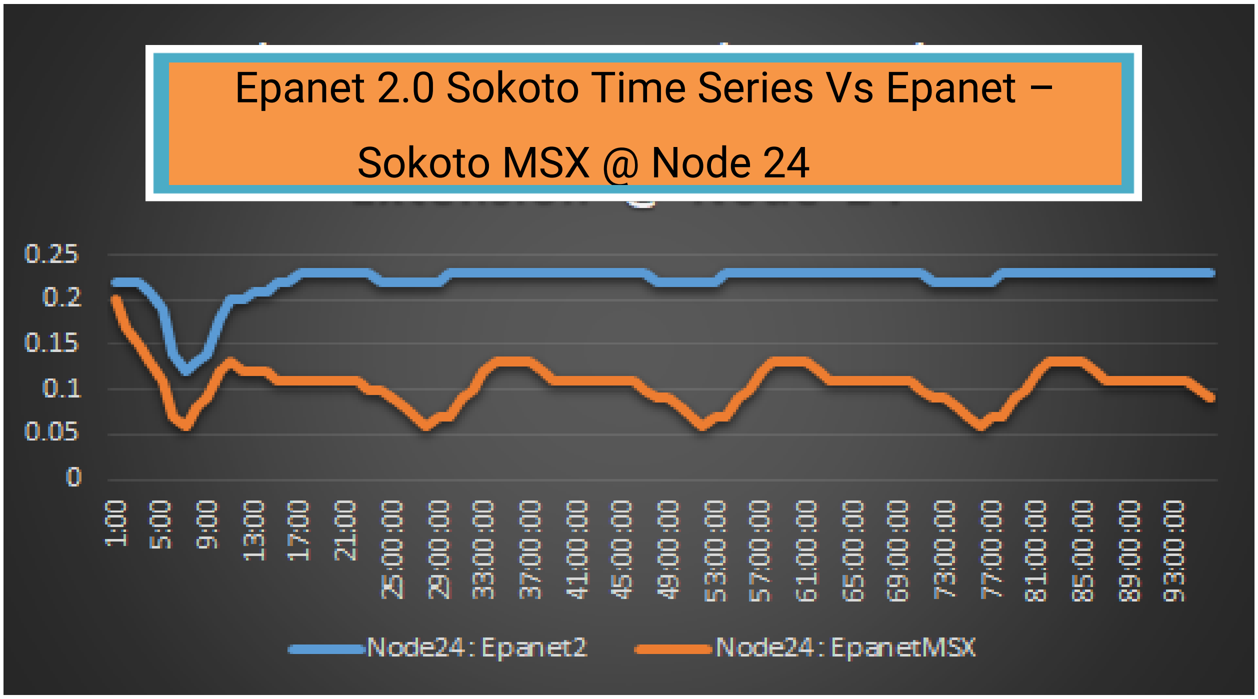

Figure 3.7: Plot of EPANET-MSX Sokoto chlorine results: depicting the extent of detailed chlorine species evolution at node 24.

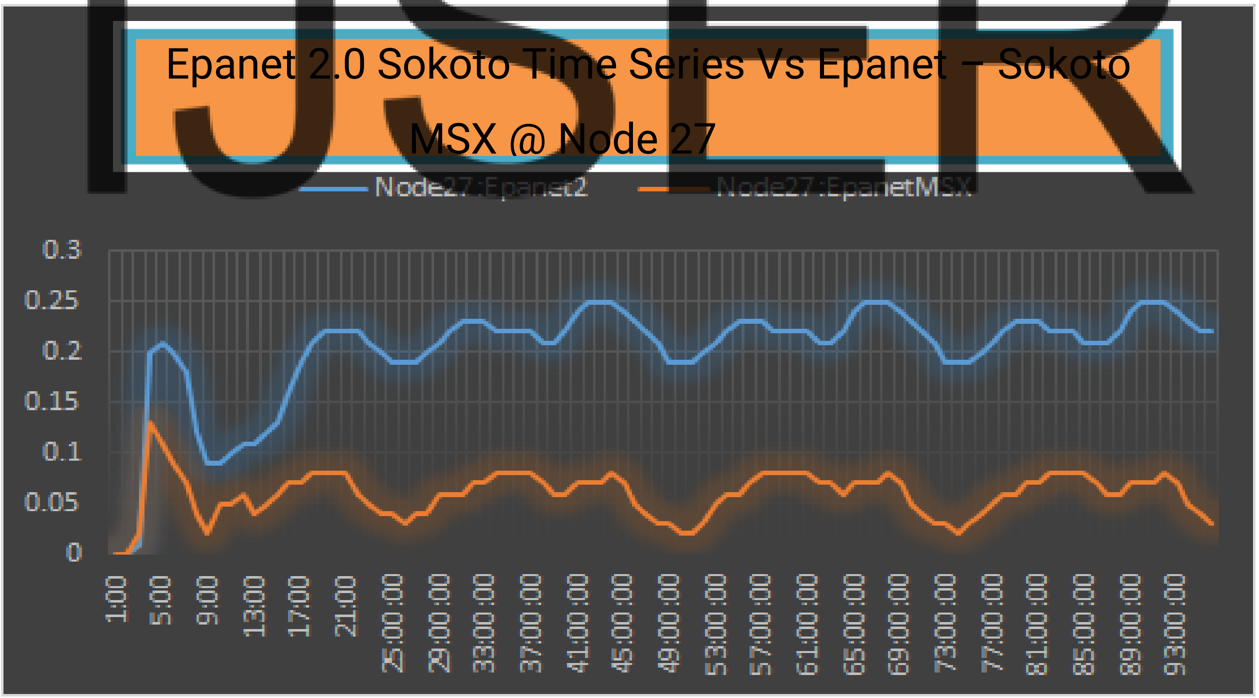

Figure 3.8: Plot of EPANET-MSX Sokoto chlorine results: depicting the extent of detailed chlorine species evolution at node 27.

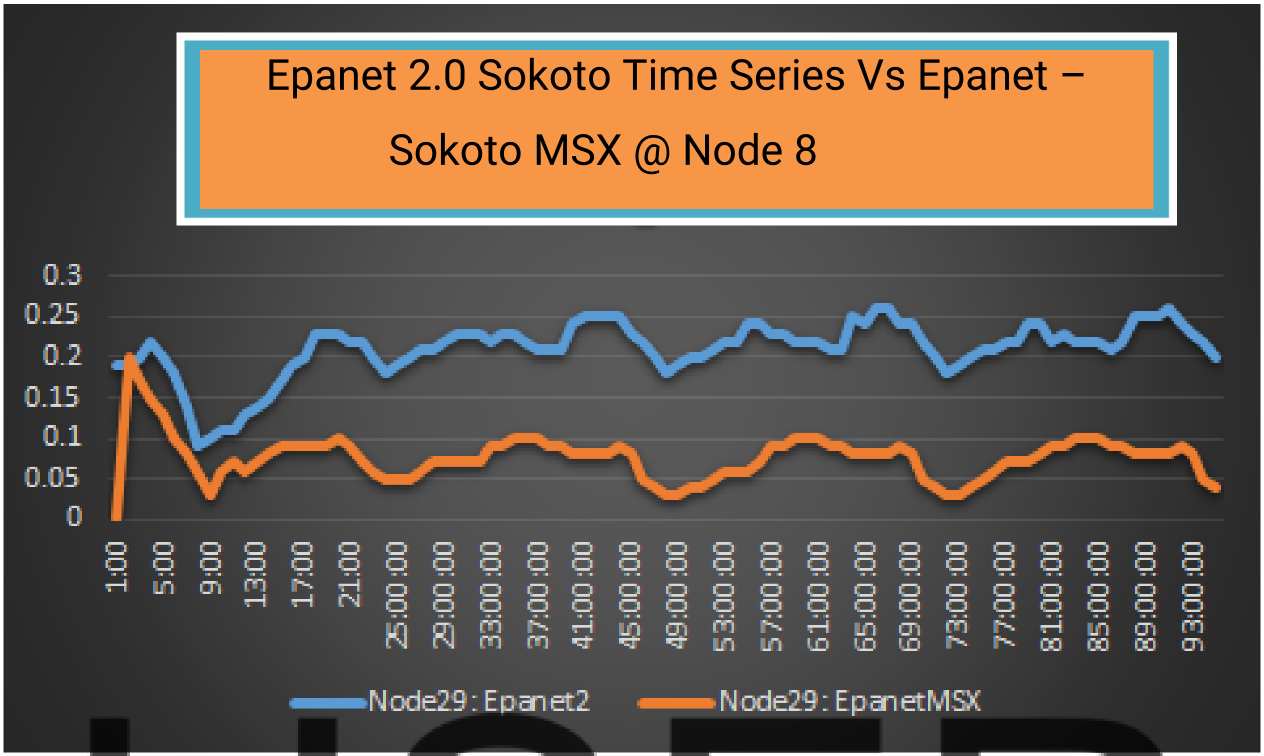

Figure 3.9: Plot of EPANET-MSX Sokoto chlorine results: depicting the extent of detailed chlorine species evolution at node 29.

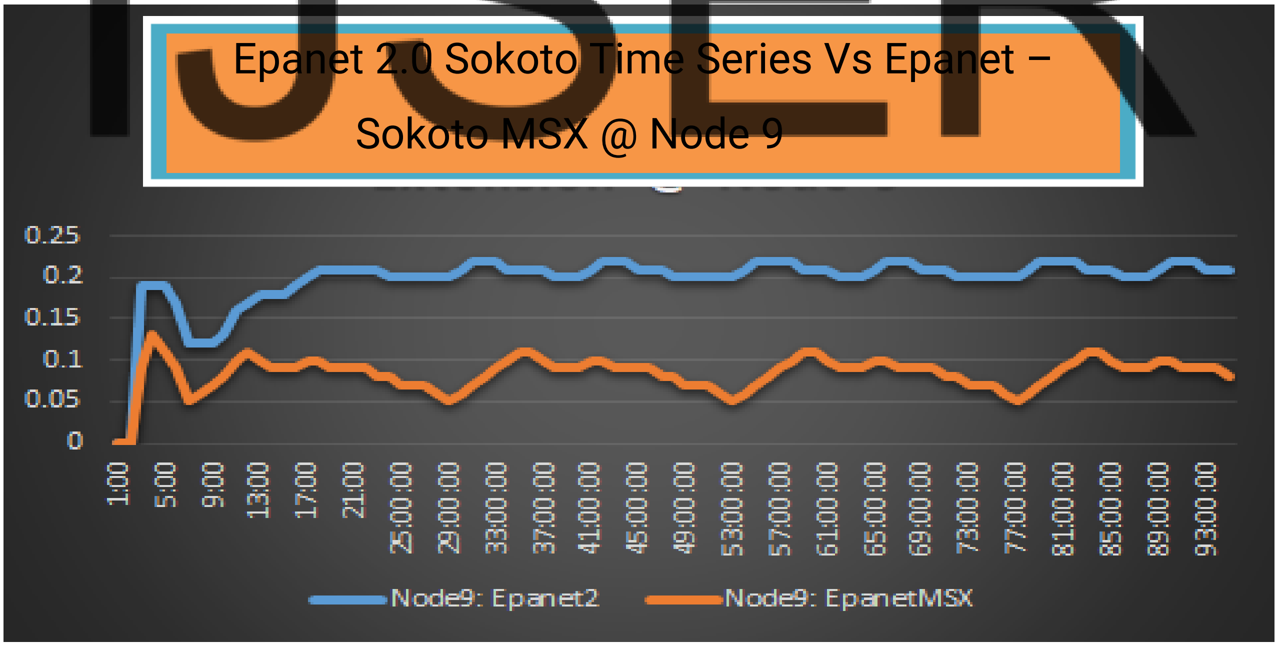

Figure 3.10: Plot of EPANET-MSX Sokoto chlorine results: depicting the extent of detailed chlorine species evolution at node 9.

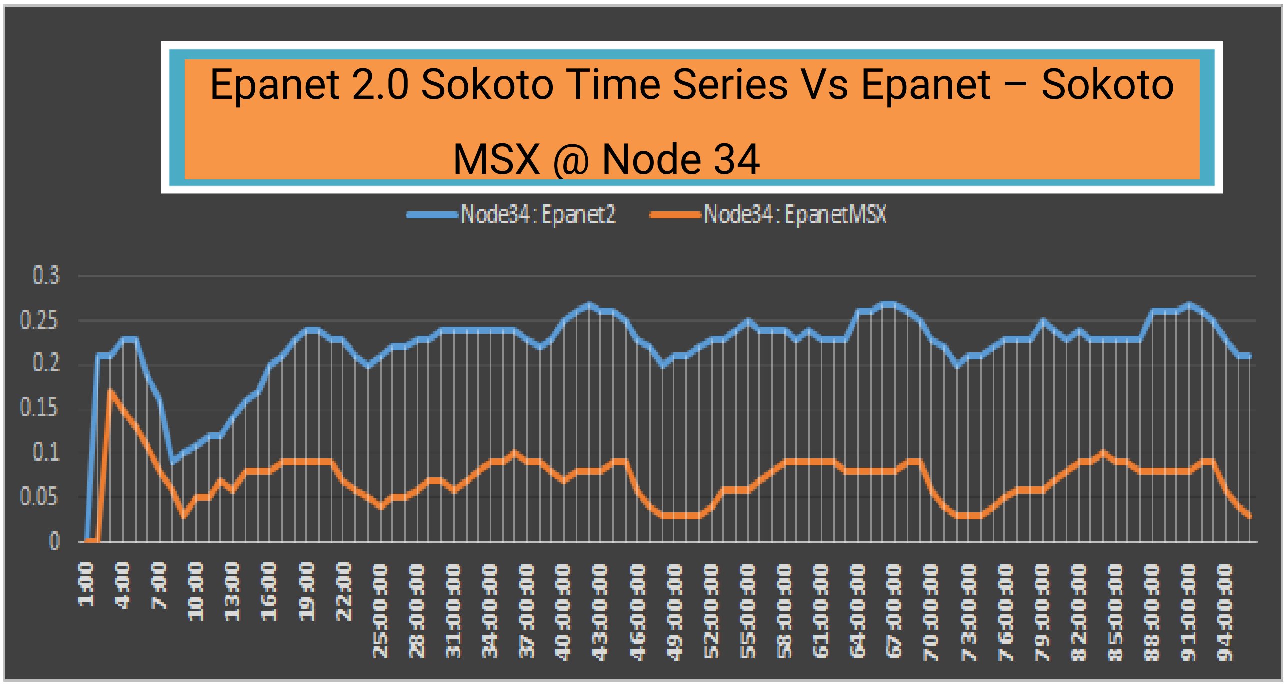

Figure 3.10.1: Plot of EPANET-MSX chlorine results: depicting the extent of detailed chlorine species evolution at node 34.

3.4: Ratification of EPANET 2.0 and EPANET Multispecies Extension Model for Sokoto

1. Epanet 2.0 model results obtained from the Sokoto water distribution network analysis through the application of existing Sokoto input node and link facts to Epanet2 hydraulic and water quality modeling software was initially marred by deficiency features in all hydraulic parameters and subsequent endorsement and acceptance after laborious and painstaking steps of tweaking and tinkering EPANET2 Sokoto chlorine results obtained and approved after the successful completion of calibration and validation of the observed and computed data, which gives R^2 0.908 and 0.648 respectively.

2. For the relatively common situation where more than one water source supplies a distribution system, EPANET 2 model are not able to represent meaningful differences

in source water quality, as they relate to water quality evolution in the distribution system. Such an approach has obvious deficiencies when attempting to model distribution system zones where sources blend together, and these zones are sometimes the focus of water quality issues. Most of water quality issues of this nature cannot be accurately modeled by using the single-species capabilities of the EPANET 2 program. This shortcoming provides the motivation to extend Epanet so that it can model reaction systems of any level. Therefore, Sokoto EPANET Multispecies Extension chlorine results obtained from the command line version of EPANET-MSX after a successful run of multispecies water quality analysis for Sokoto pipe network using Sokoto Epanet2 calibrated and validated data (during MSX input file sokoto.msx processing) is well represented. The hydraulic report preceding the water quality output gives the hydraulically balanced system for better performance in Sokoto multispecies water quality analysis, the results obtained depicts the influence of multiple, interacting chemical species in the network and the possible effect of available two water sources in the study area (River Rima and River Sokoto). The chlorine results are reflection of the complexity in other portent species and the effect of blending water sources as it influences the chlorine decay process.

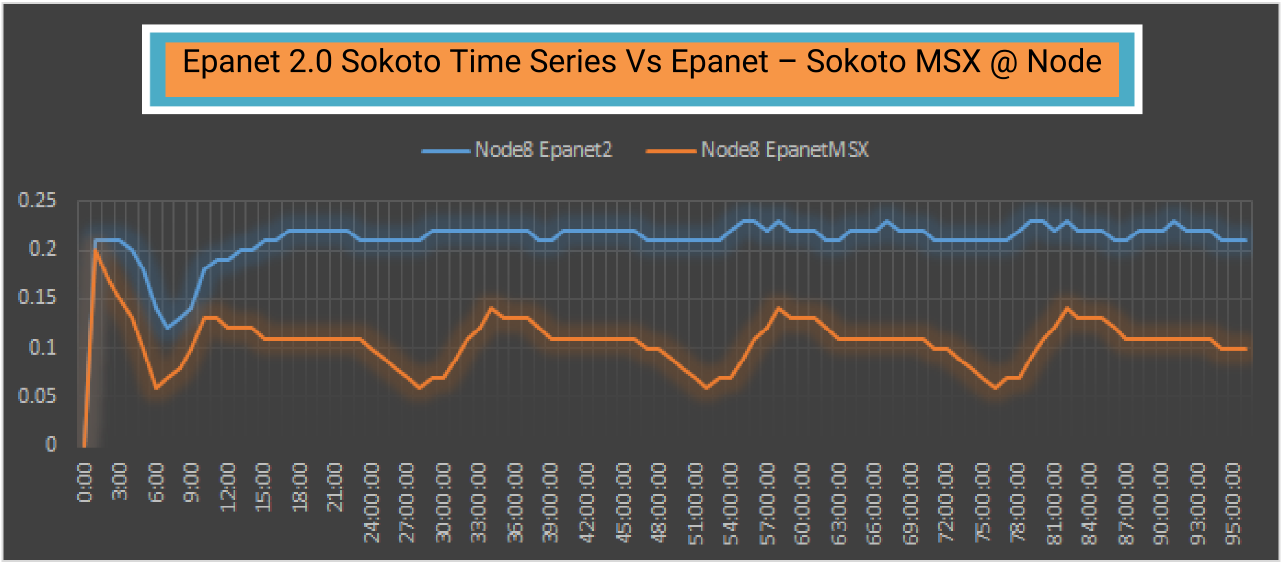

Figure 3.10.2: Plot of Epanet-MSX Sokoto chlorine results: depicting the extent of detailed chlorine species evolution at the most critical node.

3.5 Results of Temperature Effect on Chlorine Implementedinto Epanet-MSX Chlorine Values

Sokoto state is located in the Sokoto Rima River Basin at the north- western extreme of Nigeria. The land spreads between longitude 4° 11’ E to 6° 45’and Latitude 11°43’ N 13° 49’ N. it is a high temperate and tropic region, with its annual temperature oscillating between 30 °C to 45°C. Chemically speaking, water temperature is important due to its effects on copper solubility, the rate of corrosion, lead leaching from brass fixtures, bulk chlorine decay rate and formation of disinfection by-products. Higher water temperatures aggravate the corrosion of pipes. (Ljiljana *et al.* 2017).All the 120 samples tested for the study area, were within the range of 29°C and 32.6 °C at Unguwan Rogo and Kanwuri areas respectively. The lowest temperature value of 26 °C was recorded at Kofar Taramniya (3rd week) and highest temperature value of 38.4 recorded at Kofar Atiku area. Table 3.1 shows the extracted one drawback results for *chlorine vs tempt.*

EPANET-MSX water quality command line approach per hour at node 29, Figure 3.10.3 shows 6 hour variation of EPANET-MSX; chlorine cum temperature effect in Sokoto water distribution networks and Figure 3.10.4 clearly show EPANET-MSX, temperature effect on residual chlorine. The same results is replicated for nodes 8, 19 and 34. (Figures 3.10.3 – 3.10.4)

Table 3.1: EPANET-MSX Temperature Effect at Node 29

NODE 29: EPANET-MSX; TEMPERATURE EFFECT ON RESIDUAL CHLORINE						
Tempt. ºC	Cl_2 @ t_1	Cl_2 @ t_2	Cl_2 @ t_3	Cl_2 @ t_4	Cl_2 @ t_5	Cl_2 @ t_6
26	0.2	0.17	0.14	0.12	0.1	0.07
28	0.19	0.16	0.13	0.11	0.08	0.06
30	0.18	0.15	0.12	0.1	0.07	0.05
32	0.18	0.14	0.11	0.08	0.06	0.04
34	0.17	0.13	0.09	0.07	0.05	0.03
36	0.16	0.11	0.08	0.06	0.04	0.02
38	0.15	0.1	0.07	0.04	0.03	0.02
40	0.14	0.09	0.05	0.03	0.02	0.01
42	0.13	0.07	0.04	0.02	0.01	0.01
44	0.12	0.06	0.03	0.02	0.01	0

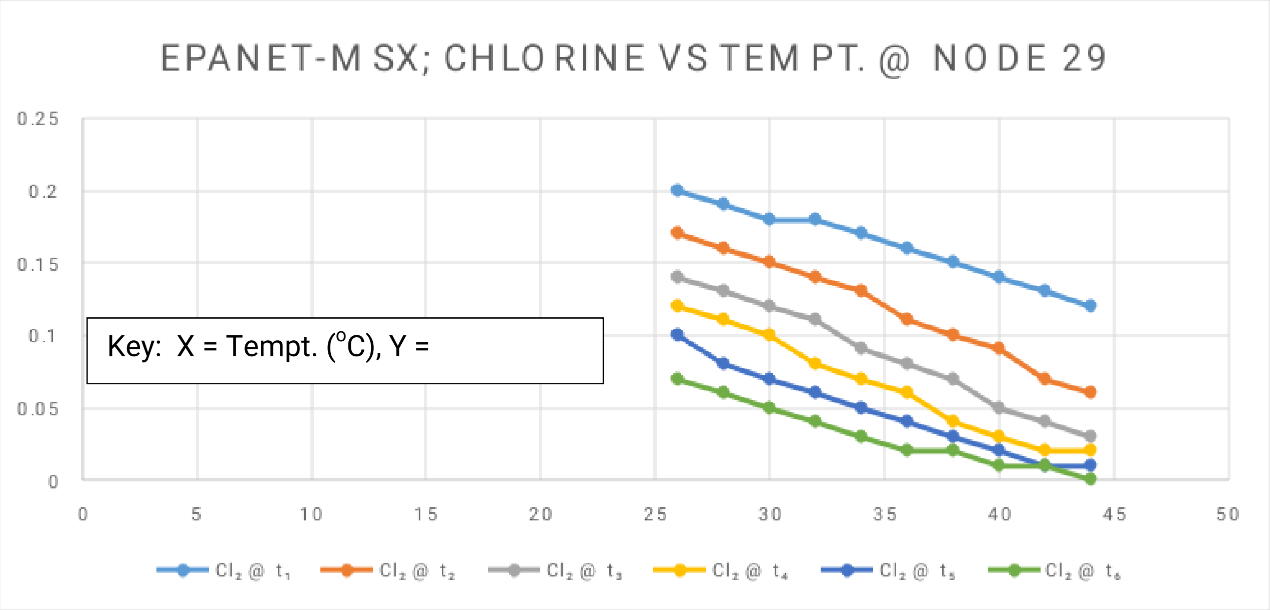

Figure 3.10.3: Hourly Variation of EPANET-MSX; Chlorine cum Temperature Effect.

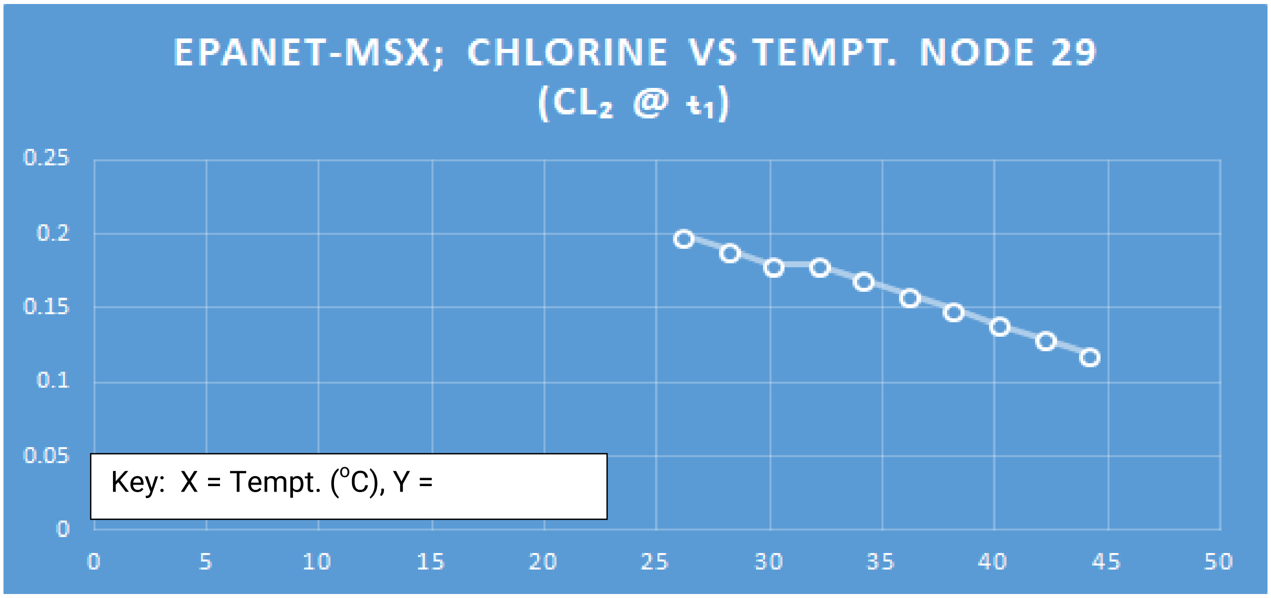

Figure 3.10.4: EPANET-MSX; Chlorine cum Temperature Effect.

Table 3.2 EPANEt-MSX Temperature Effect at Node 8

NODE 8: EPANET-MSX;TEMPERATURE EFFECT ON RESIDUAL CHLORINE

Tempt. °C	Cl_2 @ t_1	Cl_2 @ t_2	Cl_2 @ t_3	Cl_2 @ t_4	Cl_2 @ t_5	Cl_2 @ t_6
26	0.2	0.17	0.14	0.12	0.1	0.06
28	0.19	0.16	0.13	0.11	0.8	0.05
30	0.18	0.15	0.12	0.1	0.07	0.04
32	0.18	0.14	0.11	0.08	0.06	0.03
34	0.17	0.13	0.09	0.07	0.05	0.03
36	0.16	0.11	0.08	0.06	0.04	0.02
38	0.15	0.1	0.07	0.04	0.03	0.01
40	0.14	0.09	0.08	0.03	0.02	0.01
42	0.13	0.07	0.04	0.02	0.01	0.01
44	0.12	0.06	0.03	0.02	0.01	0

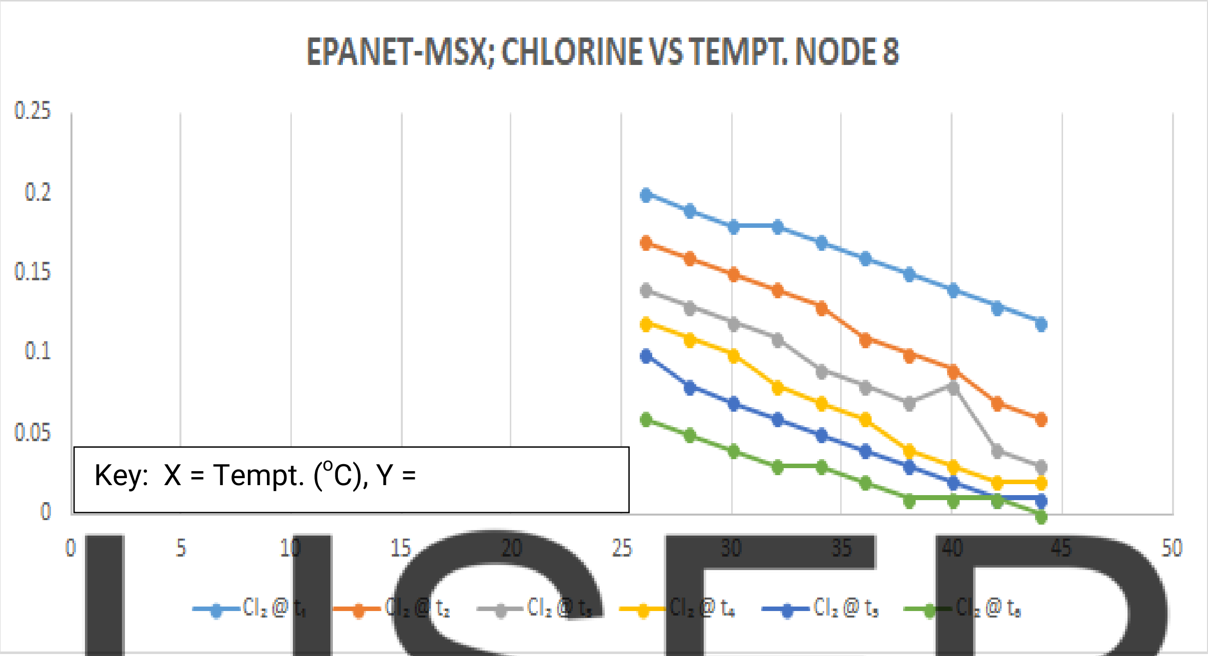

Figure 3.10.5: Hourly Variation of EPANET-MSX; Chlorine cum Temperature Effect.

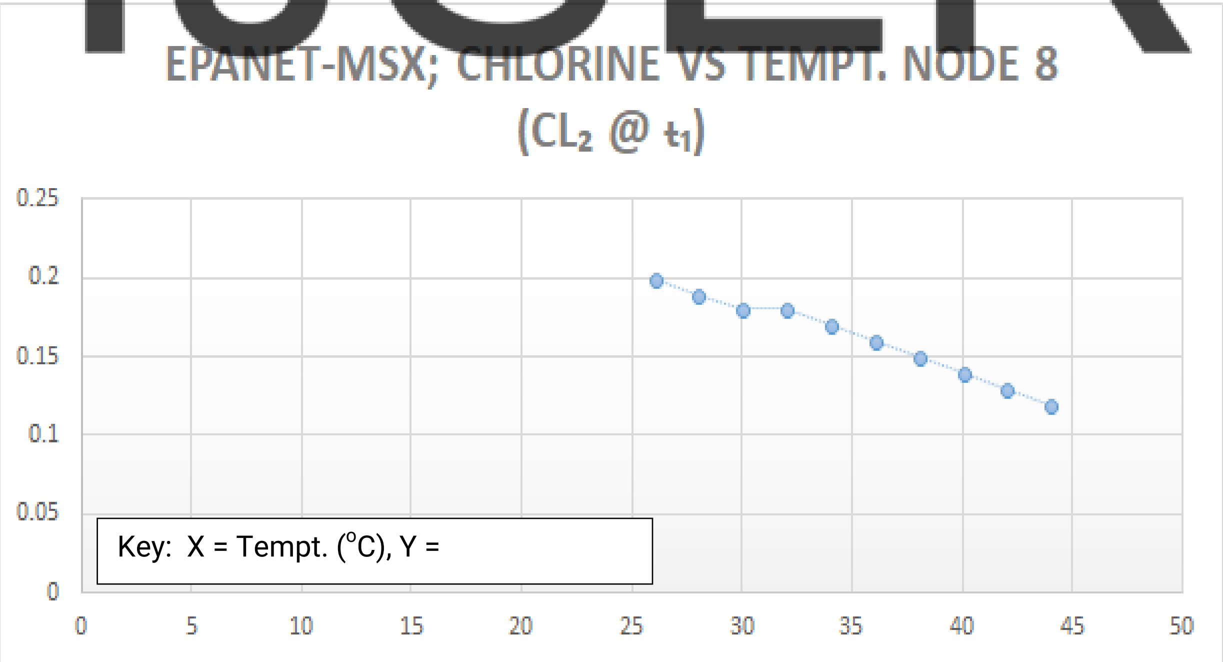

Figure 3.10.6: EPANET-MSX; Chlorine cum Temperature Effect.

Table 3.3 EPANET-MSX Temperature Effect at Node 19

NODE 19: EPANET-MSX;TEMPERATURE EFFECT ON RESIDUAL CHLORINE						
Tempt. ºC	Cl_2 @ t_1	Cl_2 @ t_2	Cl_2 @ t_3	Cl_2 @ t_4	Cl_2 @ t_5	Cl_2 @ t_6
26	0	0	0	0.08	0.11	0.09
28	0	0	0	0.07	0.09	0.08
30	0	0	0	0.06	0.08	0.06
32	0	0	0	0.05	0.06	0.05
34	0	0	0	0.05	0.05	0.04
36	0	0	0	0.04	0.04	0.03
38	0	0	0	0.03	0.03	0.02
40	0	0	0	0.02	0.02	0.01
42	0	0	0	0.02	0.01	0.01
44	0	0	0	0.01	0.01	0

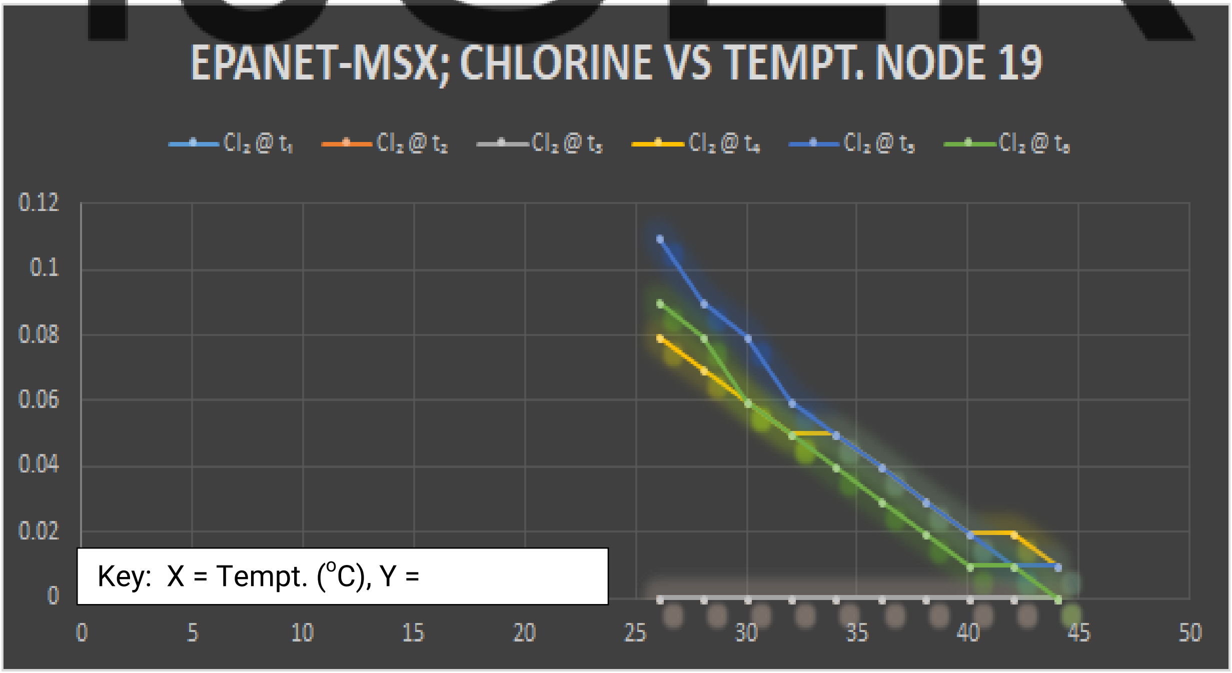

Figure 3.10.7: Hourly Variation of EPANET-MSX; Chlorine cum Temperature Effect.

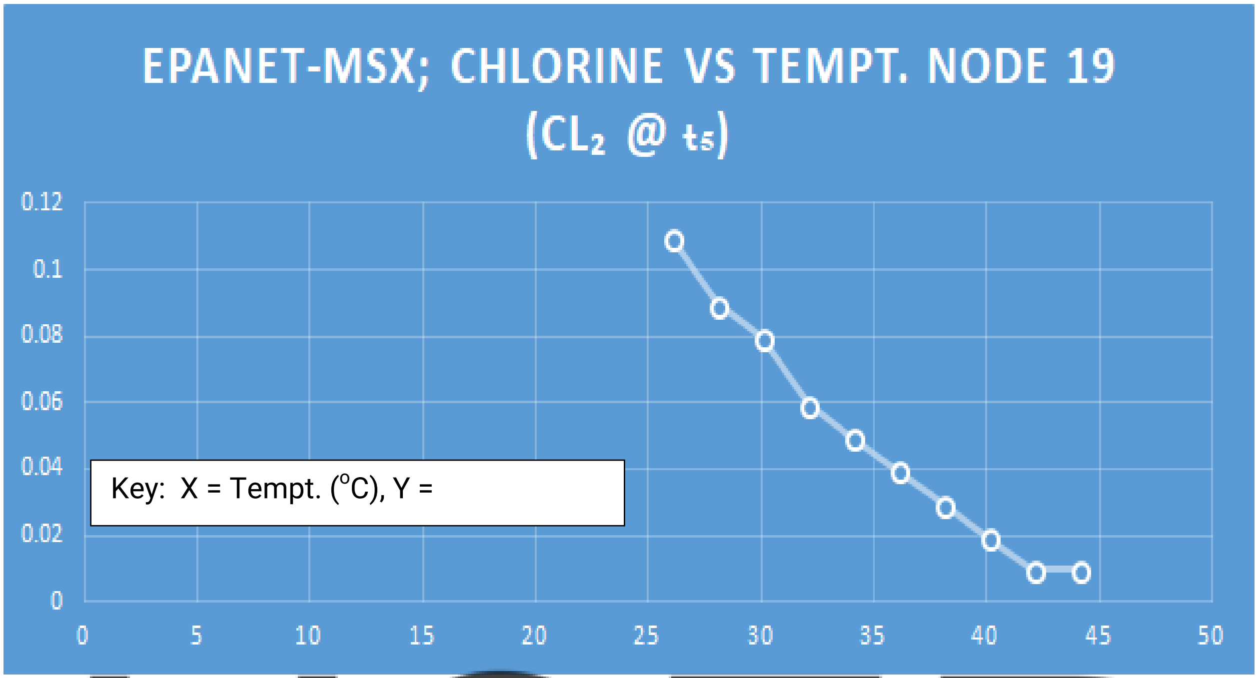

Figure 3.10.8: EPANET-MSX; Chlorine cum Temperature Effect.

Table 3.4 EPANET-MSX Temperature Effect at Node 34

NODE 34: EPANET-MSX;TEMPERATURE EFFECT ON RESIDUAL CHLORINE						
Tempt.°C	Cl_2 @ t_1	Cl_2 @ t_2	Cl_2 @ t_3	Cl_2 @ t_4	Cl_2 @ t_5	Cl_2 @ t_6
26	0	0.17	0.14	0.12	0.1	0.07
28	0	0.16	0.13	0.11	0.09	0.06
30	0	0.15	0.12	0.1	0.08	0.05
32	0	0.14	0.11	0.08	0.06	0.04
34	0	0.13	0.09	0.07	0.05	0.03
36	0	0.11	0.08	0.06	0.04	0.02
38	0	0.1	0.07	0.04	0.03	0.02
40	0	0.09	0.05	0.03	0.02	0.01
42	0	0.07	0.04	0.02	0.01	0.01
44	0	0.06	0.03	0.02	0.01	0

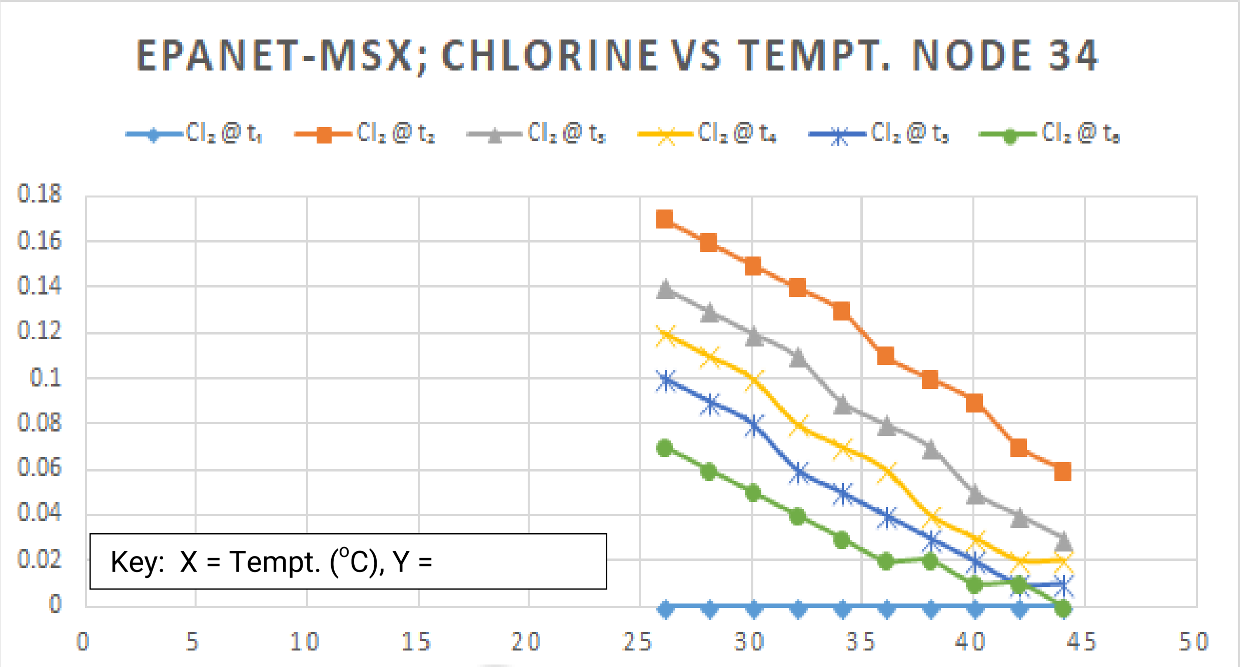

Figure 3.10.9: Hourly Variation of EPANET-MSX; Chlorine cum Temperature Effect.

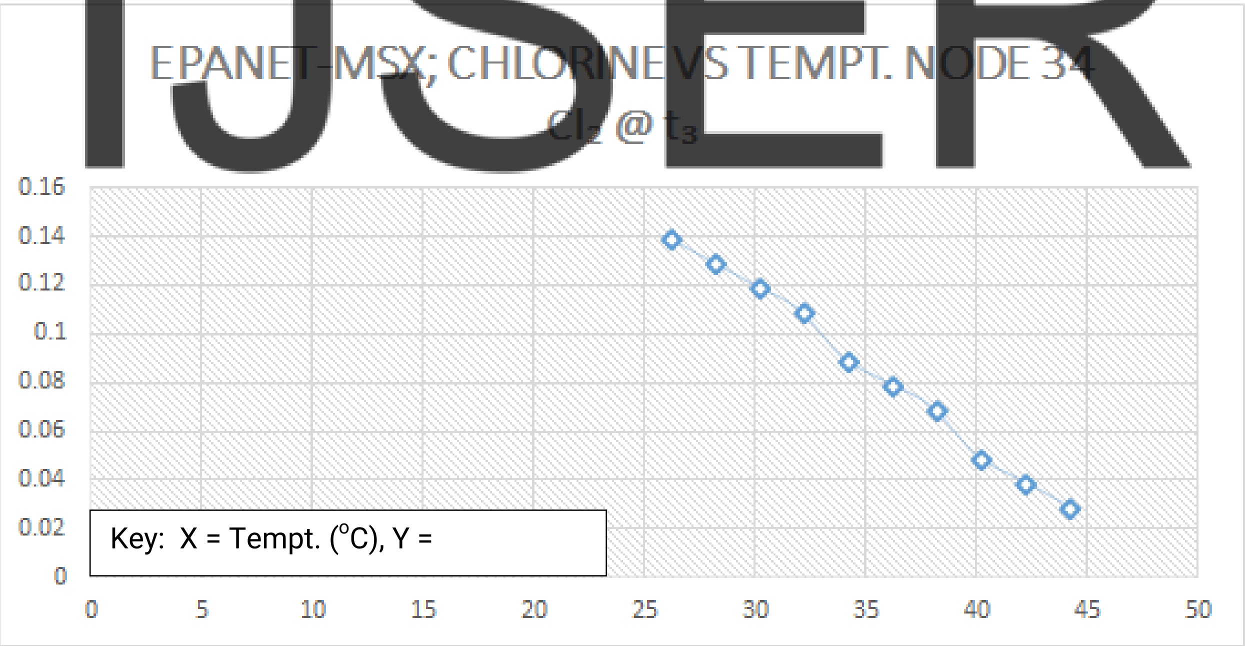

Figure 3.11: EPANET-MSX; Chlorine cum Temperature Effect.

4.0 CONCLUSIONS AND RECOMMENDATIONS:

4.1 CONCLUSIONS

1. The chlorine evolution simulation for the validated data was performed with command line version of EPANET-MSX and correlation with Epanet 2.0 for best performance.
2. Temperature effect on residual chlorine in Sokoto water distribution was implemented into EPANET-MSX.

4.2 Recommendations

1. There should be urgent integration of EPANET-MSX into the windows version of EPANET 2.0 for reliability motivated outcomes.
2. That, the software be made flexible enough to permit adjustment and tweaking of some of its properties, especially for some countries with peculiarities of intermittent water supply systems.
3. Water supply providers should use EPANET-MSX for the implementation of temperature effect on residual chlorine during the planning stage to avert waterborne infectious diseases in there distribution networks.

4.3 Contribution To Knowledge

1. Sokoto chlorine evolution simulations was developed with command line version of EPANET-MSX, which provide more detailed settings of chlorine decay.

2. Dual water supply source for a distribution system may have affects the water quality outcomes of EPANET-MSX and the research also discovered EPANET 2.0 to be more suitable in relation to the measured values at the locations.
3. Effect of temperature on residual chlorine within water distribution network was discovered and implemented in EPANET-MSX.

5.0 References

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