WATER CONSUMPTION PREDICTION USING FUZZY TIME SERIES - A CASE STUDY IN PRIVATE COMPANY OF TANGERANG DISTRICT INDONESIA

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Abstract

Consumption of water in the Tangerang Regency continuously increases from year to year due to the increasing population and birth rates an average increase of 3% every year. So, the water demand prediction to be important to meet customer or community needs. The private water utility company needs to use a new method for predicting future monthly water consumption values and improves accuracy when forecasting time series using a visibility graph and presents to make more accurate predictions. In this study, we aim to measure the trend analysis volume of water consumption prediction by Fuzzy Time Series versus actual usage volume. Fuzzy Time Series (FTS) is a concept plan method that uses fuzzy logic that is able to provide predictions (estimates) of time series data analysis for the next several periods. Mean Absolute Percentage Error (MAPE) is obtained for different configurations of the input sets and of the FTS model structure. From the results of the average value error accuracy was only 4.5% using FTS Chen Method and included in the low category and water consumption actual versus prediction with the FTS Chen method shown related stable.

Keywords: water consumption; water demand; fuzzy time series; MAPE; FTS Chen method; forecasting

1. Introduction

Estimation future of water consumption is the most important for the planning of a regional water-supply system. Furthermore, the planning of operating water distribution system with adequate water quality in volume at a reasonable pressure and a reliable so that an increase of satisfying consumer demand (Zhou, McMahon, Walton, & Lewis, 2002). Increasing population, as well as economic and industrial activities in Tangerang Regency, especially in 8 Sub-districts, needs to be supported by an adequate clean water provision and services. The limited supply and service of clean water in those sub-district areas has led to excessive groundwater exploitation, causing high economic costs and declining environmental quality.

Based on the interview of the internal clerk the consumption of water in the Tangerang Regency in continually to increase from year to year due to the increasing population and birth rates in the area. And based on Central Bureau of Statistics that number of population by Sub district with an average increase of 3% every year. Forecasting can be basic for short-term planning and to be required to minimize the errors in it. Models forecasting for water utility or water consumption have been developed and implemented towards the needs of one-day-ahead. For the short-term forecast such as Artificial Neural Networks and Econometric models with simulation or scenario-based forecasting tends to be used for long-term strategic decisions. (Donkor, Mazzuchi, Soyer, & Alan Roberson, 2014)

For the water demand forecast, various methods have been developed and tested. Water consumption can be done based on the base consumption, seasonal consumption. And evaluated with and without using weather inputs, in order to assess the performance improvement of using weather data (Bakker, Van Duist, Van Schagen, Vreeburg, & Rietveld, 2014). Several research prediction of water demand such as a new hybrid approach based on structure optimization learning algorithm for Fuzzy Cognitive Maps (FCM), Artificial Neural Network (ANN) (Jenitha, 2017; Papageorgiou, Poczęta, & Laspidou, 2016). Using an FCM learning algorithm to Prediction capabilities in the problem of water demand forecasting by calculating the known prediction errors (Papageorgiou et al., 2016). Multivariate analysis methods such as ARIMA, ANN, winters, and hybrid were applied for urban water demand forecasting of the island of Skiathos (Kofinas, Mellios, Papageorgiou, & Laspidou, 2014; Laspidou, 2014). The other paper using ANN (Artificial Neural Network) and Multiple Linear Regression (MLR) combined with MAPE for the future daily forecast of water consumption and humidity forecast(Piasecki,
Jurasz, & Kaźmierczak, 2018). Combine method of ANFIS and Mamdani fuzzy inference system (MFIS) models and can be successfully applied for prediction of water consumption time series (Firat, Turan, & Yurdusev, 2009).

To predict water demand using several methods, one the so-called fuzzy time series (FTS) where this method is usually used for predicting data with the historical of water consumption (Cai, Zhang, Wu, & Leung, 2013). PDAM Malang Using the method of Fuzzy Time Series with a genetic algorithm and a MAPE (Mean Absolute Percentage Error) for measuring errors that can be generated by forecasting methods. It results in applying parameters with best testing results and effectively results in more be value predictive accurate (Istiqara dkk, 2018).

In this paper, related time series model reviews will be carried on only as we chose to forecast on water consumption by time series model approach FTS method is able to provide predictions (estimates) of time series data analysis for the next several periods for prediction of water consumption due to water demand prediction to be important to meet customer or community needs and MAPE for measurement of error level from the result of prediction calculation. We use actual data of consumption water for about three years in the private company, Tangerang Regency.

To explain the details of methods, this paper is organized as follows; section I explained of research background; section II presents the related framework of research, instrument data with FTS methods and data analysis technique; section III result of water consumption analysis using step of Fuzzy Time Series method.

2. Research Methodology
A. Fuzzy Time Series Algorithm

According to Chen, the Fuzzy time series is one of the soft computing methods to predict data using a fuzzy basis. In predicting or forecasting with the fuzzy time series method using the value in the fuzzy set that has been obtained from real numbers. Fuzzy set in this method is used as a substitute for previous data into expected data (Chen, 1996). Developing a fuzzy time series method with a combination of Zadeh's work and time series as well as Chen and Chissom (Song & Chissom, 1993)(Song & Chissom, 1994). Using fuzzy time series from Chen Method more be simplify for this research to get better forecasting(Chen, 1996). The steps to make predictions using fuzzy time series begins with the determination of average-based intervals are as follows:

- **Determine the Universe of Discourse**

For universe is:

\[ U = \{U1, U2, U3, \ldots, Un\} \] .......................... (1)

\[ Ui: \text{The amount of distance at } U, \text{ for } i = 1,2,\ldots,n \]

We can use universe of discourse and divide it into class using:

- **Determine the interval length based on its Universe**

We can form a number of linguistic values to represent a fuzzy set from set of universes using sturges work.

\[ 1 + 3.32 \log(n) \] .........................................(3)

Where:

- \( n \): Observable data

B. Research Framework

To build forecasting for water demand in Tangerang Regency we need 2 important components which are training set and the other one would be forecasting algorithm that can compute and simulate data. Figure 1 shows research framework.

![Figure 1. Framework of Research](image-url)
3. Result and Analysis

Determine the Universe of Discourse

D1 and D2 are positive (arbitrary) numbers to determine the universal set of historical data sets determined by the researcher. Using this equation we show universe of discourse on Table 1.

| Table 1. Universe of Discourse Water Consumption |   |   |
|------------------------------------------------|---|---|
| Min                                           | Max |   |
| 1,475,481                                     | 2,173,437 |   |
| D1                                            | D2  |   |
| 481                                           | 63  |   |

Min 1

| Max 2 | 1,475,000 | 2,173,500 |

Determine the interval length based on its Universe

Using equation 3, we can divide the set of universes into several intervals with the same distance. Table 2 shows several class intervals with the same length.

| Table 2. Class Interval | Class | Lower Limit | Upper Limit | Median |
|-------------------------|-------|-------------|-------------|--------|
| A1                      | 1,475,000 | 1,590,559 | 1,532,779 |
| A2                      | 1,590,560 | 1,706,118 | 1,648,339 |
| A3                      | 1,706,119 | 1,821,678 | 1,763,898 |
| A4                      | 1,821,679 | 1,937,237 | 1,879,458 |
| A5                      | 1,937,238 | 2,052,797 | 1,995,017 |
| A6                      | 2,052,798 | 2,168,356 | 2,110,577 |

Based on class interval table we have fuzzy linguistic set also in Table 2. Using table 2 we can perform fuzzification on Water Consumption. Table 3 shows fuzzification Water Consumption table.

Determine Fuzzy Logical Relationship (FLR) and Fuzzy Logical Relationship Group (FLRG)

To determine FLR, we are using the first order fuzzy logical relationships. To do this we need to pair the current month water consumption data to the next month water consumption data. After FLR done we grouping the FLR based on current month group, for example was for FLR A1->A2, A1->A3, and A1->A6 to become G1 group. Therefore we in table 5 we have FLR and FLRG shown.

| Table 3. Water Consumption Fuzzification | Month | Volume (m$^3$) | Fuzzification |
|----------------------------------------|-------|---------------|---------------|
| Jan'17                                 | 1,542,323 | A6            |               |
| Feb'17                                 | 1,531,075 | A6            |               |
| Mar'17                                 | 1,482,550 | A6            |               |
| Apr'17                                 | 1,674,524 | A6            |               |
| Mei'17                                 | 1,552,133 | A6            |               |
| Jun'17                                 | 1,628,890 | A6            |               |
| Jul'17                                 | 1,475,481 | A6            |               |
| Aug'17                                 | 1,693,114 | A6            |               |
| Sep'17                                 | 1,738,058 | A6            |               |
| Okt'17                                 | 1,712,688 | A6            |               |
| Nov'17                                 | 1,804,072 | A6            |               |
| Des'17                                 | 1,753,580 | A6            |               |
| Jan'18                                 | 1,755,638 | A6            |               |
| Feb'18                                 | 1,760,083 | A6            |               |
| Mar'18                                 | 1,705,896 | A6            |               |
| Apr'18                                 | 1,738,713 | A6            |               |
| Mei'18                                 | 1,794,671 | A6            |               |
| Jun'18                                 | 1,716,302 | A6            |               |
| Jul'18                                 | 1,753,834 | A6            |               |
| Aug'18                                 | 1,835,558 | A6            |               |
| Sep'18                                 | 1,902,058 | A6            |               |
| Okt'18                                 | 1,968,283 | A6            |               |
| Nov'18                                 | 2,100,222 | A6            |               |
| Des'18                                 | 1,978,579 | A6            |               |
| Jan'19                                 | 1,861,209 | A6            |               |
| Feb'19                                 | 2,021,665 | A6            |               |
| Mar'19                                 | 1,950,961 | A6            |               |
| Apr'19                                 | 1,961,783 | A6            |               |
| May'19                                 | 2,021,682 | A6            |               |
| Jun'19                                 | 1,782,517 | A6            |               |
| Jul'19                                 | 2,083,732 | A6            |               |
| Aug'19                                 | 2,173,437 | A6            |               |
| Sep'19                                 | 2,125,508 | A6            |               |
If the result of fuzzification in month $t$ is $A_j$ and $A_j$ has several FLRs on FLRG, for example $A_i \rightarrow A_j$, $A_j2$, ..., $A_jk$ where $A_i, A_j1, A_j2, ..., A_jk$ is the fuzzy set and the maximum value of the function the membership of $A_j1, A_j2, ..., A_jk$ is at the interval of $uj1, uj2, ..., ujk$ and $mj1, mj2, ..., mjk$, then the predicted results of $F_t + 1$ are as follows:

$$F_{t+1} = (mj_1 + mj_2 + \cdots + mjk)/k$$

Table 5 shows defuzzification Water Consumption table based on FLRG on Table 4.

### Defuzzification

If the result of fuzzification in month $t$ is $A_j$ and $A_j$ has several FLRs on FLRG, for example $A_i \rightarrow A_j$, $A_j2$, ..., $A_jk$ where $A_i, A_j1, A_j2, ..., A_jk$ is the fuzzy set and the maximum value of the function the membership of $A_j1, A_j2, ..., A_jk$ is at the interval of $uj1, uj2, ..., ujk$ and $mj1, mj2, ..., mjk$, then the predicted results of $F_t + 1$ are as follows:

$$F_{t+1} = (mj_1 + mj_2 + \cdots + mjk)/k$$

Table 5 shows defuzzification Water Consumption table based on FLRG on Table 4.

### Analysis of FTS

To assess the forecasting performance and accuracy of the models created using MAPE (Mean Absolute Percentage Error) methods. The mean absolute percentage error (MAPE) is one of the most widely used measures of forecast accuracy, due to its advantages of scale-independency and interpretability and the most popular measures from the most textbooks (Kim & Kim, 2016). Table 6 and Figure 2 shown accuracy error testing using MAPE for Water Consumption versus Water Consumption prediction using FTS Chen methods.
Water Consumption volume Versus Prediction with FTS Chen

![Chart showing water consumption volume versus prediction with FTS Chen](chart.png)

**Figure 2.** Forecast Water Consumption using Chen Method

### Table 6. Water Consumption Prediction Using FTS Chen Methods and MAPE Value

| Month  | Volume (m³) | Fuzzification | FLR   | FLRG  | Chen Forecast | MAPE  | %  |
|--------|-------------|---------------|-------|-------|---------------|-------|----|
| Jan'17 | 1,542,323   | A1            |       |       | 1,602,115     | 0.05  | 4.64|
| Feb'17 | 1,531,075   | A1->A1        | G1    |       |               |       |     |
| Mar'17 | 1,482,550   | A1->A1        | G1    |       | 1,602,115     | 0.08  | 8.06|
| Apr'17 | 1,674,524   | A2            | A1->A2| G1    | 1,602,115     | 0.04  | 4.32|
| Mei'17 | 1,552,133   | A1            | A2->A1| G2    | 1,648,339     | 0.06  | 6.20|
| Jun'17 | 1,628,890   | A2            | A1->A2| G1    | 1,602,115     | 0.02  | 1.64|
| Jul'17 | 1,475,481   | A1            | A2->A1| G2    | 1,648,339     | 0.12  | 11.72|
| Aug'17 | 1,693,114   | A2            | A1->A2| G1    | 1,602,115     | 0.05  | 5.37|
| Sep'17 | 1,738,058   | A3            | A2->A3| G2    | 1,648,339     | 0.05  | 5.16|
| Okt'17 | 1,712,688   | A3            | A3->A3| G3    | 1,795,415     | 0.05  | 4.83|
| Nov'17 | 1,804,072   | A3            | A3->A3| G3    | 1,795,415     | 0.00  | 0.48|
| Des'17 | 1,753,580   | A3            | A3->A3| G3    | 1,795,415     | 0.02  | 2.39|
| Jan'18 | 1,755,638   | A3            | A3->A3| G3    | 1,795,415     | 0.02  | 2.27|
| Feb'18 | 1,760,083   | A3            | A3->A3| G3    | 1,795,415     | 0.02  | 2.01|
| Mar'18 | 1,705,896   | A2            | A2->A3| G3    | 1,795,415     | 0.05  | 5.25|
| Apr'18 | 1,738,713   | A3            | A2->A3| G3    | 1,648,339     | 0.05  | 5.20|
| Mei'18 | 1,794,671   | A3            | A3->A3| G3    | 1,795,415     | 0.00  | 0.04|
| Jun'18 | 1,716,302   | A3            | A3->A3| G3    | 1,795,415     | 0.05  | 4.61|
| Jul'18 | 1,753,834   | A3            | A3->A3| G3    | 1,795,415     | 0.02  | 2.37|
| Aug'18 | 1,835,558   | A4            | A3->A4| G3    | 1,795,415     | 0.02  | 2.19|
| Sep'18 | 1,902,058   | A4            | A4->A4| G4    | 1,956,498     | 0.03  | 2.86|
| Okt'18 | 1,968,283   | A5            | A4->A5| G4    | 1,956,498     | 0.01  | 0.60|
| Nov'18 | 2,100,222   | A6            | A5->A6| G5    | 1,956,498     | 0.07  | 6.84|
| Des'18 | 1,978,579   | A5            | A6->A5| G6    | 1,956,498     | 0.01  | 1.12|
| Jan'19 | 1,861,209   | A4            | A5->A4| G5    | 1,956,498     | 0.05  | 5.12|
| Feb'19 | 2,021,665   | A5            | A4->A5| G4    | 1,956,498     | 0.03  | 3.22|
| Mar'19 | 1,950,961   | A5            | A5->A5| G5    | 1,956,498     | 0.00  | 0.28|
| Apr'19 | 1,961,783   | A5            | A5->A5| G5    | 1,956,498     | 0.00  | 0.27|
| May'19 | 2,021,682   | A5            | A5->A5| G5    | 1,956,498     | 0.03  | 3.22|
| Jun'19 | 1,782,517   | A3            | A5->A3| G5    | 1,956,498     | 0.10  | 9.76|
| Jul'19 | 2,083,732   | A6            | A3->A6| G3    | 1,795,415     | 0.14  | 13.84|
| Aug'19 | 2,173,437   | A6            | A6->A6| G6    | 1,956,498     | 0.10  | 9.98|
| Sep'19 | 2,125,508   | A6            | A6->A6| G6    | 1,956,498     | 0.08  | 7.95|

**4. Conclusion**

Based on the steps to make predictions water consumption using fuzzy time series begins with the determination of average-based intervals include fuzzification, develop FLR and FLRG, defuzzification, assess a value error with MAPE.

The result is shown:
• The data volume of water consumption actual versus prediction with FTS Chen method shown related stable in each of month (figure 2). There are no significant deviation of data.
• The result of the average value error accuracy was only 4.5% using FTS Chen Method. The error value obtained is included in the low category. If the accuracy error result of MAPE below 10% was included as a high accuracy (Anggrainingsih, Aprianto, & Sihwi, 2015).
• Refer to figure 2 and the average MAPE value shown that the previous actual volume of consumption water still on good and predicting using FTS Chen methods has not yet obtained an optimal volume prediction. And for the future estimation, FTS Chen methods can be used to get an increase in demand.

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