Preservation of Required Chlorine Concentration in Baghdad Water Supply Networks using On-Site Chlorine Injection

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Abstract

The chlorine concentration variation in Baghdad water networks was studied. The chlorine data were collected from Mayoralty of Baghdad and Ministry of Environment (MOE) for the networks for both sides of the city Karkh and Rasafa for (2008-2009). The study of these data indicates that there are no systematic testing program .Classified GIS maps showed that the areas far from the treatment plants have almost always low chlorine concentration .This indicates that the problem of the low chlorine concentration in the far areas is due to cracks of pipe along the conveyance path ,as expected. The area's most frequently have low concentration are Al-sadir,Al-Kadhimya, and Al-Amiria . It was found also that the chlorine concentrations were lowest in summer months than those in winter months.The Amiria area district (636) was selected as a case study to test the ability of using the quantitative- qualitative model in the EPANET software, to find the required onsite chlorine injection point number, locations and dose, so as to raise the chlorine concentration to the acceptable limits in the other nodes of the network. The bulk decay coefficient was found to be (-2.212)1/day and the wall coefficients were found to be between (-0.001)to(-0.9)1/day The main conclusion of this study is that the onsite injection can improve the chlorine concentration in Baghdad water supply networks. The EPANET model can be used effectively to obtain the required injection program for this purpose.

الخلاصة

حفظ تركيز الكلور المطلوب في شبكات مياه الشرب في بغداد بأستعمال حقن الكلور في الموقع .

في البحث تم دراسة تلوث المياه في شبكات ماء بغداد من ناحية تركيز الكلور المتبقي فقط. ثم جمع المعلومات والخرائط الخاصة بشبكات المياه ومشاريع التصفية في بغداد من الكرخ والرصافة .كما تم جمع البيانات الخاصة بقياسات تركيز الكلور في تلك الشبكات من الجهات التي لهاعلاقة (وزارة البيئة وأمانة بغداد) وتم توحيدها في نظام المعلومات الجغرافية(GIS). البيانات المتوفرة لسنتين (2008-2009).

من خلال دراسة تلك البيانات تبين عدم وجود نظام قياسات متبع لاجراء القياسات في أوقات محددة أو أماكن محددة ،ولكن هناك مبدأ عام هو أن يكون هناك قياس واحد على الاقل شهريا. أما من ناحية الاماكن التي يتم فيها القياس فأن المبدأ العام المتبع من قبل تلك الجهات هو تغطية جانبي الكرخ والرصافة قدر الامكان شهريا.

بين التحليل لتلك البيانات والخرائط المنتجة بنظام المعلومات الجغرافية بأن أكثر المناطق تلوثا هي المناطق الواقعة في أطراف المدينة مما يوكد بأن سبب المشكلة هي ما يطرأ من مشاكل على المياه أثناء عملية جريان المياه في الانابيب وكلما زادت المسافة كلما زاد أحتمال التلوث وبالتالي نقصان تركيز الكلور. من تلك المناطق مدينة الصدر ،الكاظمية ،العامرية.كما بين التحليل أن تركيز الكلور في فصل الصيف يكون أقل منه في الشتاء.تم أختيار منطقة العامرية (جزء من الشبكة فيها) محلة (636) كحالة دراسية لاختبار أمكانية أستخدام نموذج النوعية – الكمية الموجود في برنامج (EPANET) لايجاد نقاط الحقن الموقعي بالكلور وكمية الجرعة بحيث ترفع نسبة الكلور في نقاط تلك الشبكة الى 0,5 ملغم/لتر أو اعلى بقليل.قبل أمكانية تطبيق البرنامج يتطلب حساب معامل التحلل العام (Bulk decay coefficient) ومعامل التحلل بجدار الانبوب (Wall decay coefficient). لحساب المعامل الاول جمعت عينات من الماء تم فحصها باوقات مختلفة لايجاد تغاير تركيز الكلور مع الزمن ومن ثم تم أيجاد المعامل على انه انحدار المنحني ()$\frac{C_t}{C_0}$ مع الزمن (t) وقد كانت قيمته (2.212-)1\day.أما بخصوص حساب معامل التحلل لجدار الانبوب فقد تم أولا أجراء قياسات حقلية لتركيز الكلور في الشبكة المستخدمة كحالة دراسية في 17 نقطة ولمدة (6) أشهر وتم حساب معامل الجدار باستخدام طريقة المحاولة والخطأ بأستخدام البرنامج (EPANET) حيث يضخ البرنامج في نقطة المصدر بالقيمة المقاسة ويحسب بالنقاط الاخرى بأستخدام قيم مفروضة ويتم تعديلها الى ان تتطابق القيم المقاسة مع القيم المحسوبة بالبرنامج .أعتمد مبدأ مجموع مربعات الفروق بين القيم المقاسة والقيم المحسوبة.قد بينت النتائج أن قيم معامل التحلل للجدارتتراوح بين -0.9 to - 0.001)1/day.

تم تطبيق البرنامج EPANET لايجاد نقاط الضخ الموقعي للكلور على حالة معدل الجريان اليومي وتم استخدام عدة حالات ادرجت منها افضل حالتين .حالة (A)حيث ان نقطة ضخ الكلور الموقعي في نقطة رقم (5) وخلال فترتين في اليوم من الساعة 7-11 صباحا ومن الساعة 4-8 مساءا وبجرعة (1.5) ملغم/لتر .أما الحالة (B) بنفس النقطة ونفس الفترة ولكن بجرعة قدرها (0.8) ملغم/لتر. أظهرت النتائج بأن الحالة (A) هي الافضل لكونها ترفع تركيز في تلك الفترات في النقاط المختلفة للشبكة الى قيمة تقع ضمن الحدود المقبولة لتركيز الكلور وهي (2-0.5) ملغم/لتر.ولكن يجب الاشارة الى انه أن كان هناك تلوث كبير في الشبكة الحالة (A)هي المفضلة أما في حالة التلوث القليل فأن الحالة (B) هي الافضل .

Key word: Water ,Supply ,Network , EPANET , Geographical ,Information ,System , Sectoral, Chlorine, Injection .

Introduction

As it is well known, Baghdad is one of the largest cities in the middle east. During the last three decades the city was subjected to large extension which effects the level of infra-structure services such as water supply networks. Due to wars and sanction these old networks were subjected to deterioration, Such as many cracks in pipes and leakage. These factors had resulted many water pollution detected in the networks. in order to solve this problem large maintenance efforts and pipes changing are required . This solution is rather expensive and needs large efforts and may disturb the life activities and traffic movement specially in old crowded areas near the center of the city .An inexpensive solution is required to improve the water quality in these networks by using onsite injection of chlorine in a selected points and with the required dosage. In order to evaluate such solution a quantitative qualitative water model is required. Using such model the required number of these injection points their locations and the proper chlorine dosage can be found. There are many water quality testing points in the networks of Baghdad available from the Ministry of Environment (MOE) and Mayoralty of Baghdad .These testing points can be used to classify the water quality in Baghdad networks using GIS. The water quantitative qualitative model can be built to evaluate the effectiveness of an onsite injection program using one of the areas as a case study , where a low chlorine concentration is deducted and classified through the GIS model.

Previous Studies:

Islam and Chaudhry (1997), had presented. The Surface Water Treatment Rule under the Safe Drinking Water Act and its amendments require that the water utilities maintain a detectable disinfectant residual throughout the distribution system at all times. A computer model was presented to directly calculate the chlorine concentrations needed at the source(s) to have specified residuals at given locations in a pipe network in unsteady flow conditions by using an inverse method.

Rossman,et .al. (1994), had presented, a mass-transfer-based model developed for predicting chlorine decay in drinking-water distribution networks. The model considers first-order reactions of chlorine to occur both in the bulk flow and at the pipe wall.

Clark, et.al.(1988), had presented . The Safe Drinking Water Act (SDWA) of 1974 requires that the U.S. Environmental Protection Agency (EPA) establish maximum contaminant levels (MCLs) for each contaminant which may have an adverse effect on the health of persons. The approach suggested in this research will provide useful insight into the water quality variations that may impact consumers at the tap and the development of time and spatially sensitive monitoring strategies.

Clark, et.al. (1993). Had presented, that the Safe Drinking Water Act and its Amendments (SDWAA) will pose a massive challenge for the drinking-water industry in the United States. As the SDWAA regulations reach implementation, increasing effort will be devoted to understanding the factors causing deterioration of water quality between treatment and consumption. Models are used to predict the propagation of chlorine residual in one portion of the water supply system. It was found that residuals varied widely both spatially and temporally.

Shang, and et.al. (2002), had presented, it was a novel input-output model of water quality in water distribution systems .presented as a particle (water parcel) backtracking algorithm (PBA). The PBA is a simpler and more efficient version of that described by **Zierolf and et.al. (1998)** and is extended to allow storage tanks and multiple water sources and quality inputs.

Zierolf , (1998), had presented ,that chlorine concentrations within drinking water distribution system (DWDS) must be maintained between an Environmental protection agency enforced minimum and maximum values driven by formation of harmful disinfectant byproducts .The DWDS input-output (I-O) model developed expresses the chlorine concentration at a given pipe junction and time as a weighted average of exponentially decayed values of the concentrations at all adjacent upstream junctions.

Dominic and et. al:(1998), had presented, that a booster disinfection is the addition of disinfectant at location distributed throughout a water distribution system. such a strategy can reduce the mass of disinfectant required to maintain a detectable residual at points of conception in the distribution system.

Rossman, and et.al. (1993), had presented. An explicit dynamic water-quality modeling algorithm developed for tracking dissolved substances in water-distribution networks. The algorithm is based on a mass-balance relation within pipes that considers both advective transport and reaction kinetics.

Boulos and et.al.(1995), had presented , an efficient system simulation methodology that solves the contaminant-transport problem in drinking-water-distribution systems is developed. **Islam and chaudhry (1998)**,had presented ,a new computer model is presented to predict the spatial and temporal distribution of residual constituent in a pipe network under slowly varying unsteady flow conditions.

Geographical Information System Analysis

Baghdad has a large water supply networks. These networks could be an old one, or relatively new one. As these networks ,were constructed in different times ,different pipe types were used ,such as ductile ,asbestos ,p.v.c ,and others. Since many of these networks were subjected to deterioration due to sanction and wars ,it has many defects such as leaks and interference with sewerage water ,which cause water contamination in these networks. Due to the problem of local contamination of the water in the networks because of the defects mentioned above ,and as traditional monitoring system for water quality related authorities were conducting a water testing program. Amanat Baghdad and Ministry of Environment (MOE) are the main water quality monitoring authorities for Baghdad water supply systems. There are no systematic clear testing program for water testing in the city, i.e. no certain time period for the frequency of testing. However it can be approximately considered that the testing program is on monthly measurements basis. In addition, the testing program may be affected by a call from the ministry of health, if water borne disease is recorded in a certain location. Moreover testing points and frequency were increased at the areas, where the network is considered as old.The chlorine data available for the water quality in Baghdad networks are as shown in table (1) below.

The locations of measurements were randomly distributed. Upon discussion with the testing teams of Amanat Baghdad and the Ministry of Environment (MOE), the researcher observed the followings.

1- There is no coordination between the two – teams of both autherties.

2- Even though the testing locations were selected randomly, both teams clarify that, their concept of testing location selection is trying to cover the areas of the city ,in both sides karkh and Rasafs each month.

3- Sometimes the location of testing is selected accoarding to claims of citizens in a certain area of bad water quality water ,or due to a notice from the Ministry of Health (MOH). The GIS analysis was conducted for two years (2008to 2009),where the data is available.Fig(1) shows the chlorine distribution in Baghdad water supply networks.This GIS map includes all the data collected during 2008. This shows that the chlorine concentration is less than 0.5 mg/L, for (4.167) %of the area of Baghdad. Figs (2) and (3) shows the GIS map of chlorine concentration in year 2008 in winter and summer respectively. It is clear from comparison that the case is better in winter than that in summer. The percentages of area of chlorine less than 0.5 mg/L are (1.827)% and (5.676)% respectively.Figs (4), (5) shows the GIS map of chlorine concentration in year 2009 in winter and summer respectively. Same condusions as in year 2008 could be concluded that the case is better in winter than in summer. The percentages area of less than 0.5 mg/L chlorine concentrations are (0.989) % and (1.582) % respectively. Fig (6) shows the chlorine distribution in Baghdad water supply networks, for year 2009.

Experimental Work ,and EPANET Modeling For Onsite Chlorine injection .

From the GIS analysis presented in the previous section , any location had introduced chlorine concentration less than 0.5mg/L during, any periods in years 2008and 2009, can be used as a case study for the onsite chlorine injection presentation. One of these locations were selected as a case study, that is district 636 in the karkh side, Al-Amiria .The water supply network at this district is shown in fig (7)

A site testing program for chlorine concentration was conducted during six month in 2009; Jan; Feb; March (winter), and (June, July, and August), summer. Tables (2) and (3) show the locations, NE coordinates, pipes and nodes details, and the chlorine concentration during the six months. Table (5) shows the average and standard deviation of chlorine concentration in each node.

The measurements were conducted using portable chlorine concentration measuring device (ELAMOTTE,OCTA-SLIDE.CODE1100) .In order to apply the EPANET model for the case study ;the bulk decay coefficient of chlorine should be estimated .The measurement were conducted using 16 samples collected .

The measured chlorine concentration is then calculated in different times as shown in Table(6).

1- Bulk Decay Coefficient:
Referring to table (6) the data of log(c_1/c_o) versus time is plotted as shown in fig(8) the slope of this line (-2.212)/day is the bulk decay coefficient .

2- Wall Decay Coefficient
The wall decay coefficient can be estimated using EPANET by a trial and error approach. This can be accomplished by assuming a wall decay coefficient for all or, each pipe. Then after running the hydraulic and quality analysis using EPANET ,the chlorine concentration in the other nodes could be estimated .IF these values compare well with the measured values ,the assumed wall decay coefficients were considered as the real values .IF these values were significantly different ,adjustment of the assumed values were done until a good match was obtained . Table (7) shows the final wall decay coefficients for each pipe of the case study .They are estimated using average measured concentration values on table (5)of summer months (June,July,August). Fig (9) shows the comparison between measured and estimated values which shows good match.

In order to find the location (s) of the required injection points and the required injection dose and patterns the EPANET water quality model is used. This model is used for the expected hydraulic condition of the network. The hydraulic pattern is either constant daily demand (average), or daily variation demand pattern. In order to apply the EPANET model for the network of the case study the values of the Bulk Decay coefficient and the wall Decay Coefficients of the pipes are fed to the software. After which different onsite injection proposals are tried to find which proposal is useful to raise the chlorine concentrations at the nodes of the network case study to an acceptable one. Since the operation base is daily, the concept is to use injection pattern to raise the chlorine concentrations to these acceptable values during the hours of high use of water. For the case of presentation two cases were selected .Fig, (10) shows the node numbering system of the case study network.

1- aseA:Injection of Chlorine at node 5 with 1.5 mg/lit dose for the 4 hrs from (07-11)am and 4hrs (4-8) pm.The results of the chlorine concentrations at different nodes are shown in figures (11) to (20) below. It is obvious from these figures that the injection raise the chlorine concentrations to an acceptable values for all the nodes. **(Note that the time axis start at 6.00Am in these Figures)**

2- 2-Case B :Injection of Chlorine at node 5 with 0.8 mg/lit dose for the 4 hrs from (07-11)am and 4hrs (4-8) pm.The results of the chlorine concentrations at different nodes are shown in figures (21) to (30) below. It is obvious from these figures that the injection raise the chlorine concentrations to an acceptable values for all the nodes.

3- Comparing the two cases indicates that the first case is preferable since at most nodes most of the concentration are within (0.5-2)mg/lit. However, for high contaminated water case (A) is the better, while for low contamination case (B) is preferable. Table (8) shows the concentrations at the nodes for the two cases.

Conclusions.

1. There is no obvious chlorine testing program for Baghdad water networks adopted by the responsible Authorities. However concerning temporal variation, one can say the testing is on monthly basis. Random spatial test selection locations is selected by these authorities trying to cover Karkh and Rasafa each month. Moreover there are no any coordination between the two authorities responsible for this testing.
2. Geographical Information System analysis for Baghdad water networks chlorine concentrations had indicated the followings.
   a) The number of locations of low chlorine concentration is increased in summer months than those in winter, due to chlorine depletion.
   b) The most frequent areas of low chlorine concentration are at Al-sader, Al- Zafarinia, Al-Kadhimia, and Al-Amiria .
   c) The areas of low chlorine concentrations usually located distances far from the treatment plants, which indicates that this low concentrations is due to conveyance problems.
3. The Experimental work indicated that the Bulk decay coefficients for the water network of the selected case study (Al-Amiria network) is (-2.212)/ day.
4. The wall decay coefficient found using EPANET for all the pipes of the network case study is within the range (-0.001 to -0.9).

   EPANET model can be used to find the injection strategy for the selected network. Application of the onsite injection for the network of the case study is used using two cases A and B. For case A the injection at node 5 with 1.5 mg/lit dose of chlorine within two periods during the day each for 4 hrs. The first is for (7 to 11) am and the second for (4-8) pm. For case B the injection is at the same node and periods, but with a dose of 0.8 mg/lit. The results indicates that case A is preferable since it raise the chlorine concentration to values within the acceptable limits of (0.5 to 2) mg/lit.

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Table(1) chlorine Data used for GIS classification :

Year	Months	Average No.of location
2008	Jan,Fab,Mar,April,May,June,July,October,November.	1250
2009	Jan,Fab,Mar,April,May,June,July,August,September,October,November.	930

Table (2) Field Testing Chlorine Measurement

Nods No.	East North	Chlorine conc. Mg/l Jun	Chlorine conc. Mg/l July	Chlorine conc. Mg/l Augusts	Chlorine conc. Mg/l Jan	Chlorine conc. Mg/l Feb	Chlorine conc. Mg/l March
1-	44.17.17,1 33.18.10	0.6	0.5	0.6	1.5	1.1	1
2-	44.17.06,8 33.18.06,8	0.55	0.45	0.58	1.4	0.9	0.6
3-	44.17.03,6 33.18.09,8	0.5	0.4	0.5	1	0.8	0.7
4-	44.16.54,2 33.18.05,6	0.48	0.36	0.49	0.7	0.5	0.6
5-	44.16.50,4 33.18.04,3	0.45	0.32	0.45	0.5	0.1	0.2
6-	44.16.51,4 33.18.04,4	0.42	0.3	0.42	0.3	0.2	0.2
7-	44.16.55,6 33.18.01,9	0.4	0.27	0.4	0.6	0.4	0.3
8-	44.16.55,6 33.17.58,8	0.37	0.25	0.36	0.5	0.1	0.4
9-	44.16.54,1 33.17.56,0	0.35	0.2	0.32	0.3	0.2	0.1
10-	44.16.51,6 33.17.59,9	0.3	0.18	0.3	0.4	0.3	0.2
11-	44.16.49,3 33.18.02,9	0.38	0.39	0.39	0.48	0.35	0.3
12-	44.16.51,1 33.17.55,6	0.2	0.12	0.25	0.45	0.45	0.2
13-	44.16.46,5 33.18.01,7	0.35	0.29	0.32	0.45	0.45	0.4
14-	44.16.43,4 33.18.00,8	0.32	0.25	0.32	0.4	0.35	0.45
15-	44.16.41,0 33.17.59,3	0.28	0.23	0.29	0.37	0.4	0.45
16-	44.16.46,7 33.17.52,0	0.08	0.05	0.1	0.3	0.49	0.49
17	44.16.50,0 33.17.50,5	0.19	0.11	0.23	0.25	0.4	0.45

Table (3) Pipe Details of the Case Study

Pipe No.	Dia mm	Length m
1-	100mm	300m
2-	100mm	100m
3-	100mm	260m
4-	100mm	50m
5-	75mm	40m
6-	75mm	160m
7-	75mm	60m
8-	75mm	60m
9-	75mm	120m
10-	75mm	100m
11-	100mm	150m
12-	75mm	220m
13-	75mm	280m
14-	100mm	50m
15-	100mm	280m
16-	75mm	50m
17-	100mm	50m
18-	100mm	50m

Table (4) Nodes Details of the Case Study

Node No.	Number of the Served person	Estimated Average Demand Liter/min
2-	29	5.03472
3-	7	1.21528
4-	7	1.21528
5-	6	1.04167
6-	8	1.38889
7-	10	1.73611
8-	4	0.69444
9-	7	1.21528
10-	7	1.21528
11-	12	2.08333
12-	14	2.43056
13-	13	2.25694
14-	14	2.43056
15-	7	1.21528
16-	8	1.38889
17-	13	2.25694

Table (5) Average and Standard Deviation of the Measured Chlorine Concentration in the Nodes of the Network Case Study

Node	Av: Conc:	Standard déviation	Av summer
1-	0.883333	0.386868	0.566667
2-	0.746667	0.35393	0.526667
3-	0.65	0.225832	0.466667
4-	0.521667	0.116003	0.443333
5-	0.336667	0.159583	0.406667
6-	0.306667	0.098522	0.38
7-	0.395	0.115542	0.356667
8-	0.33	0.138275	0.326667
9-	0.245	0.094604	0.29
10-	0.28	0.08	0.26
11-	0.381667	0.059133	0.386667
12-	0.278333	0.139344	0.19
13-	0.376667	0.067429	0.32
14-	0.348333	0.06969	0.296667
15-	0.336667	0.083347	0.266667
16-	0.251667	0.204491	0.076667
17-	0.271667	0.129061	0.176667

Table (6) Chlorine Concentration Tested at Different Times.

Time hr.	Chlorine conc. Mg/L
0	0.7
1.5	0.65
3	0.6
4.5	0.55
6	0.45
7.5	0.4
9	0.35
10.5	0.32
12	0.3
13.5	0.27
15	0.25
16.5	0.22
18	0.2
19.5	0.15
21	0.1
22.5	0.07

Table (7) Pipes Wall Decay Coefficients

Pipe No.	Wall decay coefficient
1	-0.2
2	-0.9
3	-0.1
4	-0.1
5	-0.5
6	-0.02
7	-0.5
8	-0.01
9	-0.01
10	-0.10
11	-0.50
12	-0.50
13	-0.20
14	-0.70
15	-0.001
16	-0.01
17	-0.90
18	-0.10

Table (8) Obtained Chlorine Concentrations at the Nodes for the Two Cases

Node Number	Chlorine Concentration Mg/lit case A	Chlorine Concentration Mg/lit case B
1	0.566	0.566
2	0.526	0.526
3	0.47	0.47
4	0.44	0.44
5	1.5	0.80
6	1.39	0.74
7	1.27	0.68
8	1.15	0.61
9	0.98	0.51
10	1.02	0.49
11	1.5	0.66
12	0.7	0.39
13	1.23	0.78
14	1.11	0.59
15	0.98	0.51
16	0.61	0.35
17	0.61	0.33

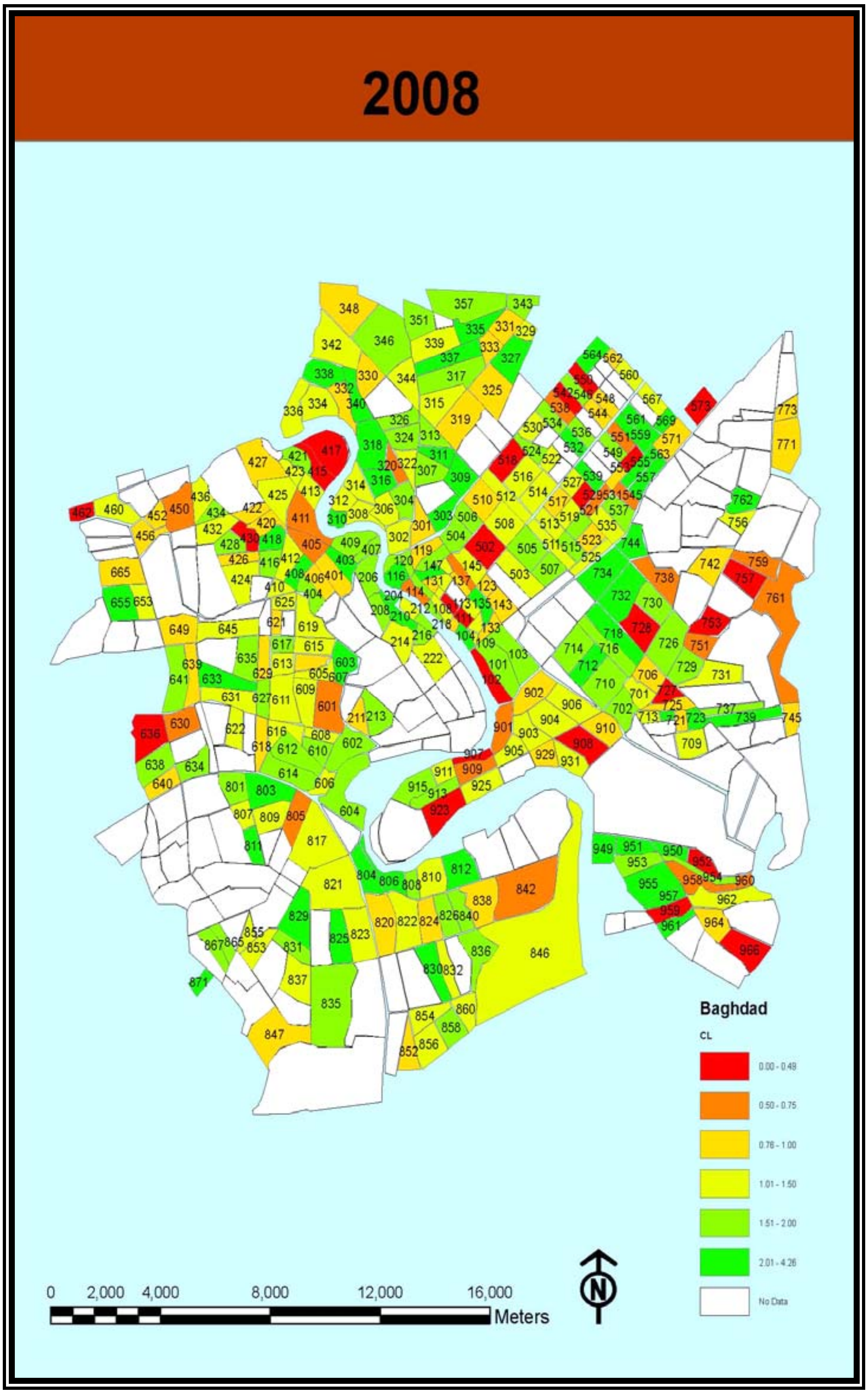


Fig (1) Residual chlorine distribution in Baghdad water supply Networks Year, 2008.

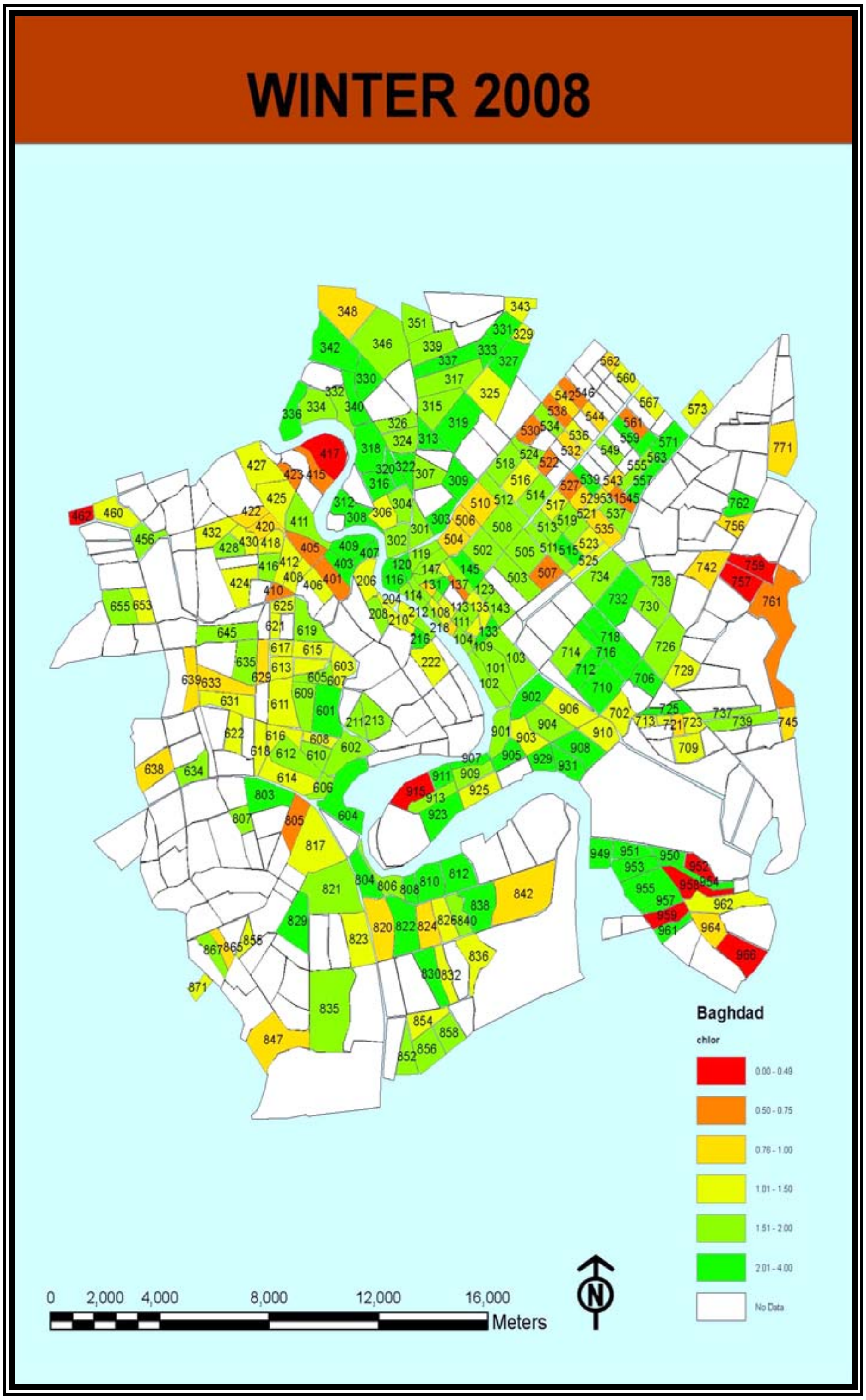


Fig (2) Residual chlorine distribution in Baghdad water supply Networks Win, 2008.

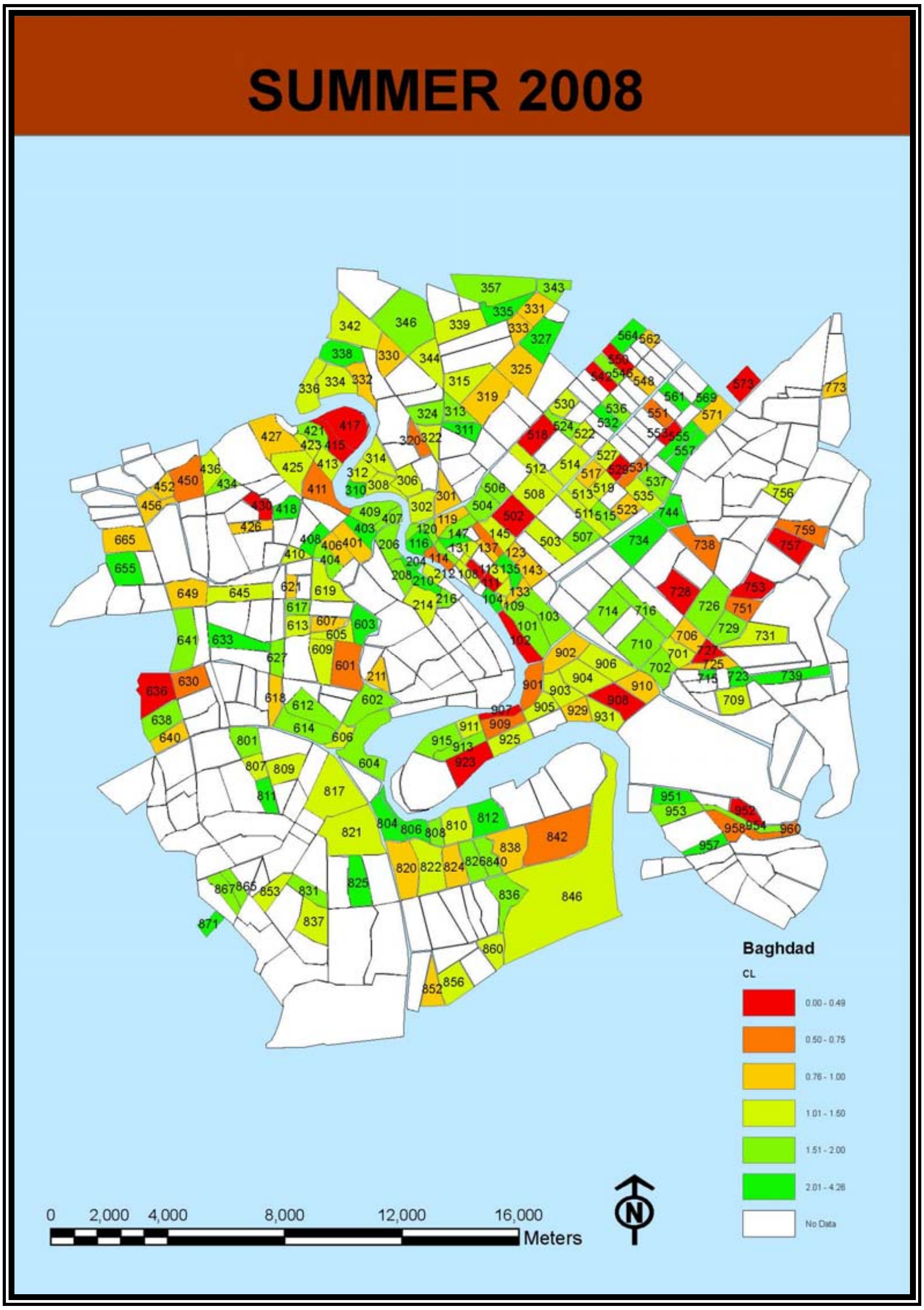


Fig (3) Residual chlorine distribution in Baghdad water supply Networks Sum, 2008.

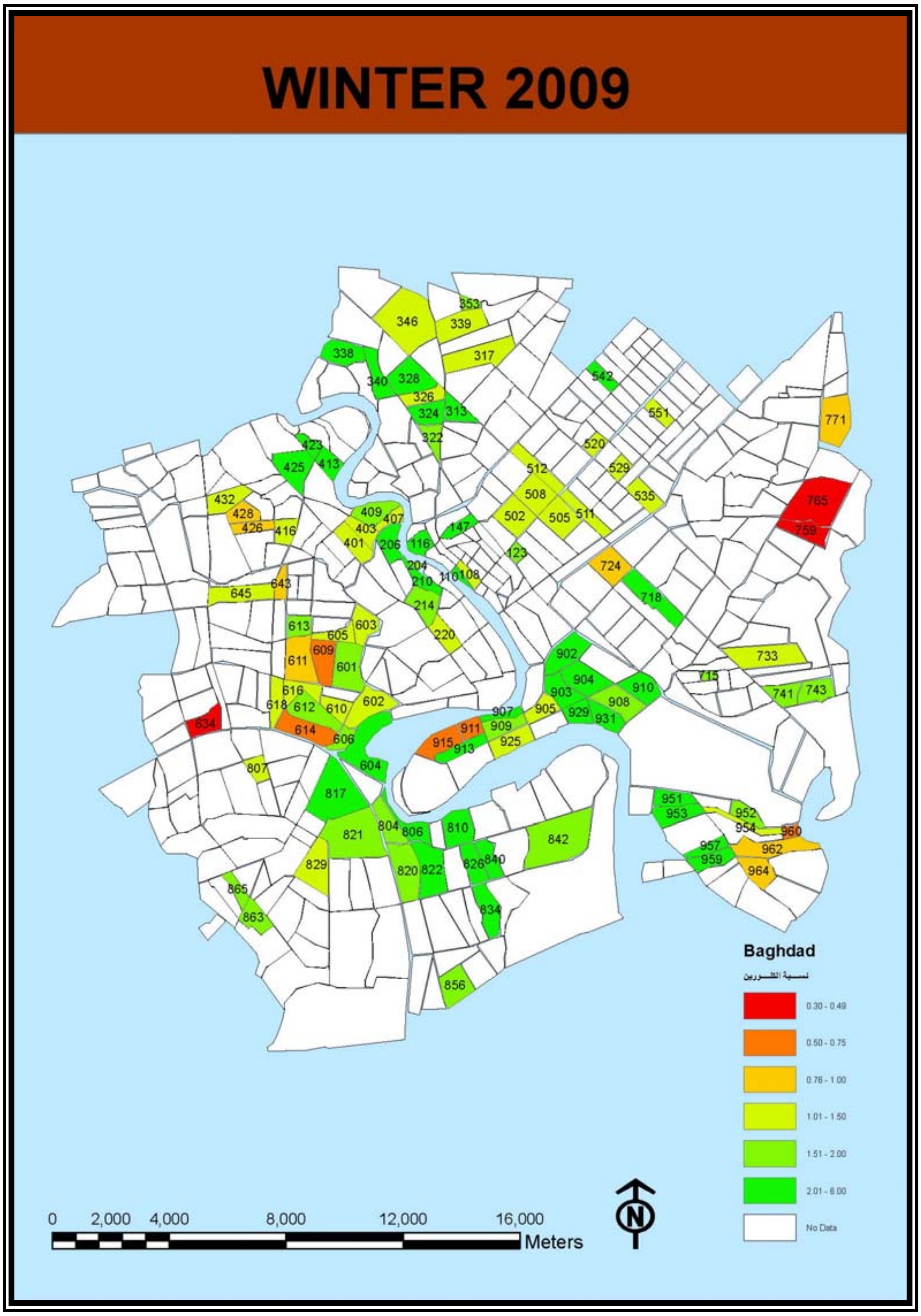


Fig (4) Residual chlorine distribution in Baghdad water supply Networks Win, 2009.

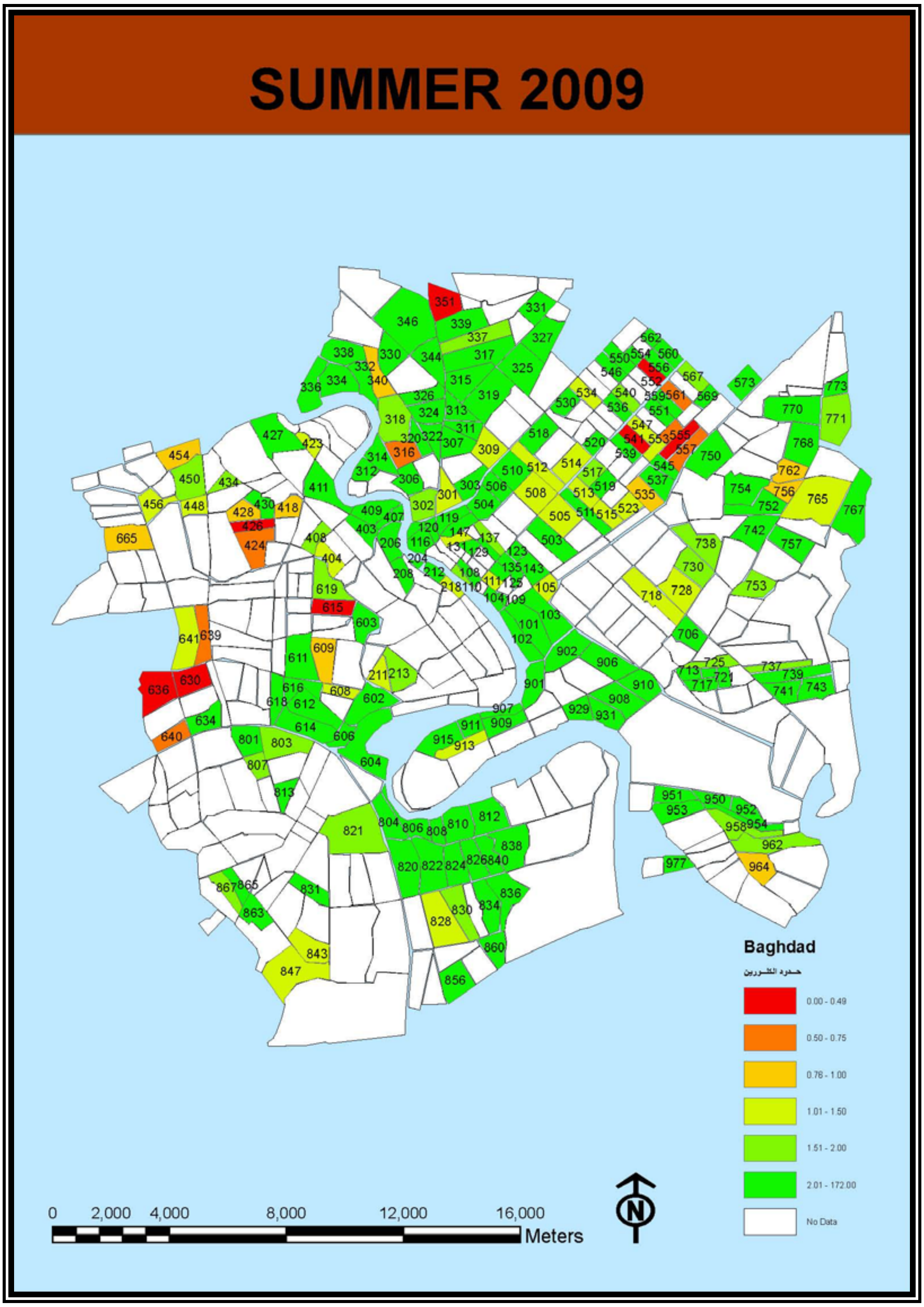


Fig (5) Residual chlorine distribution in Baghdad water supply Networks Sum, 2009 .

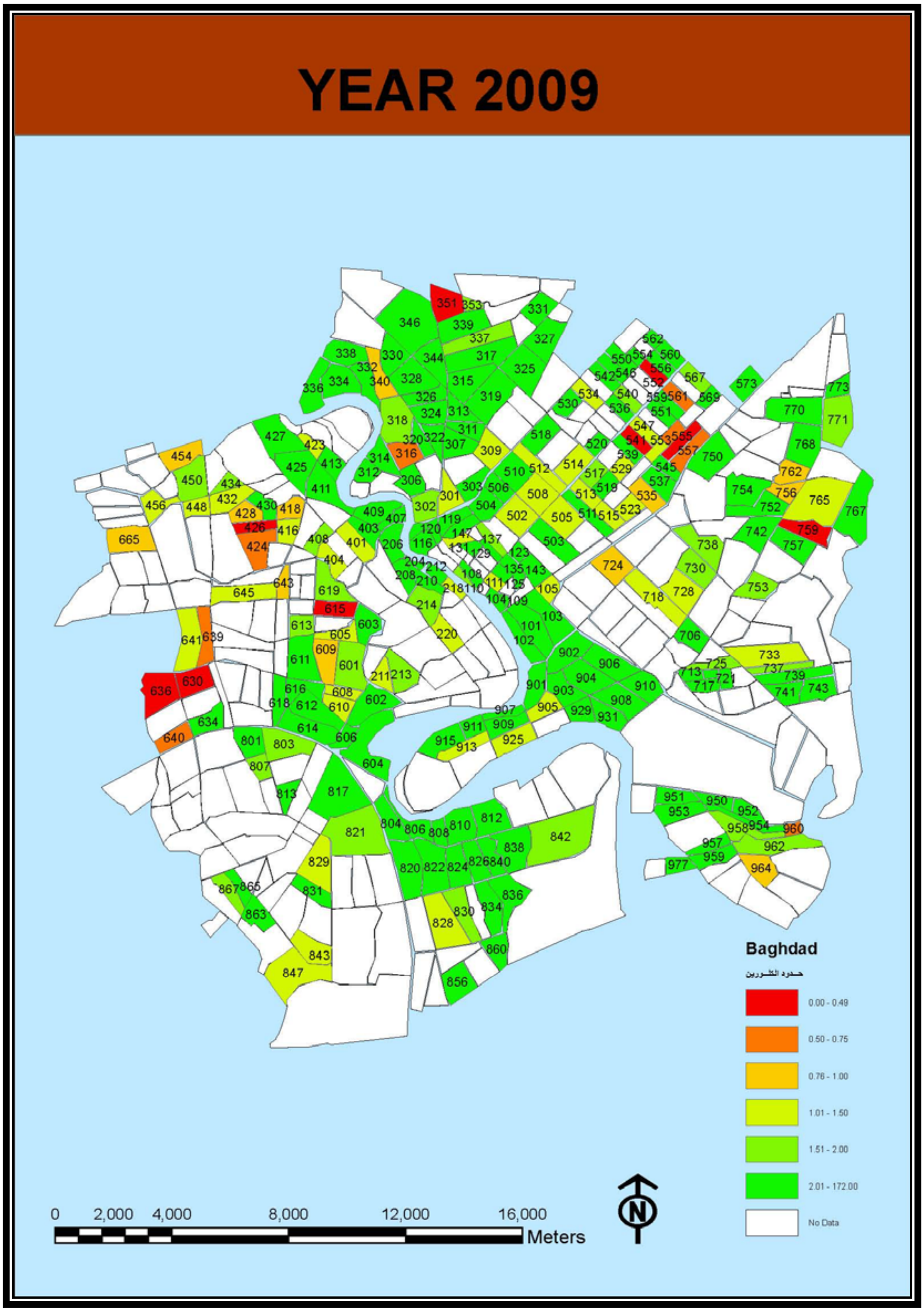
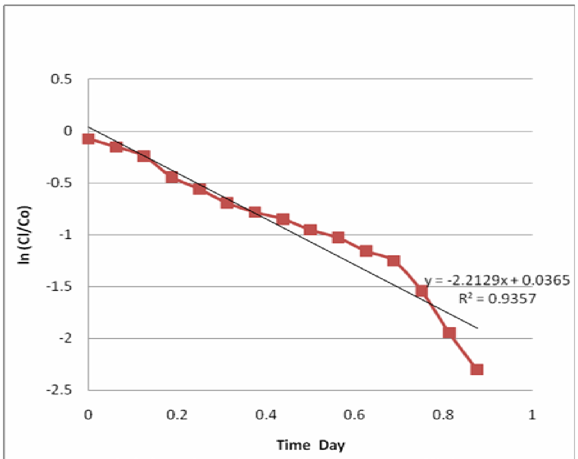
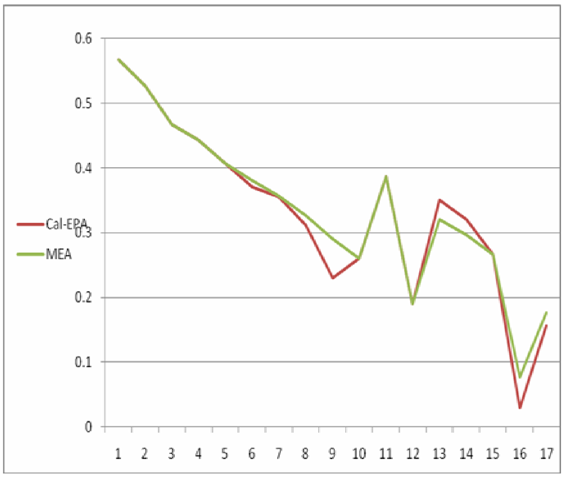


Fig (6) Residual chlorine distribution in Baghdad water supply Networks Year, 2009.

Fig (7)The Water Supply Network in District 636 AL-Amiria , Karkh, Baghdad.



Fig(8) Estimating Bulk Decay Coefficient.



Fig(9) Comparison between measured and estimated values During Summer Months.

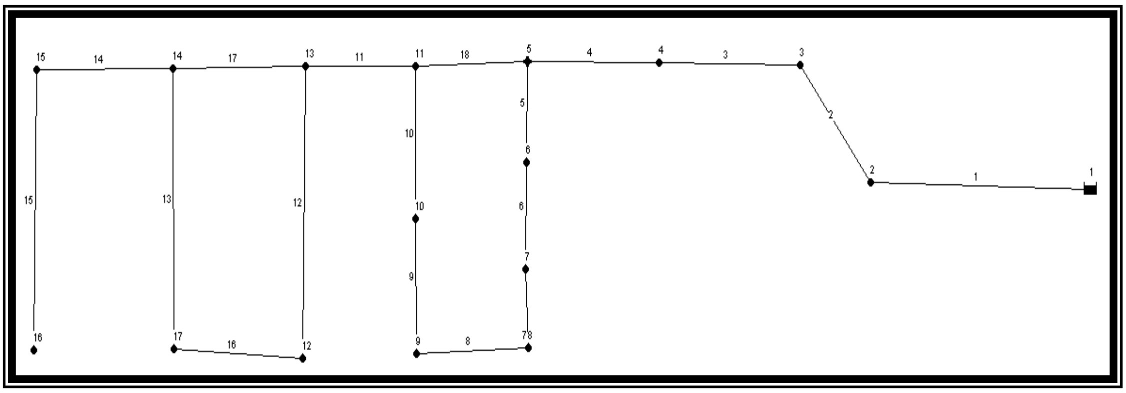


Fig. (10) Nodes Numbering of the case Study Al-Amiria.

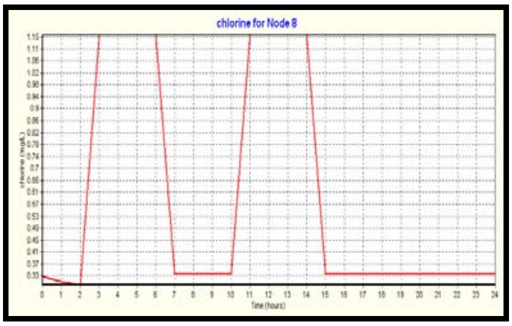


Fig.(11) Chlorine Concentration at node (8).

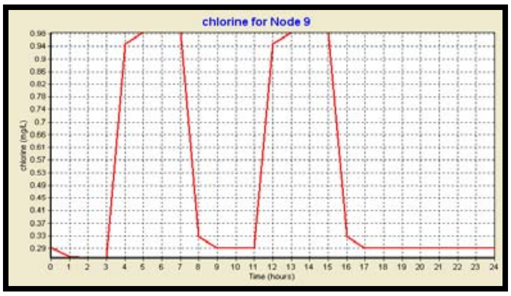


Fig.(12) Chlorine Concentration at node (9).

Fig.(13) Chlorine Concentration at node (10).

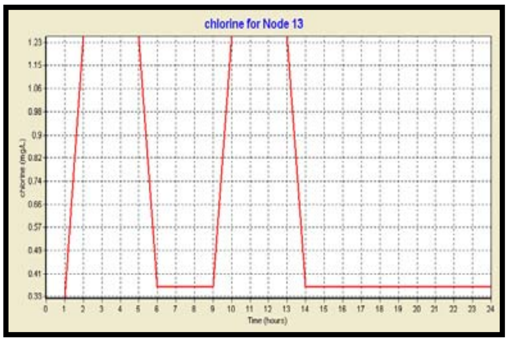


Fig.(14) Chlorine Concentration at node (13).

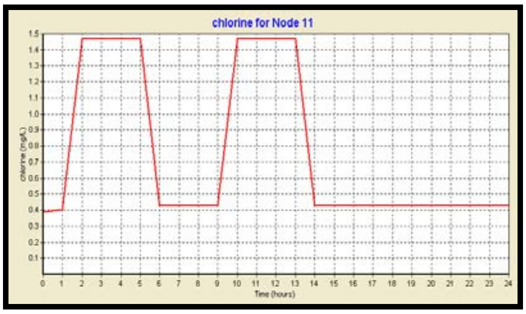


Fig.(15) Chlorine Concentration at node (11).

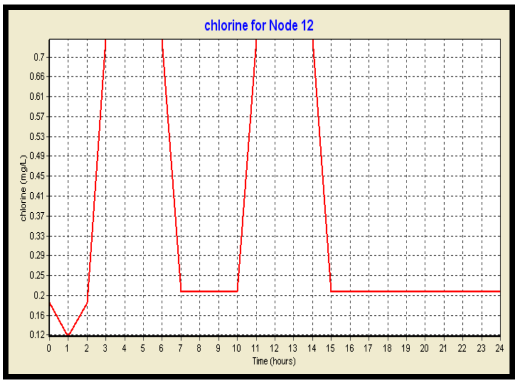


Fig.(16) Chlorine Concentration at node (12).

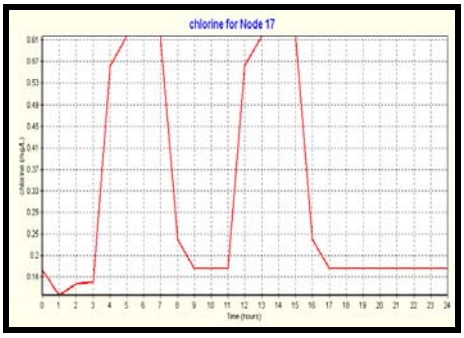


Fig.(17) Chlorine Concentration at node (17).

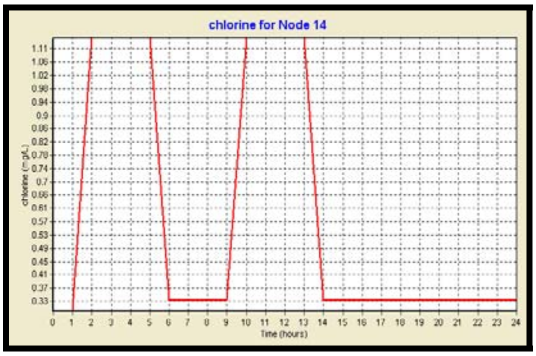
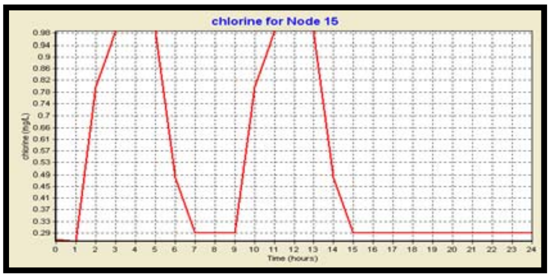


Fig.(18) Chlorine Concentration at



node (14).

Fig.(19) Chlorine Concentration at node (15).

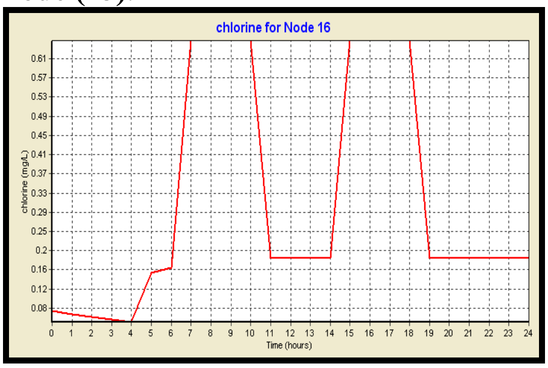


Fig.(20) Chlorine Concentration at node (16).

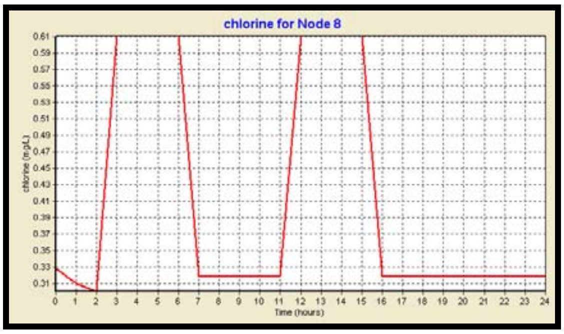


Fig.(21)Chlorine Concentration at node (8).

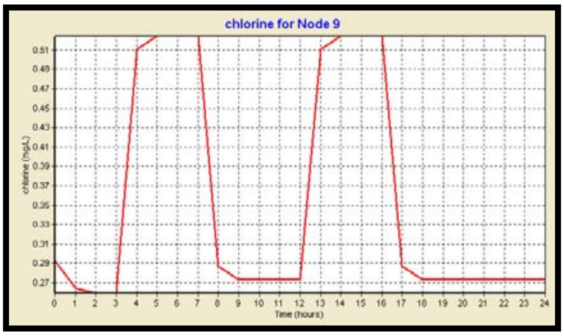


Fig.(22) Chlorine Concentration at node (9).

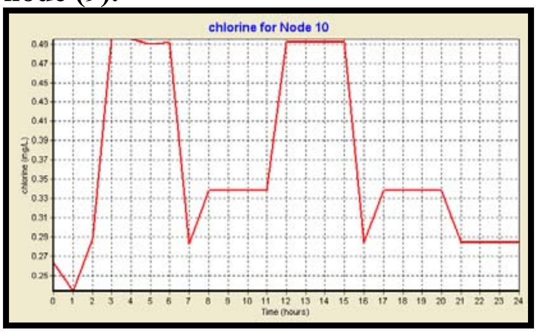


Fig.(23) Chlorine Concentration at node (10).

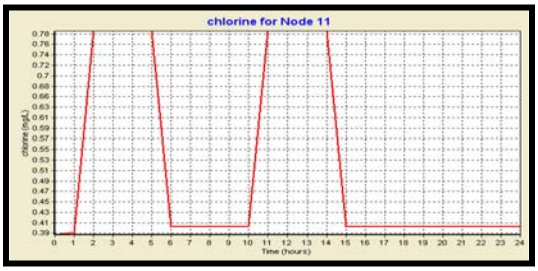


Fig.(24) Chlorine Concentration at node (11).

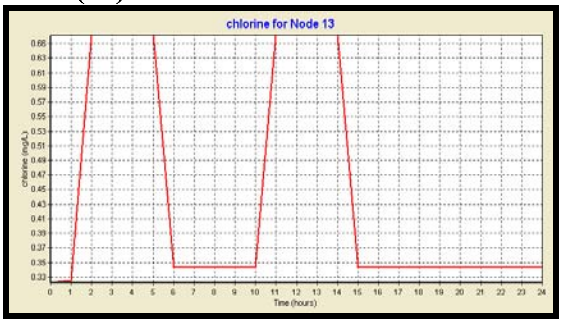


Fig.(25) Chlorine Concentration at node (13).

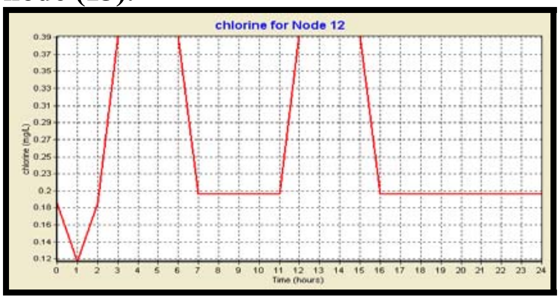


Fig.(26) Chlorine Concentration at node (12).

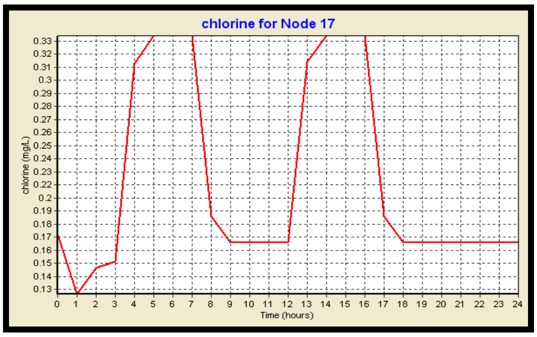


Fig.(27) Chlorine Concentration at node (17).

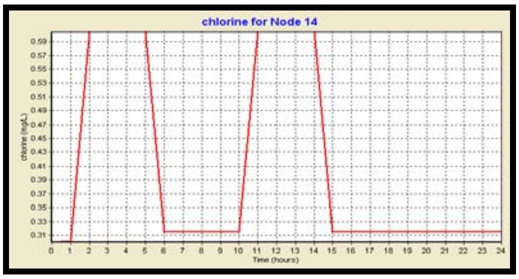


Fig.(28) Chlorine Concentration at node (14).

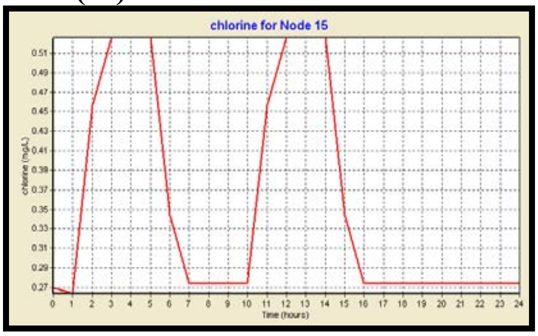


Fig.(29) Chlorine Concentration at node (15).

Fig.(30) Chlorine Concentration at node (16).