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ANALYSIS OF RESIDUAL CHLORINE CONCENTRATION IN DISTRIBUTION NETWORK OF DRINKING WATER SUPPLY AT ISTANA DIENG II RESIDENCE OF MALANG, EAST JAVA, INDONESIA

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ABSTRACT

The drinking water distribution network in Istana Dieng residence is categorized as an isolated network because it does not connect with the other water distribution networks provided by the Malang Water Company (Perusahaan Daerah Air Minum, PDAM). For this reason, the residual chlorine of the isolated distribution network needs to be monitored regularly. **Aim:** This study aims to observe residual chlorine distribution patterns and investigate the effect of distribution distance, pH, and temperature on residual chlorine concentration in the water distribution network. **Methodology and Results:** Analytical survey method with a cross-sectional approach was used in this study. The field survey results and the water analysis were inputted into the ArcGIS 10.6 software to generate an Isoconcentration map. Correlation and regression analysis were conducted using SPSS 16.0. **Conclusion, significance and impact of study:** The results showed that 65% of the residual chlorine concentration in the drinking water distribution network Istana Dieng residence did not meet the quality standard (<0.2 mg/l). Twenty-six sample points showed a value of 0.1 mg/l, which was caused by the pipe's physical condition and the use of wells connected to the PDAM network. There was a significant correlation between distance and residual chlorine concentration. The significant correlation between pH and residual chlorine concentration showed a value of -0.690. The correlation between temperature and residual chlorine concentration was -0.633. It was proven that the lower the residual chlorine concentration, the higher the pH and temperature values in the distribution network.

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- Distance
- Distribution network
- pH
- Residual chlorine
- Temperature

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1. INTRODUCTION

Water is one of the essential elements of human life. Providing a water supply is vital to developing and meeting the clean water requirement. Low access to clean water affects various aspects of life, especially health problems. Microorganisms can cause at least 20-30 types of harmful diseases to health. Poor water and sanitation management in Indonesia can cause four significant health impacts: diarrhea, typhoid, polio, and intestinal worms (Subarkah & Samino, 2014). Therefore, guidelines for drinking water quality requirements refer to the regulation of the Minister of Health of the Republic of Indonesia 495/Menkes/PER/VI/2010 must consistently be a consideration. It describes the physical, chemical, microbiological, and radioactive requirements to avoid health problems.

A Local Water Company of Malang City is an agency of the local government responsible for processing clean water services for people in the Malang city area. The drinking water treatment process is only disinfection using chlorine because physically and chemically, the quality of water sources in the Malang City area has met quality standards. In addition, chlorine is very effective in eradicating spores compared to other disinfectants. The residual chlorine is also easy to measure. It is necessary to detect residual chlorine to ensure that chlorination is properly (Fuadi, 2019). If there is a chlorination process at the spring, there will be residual chlorine in the water flowing in the network or distribution pipe.

The residual chlorine levels in the distribution network must meet the quality standards established in the regulation of the Minister of Health of the Republic of Indonesia No. 736/Menkes/Per/VI/2010, which is a minimum value are respectively 0.142 mg/l (0.2 mg/l), and the maximum is 0.479 mg/l (0.1 mg/l). In addition, the reservoir outlet is required to have a maximum chlorine level of 1 mg/l. The optimum chlorine concentration needs to be taken into account because if the residual chlorine is less, the disinfectant capacity likely will decrease. Thus, many bacteria can develop in the water and cause waterborne diseases in the community, such as skin and digestive disorders (Afrianita *et al.,* 2016). Meanwhile, if the residual chlorine is too high, the water smells of chlorine, carcinogenic, and toxic (Sofia *et al.,* 2016). People who consume them will also be affected by hazardous diseases which can lead to cancer (Hermiyanti & Wulandari, 2018).

To improve the service and fulfillment of drinking water following quality standards and

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requirements for drinking water quality, Malang Water Company of Malang has a Prime Drinking Water Zone (ZAMP). The ZAMP production is 100 percent ready-to-drink water, announced in 2016. ZAMP program uses water that can be drunk directly from the faucet without going through a conventional processing process, namely cooking. This program has spread to 100 percent of the total customers, as many as 152 thousand customers, especially in the Istana Dieng area. However, some people are still hesitant to instantly drink the water without cooking concentration (Rofida, 2018). It is caused by a leak of socialization and analysis of the distribution pattern of residual chlorine.

The distribution network for drinking water in the Istana Dieng zone is isolated and has a loose network with other networks. The drinking water distribution network must be sterile in analyzing the effect of distance on residual chlorine levels. If the network is interconnected, the residual chlorine levels from other networks will be mixed, which causes the distribution of the residual chlorine levels will be distributed randomly and not representatively (Suyanta, 2012). Because of that reason, the Istana Dieng zone was chosen for the study.

Many factors can affect the residual chlorine levels in the distribution network, one of which is the distance. The reaction occurs in the system as long as the water flows in the distribution pipe. The farther the distance between the reservoir and the customer, the smaller the distributed residual chlorine levels (Syahputra, 2012). In addition, control of the pH value (degree of acidity) is also necessary. When the pH is still at the quality standard, namely 7.28-8.12, the distribution network's drinking water treatment process can run effectively (Marwah, 2017). Temperature can also affect the value of residual chlorine levels in the distribution network of drinking water. The higher the water temperature in the distribution network, the higher the chlorine decrease.

The authors investigate to determine the quality of drinking water on the distribution pattern of residual chlorine levels in the isolated network of the Istana Dieng zone. It analyzes the effect of distance, pH, and temperature on residual chlorine levels. It can evaluate some factors that affected the distribution of Malang Water Company to improve the drinking water quality. In addition, it also can convince the public in terms of the drinking water quality provided, whether it can be consumed or not, furthermore with the ZAMP program implemented throughout the city.

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2. RESEARCH METHODOLOGY

2.1 Research Design

The research design used by the researcher is an analytical survey method using a cross-sectional approach. It is determined to study the dynamics of correlation between several risk factors and effects of distance, pH, and temperature on residual chlorine, by approaching, observing, or collecting data all at once (point-time approach).

2.2 Sampling Location

The water distribution network of the Istana Dieng zone has two reservoirs: the reservoir of Istana Dieng I (the upper reservoir) and the reservoir of Istana Dieng II (the lower reservoir). The research was only focused on the distribution network in reservoir II because the farthest distance from the drinking water distribution pipe is around 4.0 km with 1,511 customers. The method used to determine the sampling point was the cluster method by dividing the Istana Dieng area into several grids with 200-meter intervals. Then, 40 points were selected on these grids. If the research is to conduct multivariate analysis data, the number of samples is at least ten times the number of variables studied (Sugiyono, 2015). Sampling points are outlined in Figure 1 and Table 1.

Figure 1 Map of the sampling location

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Table 1 Sampling location

Node	Sampling points	Pipe Length (meters)
1	Perum Istana Dieng Utara II No. 37	586.30
2	Perum Graha Bukit Dieng Permai P.10-3	920.50
3	Perum Bukit Dieng Blok R. 11	1,144.10
4	Pisang Agung III / 39	1,276.20
5	Bukit Dieng Permai Blok T/12	1,396.70
6	Pisang Agung III/16	1,825.10
7	Pisang Agung III / 33	1,882.40
8	Perum Villa Dieng Kav B2	1,902.90
9	Pisang Agung III No.17	1,913.40
10	Perum Villa Dieng Res Kav B-6	1,921.80
11	Villa Dieng Residence Kav D-2	2,034.20
12	Pisang Agung III/20	2,050.20
13	Pisang Agung I / 1	2,194.70
14	Pisang Agung V / 10	2,223.80
15	Jl. Pisang Agung 25 A	2,381.90
16	Perum.Villa Dieng Residence Kav - 1	2,406.20
17	Perum Alam Dieng Residence A1	2,575.10
18	Sumber Alur 16	2,678.80
19	Bandulan Viii G-5	2,712.50
20	Pisang Candi Barat No. 104 B	2,738.20
21	Pisang Candi Barat No. 29	2,852.90
22	Pisang Candi Brt 54	2,891.30
23	Bandulan B VI-K1 18	2,906.40
24	Bandulan. Viii. D.539	3,106.90
25	Bandulan Vi.B / 562	3,178.80
26	Bandulan Vi/K4-16	3,196.40
27	Perum Dieng Residence Kav. B- 10	3,453.30
28	Terusan Taman Agung No. 9	3,461.20
29	Raya Bandulan No. 76	3,555.30
30	Bandulan Iv 908.B	3,616.80
31	Bandulan Iv	3,673.70
32	Bandulan II-931	3,699.10
33	Simpang Taman Agung No.31	3,771.40
34	Jl. Puncak Jaya 26	3,723.80
35	Bandulan Gg Ii -964	3,829.40
36	Simpang Mega Mendung No.34	3,873.30
37	Mega Mendung No.7	3,913.20
38	Bandahara Barat No. 30	3,973.60
39	Simpang Mega Mendung No.46	4,073.80
40	Simpang Mega Mendung I/21	4,083.10

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2.3 Sampling Time

The water sample was collected in Istana Dieng residence area, Sukun, Malang city, East Java. The sampling and analysis were conducted in triplicate and taken in the morning, around 08.30-11.00 WIB, from July 2020 to August 2020.

2.4 Sampling Technique

The sampling technique used in this study was probability sampling with simple random sampling. The water distribution of drinking water supply in the Istana Dieng zone has the same characteristics. The sample used was a grab sampling. Researchers took the samples directly from the PDAM faucets in consumer homes to test residual chlorine levels, pH, and temperature carried out in research.

2.5 Data Analysis Technique

The variables to be analyzed are distance, pH, and temperature to residual chlorine. The researcher used a correlation test and regression test analysis to investigate the relationship and influence between each variable. Besides, a normality test was also used before it.

2.5.1 Normality Test

The normality test was used to determine whether the data were normally distributed or not analytically. The normality test used was the Shapiro-Wilk normality test because the number of samples input was less than 50 samples. The data used were residual chlorine concentration, pH, and temperature of each sampling point. An SPSS 16.0 was used for analyzing data, and the results with a significant value higher than 0.05 were categorized as normally distributed.

2.5.2 Correlation Test

The correlation coefficient (r) determines the degree of relationship between variables that influence each other. The correlation test used by the researcher was Pearson Correlation test. The equations used are:

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$$r_{xy} = \frac{n\,\Sigma xy - \Sigma x\,\Sigma y}{\sqrt{[n\Sigma^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2}} \quad (1)$$

Information:

r = correlation coefficient

x = independent variable (distance, pH, temperature)

y = dependent variable (remaining chlorine)

The correlation coefficient value is in the range of -1 to +1. If the value is closer to ±1, the relationship between variables will be stronger. In addition, if the value is more comparable to zero or equal to zero (0), then the relationship between variables shows very low or no connection.

2.5.3 Linear Regression Test

The Simple Linear Regression analysis technique determines the effect between the two variables. The estimated effect between each x variable, namely distance, pH, and temperature on the residual chlorine levels, can be determined by the simple linear regression formula below:

$$y' = a + bx \quad (2)$$

Information:

y'= dependent variable i.e., residual chlorine levels (mg/l)

a = y-intercept (y' value if x = 0)

b = slope of the regression line

x = independent variable (distance, pH, and temperature)

It confirms that the values of a and b can be determined using the least-squares formula as follows:

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$$a = \frac{(\sum y)(\sum x) - b(\sum x)(\sum xy)}{n\,(\sum x^2) - (\sum x)^2} \tag{3}$$

$$b = \frac{n\,(\sum xy) - (\sum x)(\sum y)}{n\,(\sum x^2) - (\sum x)^2} \tag{4}$$

The determined values of a and b were then inputted into the simple regression equation above. The function of the regression equation above is to estimate the average value of the y variable if the value of x is known. It is used to determine the changes that occur in the y variable caused by the known value of the x variable. It also has a role in evaluating the y variable's average difference to each shift of the x variable.

2.6 Chlorine Residual Levels Modeling

The residual chlorine levels modeling will use the ArcGIS 10.6 program. It is a distribution pattern map of residual chlorine levels in contour lines with 0.1 mg/l intervals from one value to another. The distribution pattern of the residual chlorine levels will be analyzed and compared with the quality standards set by the Regulation of the Minister of Health of the Republic of Indonesia.

3. RESULTS AND DISCUSSION

3.1 Water Characteristics in the Reservoir of Istana Dieng II Malang City

Data from laboratory tests conducted by PDAM of Malang City regarding water quality parameters in the reservoir of Istana Dieng II show that physical, chemical, and microbiological parameters have met the drinking water quality standard in which the water source comes from groundwater. Groundwater is clear water because mud and bacteria will be retained in several soil layers but contain more chemicals (Kumalasari & Satoto, 2011). Water quality parameters are outlined in Table 2.

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Table 2 Water quality parameters in the reservoir of Istana Dieng II

Parameters	Water Quality standard	Units of	Result
Residual Chlorine	1	ppm	0.5
Total Solute Concentration	500	ppm	192
Turbidity	5	NTU	0.15
Air temperature	35	oC	26.1
Total Coli	0	cfu/100 mL	0
E-Coli	0	cfu/100 mL	0
Arsenic	0.01	ppm	0
Fluoride	1.5	ppm	0.09
Chromium	0.05	ppm	0
Nitrite	3	ppm	0.01
Nitrate	50	ppm	17.8
Color	15	TCU	0
Aluminum	0.2	ppm	0.02
Iron	0.3	ppm	0.01
Hardness	500	ppm	168.15
Chloride	250	ppm	5
Manganese	0.4	ppm	0.01
pH	8.5	-	7.1
Zinc	3	ppm	0
Copper	2	ppm	0.03
Ammonia	1.5	ppm	0.01

It supports the disinfection process in the water because the water becomes clear and inhibits the growth of bacteria in the water. The disinfection process in cloudy water will be complex because suspended substances will protect microorganisms from disinfectants (Sari, 2018).

3.2 The pattern of Residual Chlorine Concentration

The maximum residual chlorine levels at the reservoir outlet are 1 mg/l, and the minimum at the farthest end of the distribution unit must be 0.2 mg/l (Kementerian Kesehatan RI, 2010). Based on lab analysis. There are still many water distribution points that did not fit into the standard range of residual chlorine values, which are 26 points out of 40 sampling points with a value of 0.1 mg/l. It confirmed that more than half of the drinking water distribution area with residual chlorine levels is not within the quality standard, more than 65%. Only about 35%

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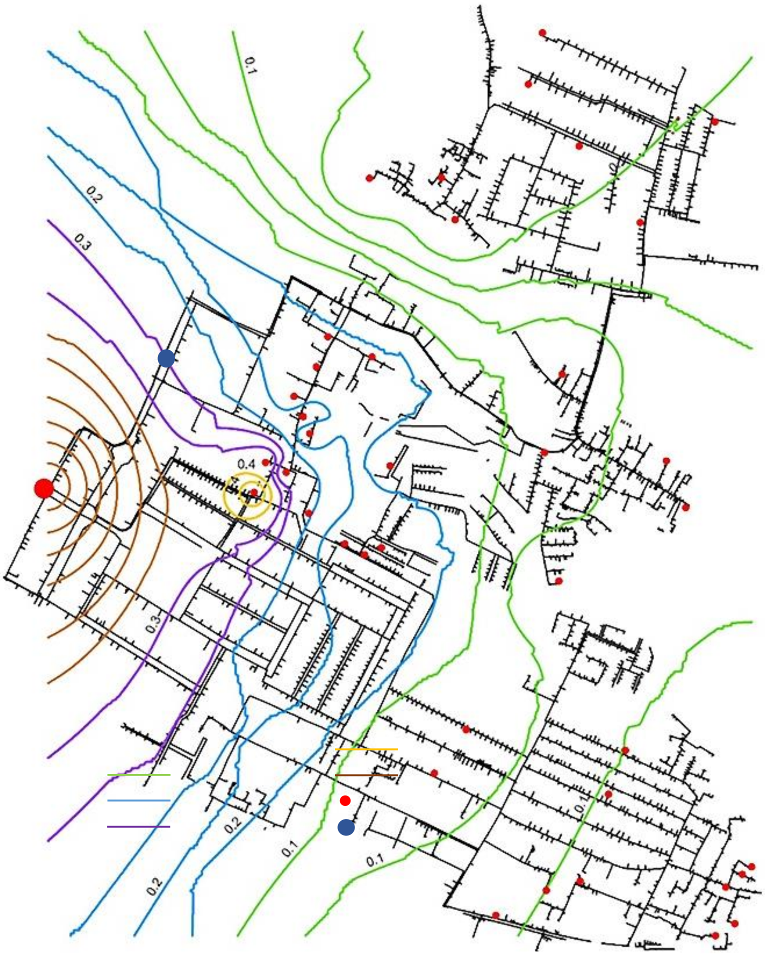
follow the quality standard. The Isoconcentration map is shown in Figure 2.



LEGEND
: 0.1 – 0.2 mg/l
: 0.2 – 0.3 mg/l
: 0.3 – 0.4 mg/l
: 0.4 – 0.5 mg/l
: >0.5 mg/l
: Sampling point
: Reservoir of Istana Dieng II

Figure 2 Isoconcentration map of the residual chlorine concentration at the Istana Dieng zone

Figure 2 shows that the area with a brown outline indicates that the residual chlorine in the distribution network is in the range of 0.5 mg/l. It is within a 0 to 500 m radius from the reservoir of Istana Dieng II. The residual chlorine levels in this area are higher because the distance is still very close to the reservoir. In addition, water within a 0 to 600-meter radius is not distributed to consumers. The starting point for water distribution is 586 m from the

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reservoir, namely at Perum Istana Dieng Utara II No. 37.

The residual chlorine levels at the distance of 600-920 meters have chlorine levels of 0.4 mg/l, indicated by a yellow contour line. It is still in Istana Dieng Regency. The purple contour line shows the area with the residual chlorine levels of 0.3 mg/l. It indicates that the residual chlorine levels have begun to decrease. This area is not far from Istana Dieng Regency, namely Graha Bukit Dieng Permai Regency and Bukit Dieng Regency with a radius of 920 meters-1.2 km. The residual chlorine of 0.2 mg/l was found at a 1.2-2.3 km, located in Villa Dieng Regency and Pisang Agung (blue contour lines). It is the area with the best residual chlorine levels because the margin of safety (safety limit value) for the appropriate chlorine dose to kill pathogens and oxidized organics in drinking water is 0.2 mg/t.

The area with the green contour line is the area with the most contour than other contour line colors. The residual chlorine levels with a value of 0.1 mg/l spread over the furthest areas of the distribution of drinking water in the Istana Dieng zone, which is in a radius of 2.3-4.0 km, namely in Sumber Alur, Pisang Candi, Bandulan, Bandahara Barat, Taman Agung, and Simpang Mega Mendung areas. It indicates that the residual chlorine levels do not meet the quality standards set by the Regulation of the Minister of Health of the Republic of Indonesia in 2010 as drinking water.

Most regional customers with green contour lines are those with the farthest distances, namely Sumber Alur, Pisang Candi, Bandulan, and Simpang Mega Mendung. In some of the customers' houses in this area, wells or private sources were found approximately 21 sampling points, connected to the PDAM's drinking water network. It is used as secondary water for daily needs because the distributed water often turns off at certain hours. Sukun has the most water wells compared to other sites (28%), especially in the Bandulan and Pisangcandi areas (PDAM Kota Malang, 2015). The use of wells connected to PDAM water affects water quality. The water distributed by the PDAM will mix with the customer's water well and cause a reduction in the residual chlorine levels of the drinking water. The mixture will reduce drinking water quality and cannot be consumed as drinking water, moreover at a 2.3-4.0 km distance. It was deficient, but the water quality still met the quality standard of Sanitation Hygiene (Menteri Kesehatan RI, 2017).

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3.3 The Effect of Distance on Residual Chlorine Concentration

The relationship between distance and residual chlorine levels is very strong. It is proved by a correlation value of -0.760 gained by the Pearson Correlation test. It confirms that the distance significantly affects residual chlorine levels in the drinking water distribution network. The symbol (-) indicates that the relationship between the variables is inverse. The farther the distribution network from the reservoir, the lower the residual chlorine concentration.

The residual chlorine levels decrease by 0.3 mg/l after being distributed at a distance of 4 km. It shows that for every 1 km distance, the residual chlorine decreases by 0.12 mg/l. The reduction of the residual chlorine concentration in our study was three times higher than in other studies conducted by Afrianita et al. (2016) in District 8 PDAM Padang City, where the residual chlorine levels only decreased by 0.036 mg/l every 1 km distance.

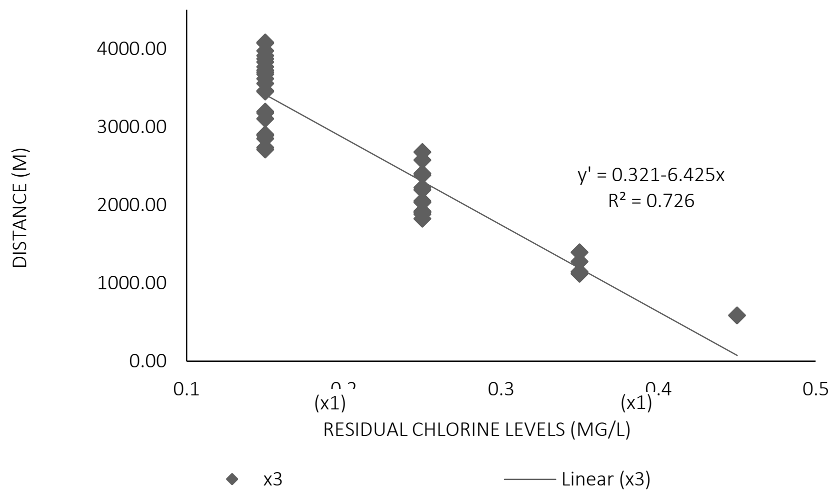

Figure 3 The effect of the distance to a residual chlorine concentration

It found that the decrease of the residual chlorine at the farthest point was due to the mixing of PDAM and wells water in the distribution area of Bandulan and Pisang Agung of Malang city. In addition, the equation value obtained from the distance regression test with residual chlorine levels is y'= 0.321-6.425x, shown in Figure 3. It informed that the residual chlorine levels would reach 0 mg/l (y=0) at 4.99 km. The significant effect of variable X on variable Y was analyzed by t-test. The table value at the considerable level of 0.05 was 2.024, smaller than the t-count of 10.041. In addition, there is a significant effect between the X and Y

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variable with a Coefficient of Determination (R^2) of 0.726. The results of testing the hypothesis above prove that there is a significant effect of 72.6% between distance and residual chlorine levels in the water distribution network of the Istana Dieng zone.

The effect of distance on the residual chlorine levels is caused by several reactions: the Bulk Reaction. Arsyadin *et al.,* (2012) explain that the chlorine reaction will be active during the journey to the consumer. It occurs due to contact with water-soluble components such as microorganisms that enter through small gaps in the piping connection or during pipe leaks.

3.4 The Effect of pH on Residual Chlorine Concentration

The pH dramatically affects the reduction in residual chlorine concentration. The disinfection process requires a normal pH (7.2-7.79) and meets the Minister of Health Regulation of the Republic of Indonesia 492/MENKES/PER/2010 concerning drinking water quality. If pH does not meet the standard requirements, the disinfection process will not run effectively (Afrianita *et al.,* 2016).

A pH affects residual chlorine levels in the distribution network of drinking water in Istana Dieng, verified by a Pearson Correlation value of -0.690, which means that the correlation of pH to residual chlorine levels is vital. The symbol (-) indicates that the relationship between the two variables is not unidirectional. The higher the pH value in drinking water, the lower the residual chlorine levels.

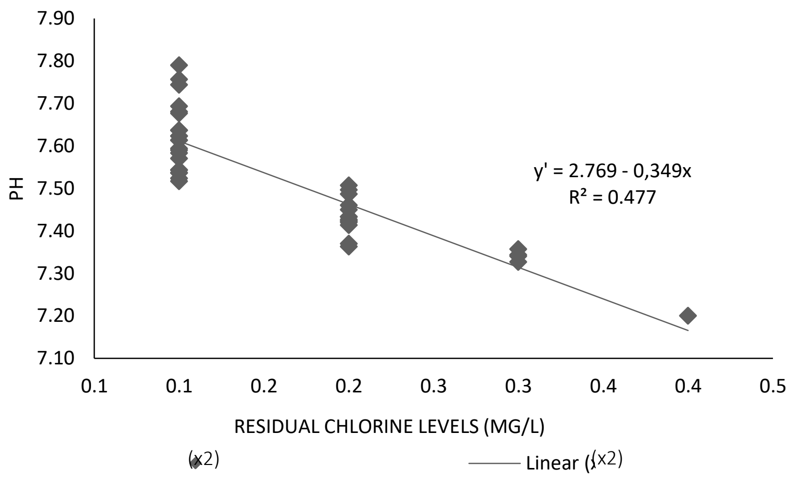

Figure 4 The Effect of distribution pH on residual chlorine levels

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As shown in Figure 4, the regression test on the variable pH to the residual chlorine levels was y'= 2.769 - 0.349x. The residual chlorine levels will be 0 mg/l (y=0) when the pH value is 2.769. The significant effect of variable x on variable y was analyzed using a t-test. The value of the t-table at a significant level of 0.05 is 2.024, which is smaller than the t-count of 5.883. It indicates that the variable x affects the variable y with a coefficient of determination (R^2) of 0.477. The results of this hypothesis test prove that there is a significant effect of 47.7% between pH and residual chlorine levels in the Istana Dieng water distribution network.

When the residual chlorine levels were 0.4 mg/l, the pH value was 7.20, and the chlorine levels of 0.1 mg/l resulted in a pH of 7.79. The higher the pH, the lower the residual chlorine concentration in the drinking water distribution network (Arsyadin *et al.,* 2012). It is due to the relationship between the action of chlorine on changes in pH in the water. Chlorine will react with water and form HOCl (hypochlorous acid) and $Ca(OH)_2$.

$$Ca(OCl)_2 + 2H_2O \rightarrow 2HOCl + Ca(OH)_2 \tag{5}$$

$$HOCl \qquad\qquad \rightarrow H^+ + OCI^- \tag{6}$$

Reaction (5) shows a reaction between chlorine and water, which produces H+ ions, namely, the higher the acidity, the lower the pH of the water. However, it is different from reaction (6). There is a reaction between chlorine and water, producing $Ca(OH)_2$. It has an alkaline nature which causes the pH value to increase.

3.5 The Effect of Temperature on Residual Chlorine Levels

The results of water temperature sampling shown an average of 25.5°C. In the residual chlorine at 0.4 mg/l, the water temperature reached 23.5°C, and 0.1 mg/l reached 27.7°C, with the temperature in the Istana Dieng area of 25.2°C. It shown that the water temperature had met the requirements of ±3ºC from the regional air temperature set by the Regulation of the Minister of Health of the Republic of Indonesia in 2010 concerning drinking water quality.

The correlation value of temperature to residual chlorine content calculated based on Pearson Correlation is -0.587. It shows that the relationship between temperature and residual

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chlorine content is strong. The symbol (-) means that the relationship between the two variables is not unidirectional. The higher the pH value in drinking water, the lower the residual chlorine levels. The water temperature increased by 0.4ºC when the residual chlorine content decreased by 0.3 mg/l. The study by Afrianita *et al.,* (2016) supports that the increase in temperature of 0.5ºC occurred when the residual chlorine was reduced by 0.24 mg/l.

The regression test on the temperature of the residual chlorine content obtains the equation y'= 1.203 - 0.041x. The residual chlorine levels will be 0 mg/l (y=0) when the temperature is 29.34°C. The significant effect of variable x on variable y was analyzed using a t-test. The value of the t-table at a significant level of 0.05 is 2,024, which is smaller than the t-count of 5,037. It indicates that variable x has a considerable influence on variable y with a coefficient of determination (R^2) of 0.400. The results of this hypothesis test prove that there is a Significant Effect of 40% between Temperature and Chlorine Residual Levels in the Water Distribution Network of the Istana Dieng zone. It can be seen in Figure 5.

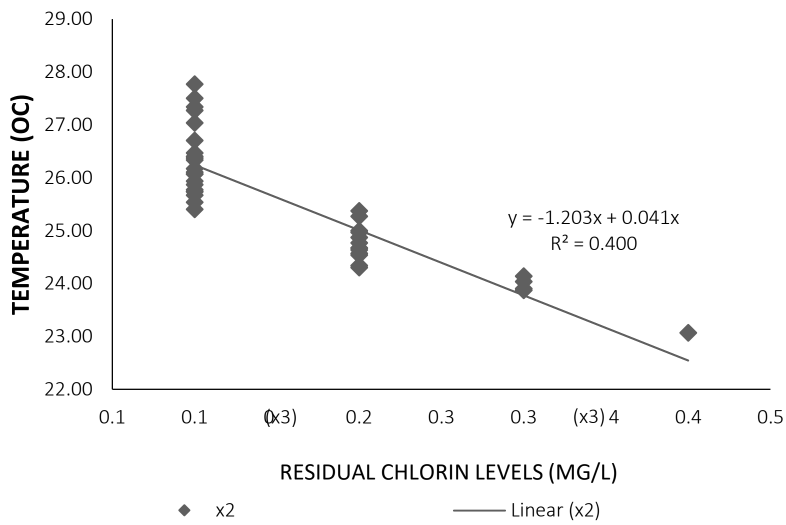

Figure 5 The effect of distribution temperature on residual chlorine levels

The higher the water temperature, the faster the decrease in residual chlorine levels. The content of microorganisms will multiply at a high temperature of +15ºC (Fisher *et al.,* 2012). The temperature will increase the potential energy of a substance. For this reason, the more microorganisms in the pipeline network, the smaller the concentration of residual chlorine

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content in the distribution network because the amount of chlorine decay is equal to the number of microorganisms (Fuadi, 2019).

4. CONCLUSION

More than 65% of the residual chlorine levels in the Istana Dieng zone distribution network do not meet the requirements for drinking water of 0.1 mg/l at a distribution distance of 2.3-4 km. The underlying reason is a large number of private wells in the area which are connected to PDAM water. The water distributed by the PDAM will mix with the customer's water well and cause a reduction in the residual chlorine levels of the drinking water. Although it cannot be used as drinking water, it can be used as raw water or for sanitary hygiene. The residual chlorine content will decrease with increasing distribution distance from the Istana Dieng II reservoir with a correlation coefficient value of -0.760, which is very strong with 72.6%. In addition, the lower the residual chlorine value, the higher the pH and temperature values , with a correlation value of 0.690 and 0.587, which have a strong relationship with an influence level of 47.7% and 40.0%.

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