Development of Forecasting Method Concerning Water Demands in the Saitama City Waterworks Service Area

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Abstract. Forecasting the water demands is very important for pure-water reservoirs. Because the value of water supply to the water supply stations cannot be changed frequently according to the variation of water demands. The goal of this study is to propose forecasting method of water demands applying all over the country in Japan. The point of this forecasting method is following three matters. 1) Based multiple regression analysis. 2) Using multiple year's data of the value of water supply per day. 3) Correcting the obtained multipl e regression formula by single regression analysis. In this paper, the value of water supply is forecasted applying proposed forecasting method using the data of water supply per day of Saitama city. In previous studies, forecasting method for a weekday and that for a holiday are proposed, respectively. In this examination, forecasting value of a weekday and a holiday are leaded applying same forecasting method. As the forecasting result, forecasting precision of this examination is equivalent to that of previous studies.

Keywords: Water demands, multiple regression model, estimation of trend, error of forecasting, forecasting precision.

1. INTRODUCTION

The value of water supply to the water supply stations cannot be changed frequently according to the variation of water demands, because management of water resources, e.g., river water, has various restrictions (e.g. the amount of extracted water from a river around unit time, etc.). Therefore forecasting the water demand is very important for pure-water reservoirs. The goal of this study is to propose forecasting method of water demands applying all over the country in Japan. In previous studies, we proposed methods of forecasting the water demands in the middle scale water works area (Kanagawa prefectural), the large scale water works area (Tokyo metropolitan) and the small scale water works area (Okinawa prefectural). These proposed methods were based on a multiple regression analysis, and be considered variations in economic conditions for the service area. We called this method "M method". In addition, forecasting precision was leaded approximately 2% by M method. In this study, we use the data of water supply per day of Saitama city, and we forecast the value of water supply per day. In Saitama prefectural, the data of water supply per day are hold by waterworks bureau of each city. There are 63 of cities in Saitama prefectural. Saitama city is one of major cities of Saitama prefectural. In addition, Saitama city is one of bed towns of Tokyo. The area of Saitama city is 217.5 square kilometers. The population of Saitama city is approximately 1.27 million which is in the ninth rank in Japan. Therefore, the higher forecasting precision of the water demands is needed. The purpose of this paper is to examine applying M method using the data of water supply per day of Saitama city. In addition, it shows that this forecasting precision is equivalent to the forecasting precision of previous studies.

2. CHARACTERISTICS OF WATER SUPPLY OF SAITAMA CITY

In this section, the characteristics of water supply of Saitama city are described.

2.1 Outline of Water Supply of Saitama City

In Saitama prefectural, there are five water purification plants. Each water purification plant sells pure-water to the Waterworks Bureau of each city. In Waterworks Bureau of each city, obtained pure-water and ground water are supplied to each home. The water supply flow of all cities is same. This flow is “a water purification plant – a clean water reservoir – a distributing plant – a distributing reservoir – each home”. In this study, used data of water supply per day are data from a distributing reservoir to each home. On the other hand, the water supply flow of Tokyo metropolitan and Kanagawa prefectural is “a water purification plant – a clean water reservoir – a distributing reservoir – each home”. In previous studies, used data of water supply per day were data from a clean water reservoir to a distributing reservoir. In this study, used data of water supply per day between Saitama city and Tokyo metropolitan and Kanagawa prefectural are assumed same kind.

2.2 Tendency of Amount of Water Supply per Day in Saitama City

In Figure 1, a transition of the value of water supply per day of Saitama city for one year is shown. In Figure 2, a transition of the value of water supply per day of Tokyo metropolitan for one year is shown. Still a transition of the value of water supply per day of Tokyo metropolitan and that of Kanagawa prefectural are similar tendency. As

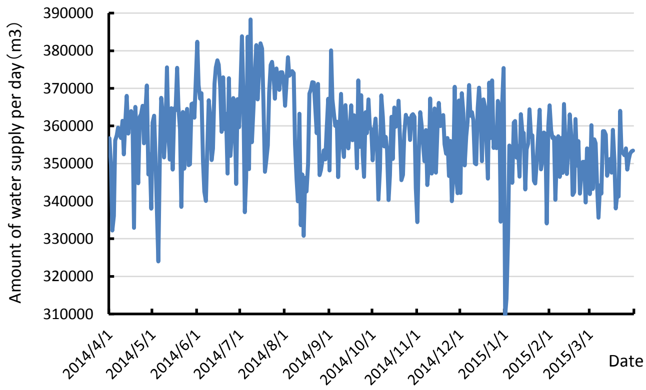


Figure 1: Transition of value of water supply per day of Saitama city

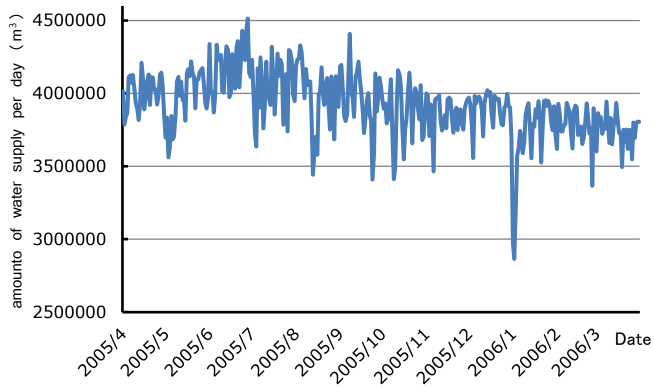


Figure 2: Transition of value of water supply per day of Tokyo metropolitan

shown in Figure 1 and Figure 2, although scale of the value of water supply per day and used data period between Saitama city and Tokyo metropolitan is different, characteristic of transition of the value of water supply per day is that the value of water supply per day in the summer period tends to increase than that in the other seasons period. Thus, a transition of the value of water supply per day of Saitama city and that of Tokyo metropolitan are similar tendency.

In Figure 3, the average value of water supply per day of each day of the week of Saitama city for one year is shown. In Table 1, the difference of the averaged value of water supply per day among day of the weeks (** in Table 1; ** means 1% significance by t-test; * means 5% significance by t-test) is small. In Figure 4, the average value of water supply per day of each day of the week of Tokyo metropolitan for one year is shown. As shown in Figure 3 and Figure 4, although scale of the average value of water supply per day between Saitama city and Tokyo metropolitan is different, characteristic of the average value of water supply per day of each day of the week is that the amount of the average value of water supply per day among

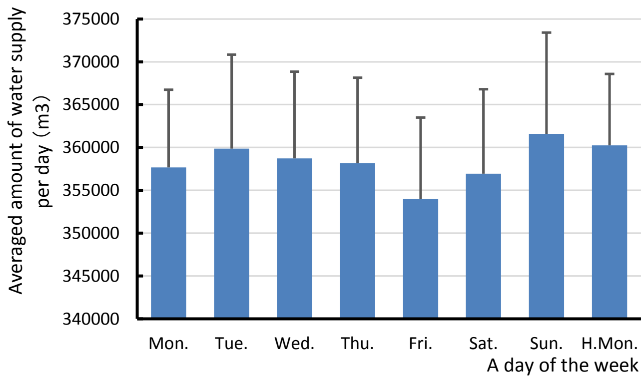


Figure 3: Averaged value of water supply per day of each day of the week in Saitama city

Table 1: Difference of the averaged value of water supply per day among day of the weeks

Factor 1	Factor 2	Decision
Tue.	Fri.	**
Wed.	Fri.	*
Thu.	Fri.	*
Fri.	Sun.	**
Sat.	Sun.	*

*: 5% significance
**: 1% significance

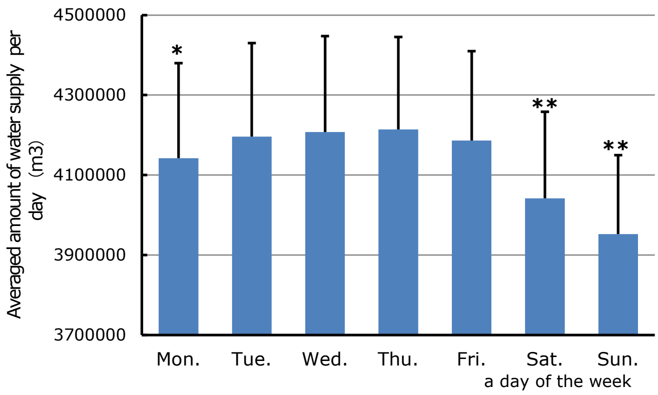


Figure 4: Averaged value of water supply per day of each day of the week in Tokyo metropolitan

each day of the week of Saitama city is smaller than that of Tokyo metropolitan. Especially, in Tokyo metropolitan, the amount of the average value of water supply per day between weekday (from Monday to Friday) and holiday (Saturday and Sunday) is large (** in Figure 4; ** means 1% significance by t-test; * means 5% significance by t-test). By this condition, in previous studies, we proposed the forecasting method of water supply per day for a weekday and that for a holiday, respectively.

3. OUTLINES OF FORECASTING METHOD OF WATER SUPPLY PER DAY

In this section, outlines of proposed forecasting method of water supply per day in previous studies are explained briefly. In this study, only proposed forecasting method of water supply per day for a weekday is applied. Because, the amount of scatter of the average value of water supply per day among each a day of the week is small as shown in Figure 5. The point of this forecasting method is following three matters. 1) Based multiple regression analysis. 2) Using multiple years data of the value of water supply per day. 3) Correcting the obtained multiple regression formula by single regression analysis. The notations are defined as follows:

- Y : A variable representing the year in the western calendar.
- M : A variable representing the month (M = 1, …, 12)
- D : A variable representing a specific day of the year (D = 1, …, 366). A value of D=1 corresponds to January 1st, and D=366 corresponds to December 31th. The date on February 29th is assumed to exist even in non-leap years, and is treated as a missing day in the actual data
- D_M : The first weekday of the year and month of the date of forecasting
- t : A variable representing period of using data to make forecasting formula. In this study, this variable is called “regression period”.
- x_i : Explanatory variables ($i = 0, 1, \cdots, m$)
- $\hat{a}_i^{(Y-j)}$: Estimator of the partial regression coefficients for Y - j year ($i = 0, 1, \cdots, m;\ j = 1, 2, \cdots, n$)
- m : Numbers of explanatory variable
- n : Numbers of past year

In addition, the procedure of this forecasting meth od consists of following five steps.

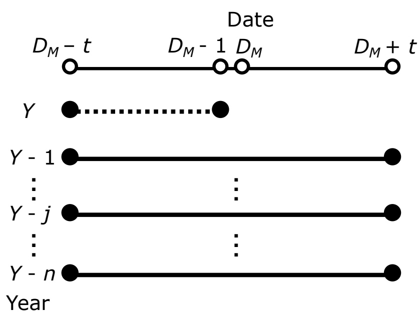


Figure 5: Used data range for multivariate regression analysis

Step 1 is collecting the data of weather information and so on which are correlative to the value of water supply per day by correlation analysis for regression period as shown in Figure 5. In Figure 5, horizontal axis represents date, and vertical axis represents year.

Step 2 is making the multiple regression formula for each year using collected data in Step 1. The obtained multiple regression formula is expressed in equation (1).

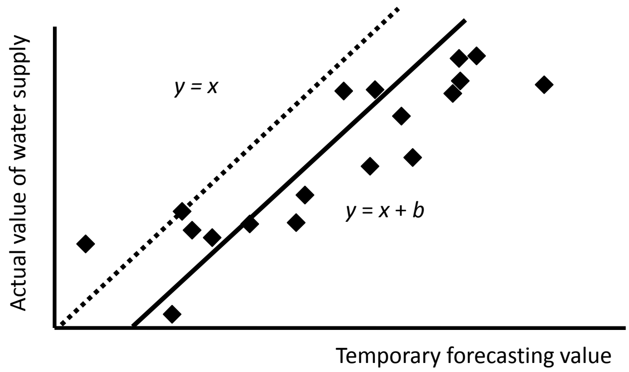
$$\hat{Z}^{(Y-j)} = \sum_{i=0,j=1}^{m,n} \hat{a}_i^{(Y-j)} x_i, (x_0 \equiv 1) \quad (1)$$

Thus, n of multiple regression formulas are obtained by multiple regression analysis.

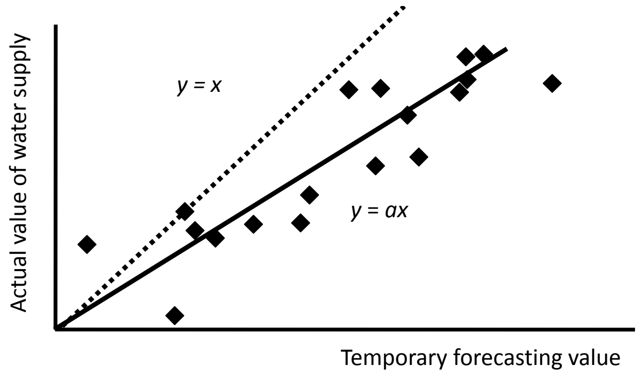
Step 3 is calculating the temporary forecasting value of water supply per day from D_M - t in Y year to D_M - 1 in Y year (period of a dotted line in Figure 5) using obtained n of multiple regression formulas.

Step 4 is correcting each obtained multiple regression formula by three correction methods with correlation between the actual value of water supply per day and the calculated temporary forecasting value of water supply per day in Step 3. In Figure 6, the concept of correction method is shown.

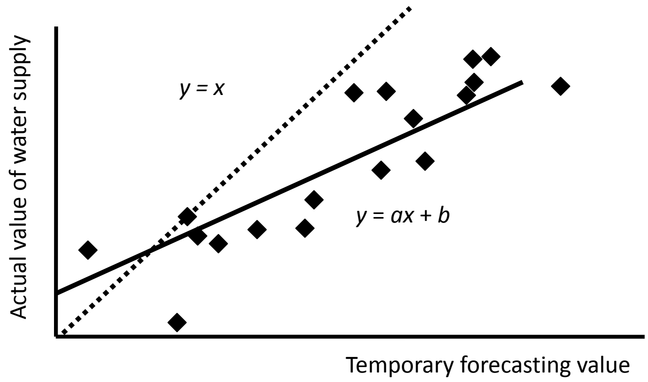
In each figure, horizontal axis represents temporary forecasting value, and vertical axis represents actual value of water supply per day. And the relationship of these values is examined. About this examination, the obtained temporary forecasting values should be ideally exhibited the actual value of water supply per day ($y = x$). As shown in this figure, however, the obtained temporary forecasting values are deviated from actual value of water supply per day. One of the reasons can be considered an annual fluctuation of economic variations and so on. Then, it assumes that a linear relationship is established between the temporary forecasting values and actual value of water supply per day. In order to minimize this deviation, the obtained temporary forecasting values are corrected by assumed three kinds of linear relationship. In this study, each correction method is called "Increment type" (Figure 6(a)), "Proportional type" (Figure 6(b)) and "Regression type" (Figure 6(c)), respectively. In "Increment type", it assumes that an annual fluctuation ensures constant increase to past years (it is assumed $y = x + b$). The obtained multiple regression formula is corrected applying the obtained estimator of increase amount ($\hat{\delta}_1$) by single regression analysis. In "Proportional type", it assumes that an annual fluctuation ensures constant ratio to past years (it is assumed $y = ax$). The obtained multiple regression analysis is corrected applying the obtained estimator of ratio ($\hat{\beta}_1$) by single regression analysis. In "Regression type", an annual fluctuation ensures constant increase and ratio to past years (it is assumed $y = ax + b$). The obtained multiple regression formula is corrected applying the



(a) Increment type



(b) Proportional type



(c) Regression type

Figure 6: Concept of correction method

obtained estimators of increase amount and ratio ($\hat{\beta}_2, \hat{\delta}_2$) by single regression analysis. Thus, n of corrected multiple regression formula are obtained.

Step 5 is averaging the corrected n of multiple regression formula. And this averaged formula is the forecasting formula. The forecasting formulas of each correction method are expressed in equation (2) to (4), respectively.

• Incremental type

$$\widehat{W}_1 = \frac{1}{n}\sum_{j=1}^{n}\left(\hat{Z}^{(Y-j)} + \hat{\delta}_1^{(Y-j)}\right) \tag{2}$$

• Proportional type

$$\widehat{W}_2 = \frac{1}{n}\sum_{j=1}^{n}\hat{\beta}_1^{(Y-j)}\hat{Z}^{(Y-j)} \tag{3}$$

• Regression type

$$\widehat{W}_3 = \frac{1}{n}\sum_{j=1}^{n}\left(\hat{\beta}_2^{(Y-j)}\hat{Z}^{(Y-j)} + \hat{\delta}_2^{(Y-j)}\right) \tag{4}$$

Actually, one correction method is selected from three kinds of correction method. A forecasting value of water supply per day is calculated substituting weather information and so on of forecasting day for the forecasting formula.

4. RESULTS OF FORECASTING VALUE OF WATER SUPPLY PER DAY

In this section, results of forecasting value of water supply per day of Saitama city are shown. Firstly, used data period, evaluation period and explanatory variables are set.

4.1 Used Data Period

The data of the value of water supply per day offered by Saitama City Waterworks Bureau are used from April 1st 2010 to March 31th 2015 for five years. And, the data of weather information for used data period are downloaded from website of Japan Meteorological Agency. Regression period sets 42days (t = 42 in Figure 5). Past year sets 4 years (n = 4 in Figure 5).

4.2 Evaluation Period

The forecasting values of water supply per day are evaluated from January 1st 2015 to March 31th 2015 for three months. Still, the forecasting values of water supply per day for this evaluation period are calculated assuming no data existence of water supply per day for this evaluation period.

4.3 Explanatory variables of Multiple Regression analysis

Explanatory variables of multiple regression analysis are set from two categories (weather information and a day of the week). About weather information, Maximum daily temperature, maximum daily temperature squared, temperature difference between today and yesterday, rainy in the morning, rainy in the afternoon, cloudy in the morning, cloudy in the afternoon, cloudy after sunny in the morning, cloudy after sunny in the afternoon, sunny after cloudy in the morning and sunny after cloudy in the afternoon (totaled 11 factors) set to explanatory variables. About a day of the week, Friday and Saturday (totaled 2 factors) set to explanatory variables. Thus, totaled 13 factors set to explanatory variables.

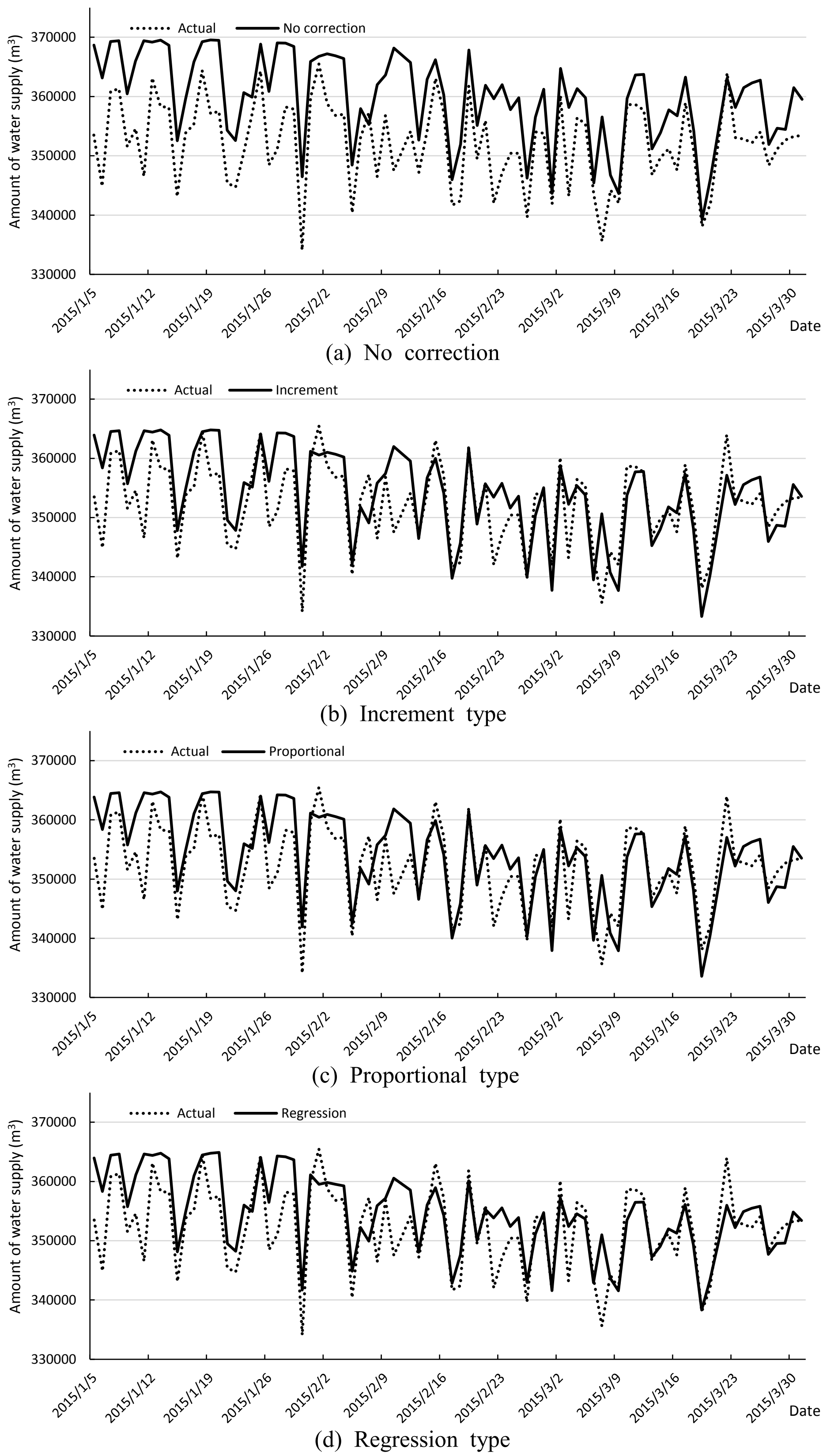
4.4 Result of Forecasting Value of Water Supply per Day

In Table 2, a part of result of forecasting value of water supply per day in evaluation period of this study is shown. As shown in Table 2, result of forecasting value of water supply per day is different among correction methods and among dates.

In addition, results of difference between forecasting values of each correction type and actual amount of water supply per day in evaluation period are shown in Figure 7. As shown in Figure 7(a), there is a little differences between forecasting values of “No correction” and actual amount of water supply per day. There, however, is little differences between forecasting values of three types of correction (“Increment” (Figure 7(b)), “Proportional” (Figure 7(c)) and “Regression” (Figure 7(d))) and actual amount of water supply per day (Figure 7(a)). Moreover, there is a little differences between forecasting values of three types of correction and that of “No correction”. Therefore, it is found that proposed three types of correction methods are effective for forecasting value of water supply per day in this evaluation period.

Table 2: Part of result of forecasting value of water supply per day in evaluation period (Unit: m^3)

	Acutual value	No correction	Increment	Proportional	Regression
2015/1/5	353510	368671.86	363928.85	363856.47	363949.84
2015/1/6	344860	363136.19	358393.17	358368.12	358308.16
2015/1/7	360890	369271.05	364528.03	364436.78	364432.51
2015/1/8	361320	369406.78	364663.77	364578.74	364625.63
2015/1/9	351560	360473.60	355730.58	355761.62	355761.15
		⋮			



(a) No correction

(b) Increment type

(c) Proportional type

(d) Regression type

Figure 7: Differences between forecasting values and actual amount of water supply per day in evaluation period

5. EVALUATION OF FORECASTING PRECISION OF WATER SUPPLY PER DAY

In this section, forecasting precision of water supply per day of Saitama city are evaluated.

5.1 Evaluation Method

In this study, the evaluation method is expressed in equation (5).

$$q = \frac{|(Forecasting\ Value) - (Actual\ Value)|}{(Actual\ Value)} \times 100 \quad (\%) \tag{5}$$

As shown in equation (5), forecasting precision (q) is evaluated using the absolute value of relative error ratio of forecasting value of water supply per day to actual value of that.

5.2 Forecasting Precision of Water Supply per Day

In Table 3, a part of forecasting precision in evaluation period of this study is shown. In Table 3, the values of"No collection"are forecasted without applying correction method. As shown in Table 3, result of forecasting precision of water supply per day is different among correction methods and among dates. In addition, the absolute values of relative error ratio drawn background represent highest forecasting precision in each day. In table 4, forecasting precision is evaluated using the absolute value of averaged relative error ratio for each month in evaluation period of this study. In addition, the absolute values of relative error ratio drawn background represent highest forecasting precision in each month. As shown in Table 4, forecasting precision of "Regression type" of correction method becomes highest in evaluation period of this study. Moreover, forecasting precision of "Regression type" of correction method becomes highest in all evaluation period of this study. This forecasting precision is 1.16%. This precision is higher than that of previous studies (approximately 2%).

Table 4: Averaged forecasting precision of each month and all period in evaluation period (Unit: %)

	No correction	Increment	Proportional	Regression
Jan. 15'	2.94	1.65	1.65	1.66
Feb. 15'	2.29	1.06	1.06	1.10
Mar. 15'	1.56	0.93	0.91	0.73
All periods	2.26	1.21	1.21	1.16

6. CONCLUTION

In previous studies, we proposed four kinds of methods of forecasting the water demands using data of value of water supply per day offered by three of self-governing bodies. And, forecasting precision is leaded approximately 2%. In this study, the amount of water supply per day is forecasted applying proposed forecasting method using the data of water supply per day of Saitama city. In Saitama city, the amount of scatter of the average value of water supply per day among each a day of the week is small. Therefore, only proposed forecasting method of water supply per day for a weekday is applied. From this application, forecasting precision is leaded approximately 1.2% in evaluation period of this examination. In addition, forecasting precision of "Regression type" of correction method becomes highest in this evaluation period of this study. As the results of this examination, it is found out that forecasting precision of this examination is higher than the forecasting precision of previous studies.

The feature tasks are considered following subject.

- Development of correction method
- Improvement of forecasting precision using data of amount of sewerage

Table 3: Part of result of forecasting precision of water supply per day in evaluation period (Unit: %)

Date	No correction	Increment	Proportional	Regression
2015/1/5（Mon.）	4.29	2.95	2.93	2.95
2015/1/6（Tue.）	5.30	3.92	3.92	3.90
2015/1/7（Wed.）	2.32	1.01	0.98	0.98
2015/1/8（thu.）	2.24	0.93	0.90	0.91
2015/1/9（Fri.）	2.54	1.19	1.20	1.20
2015/1/10（Sat.）	3.21	1.87	1.85	1.84
2015/1/11（Sun.）	6.60	5.23	5.21	5.22
2015/1/12（Mon.）	1.66	0.36	0.33	0.35
2015/1/13（Tue.）	3.13	1.81	1.79	1.80
2015/1/14（Wed.）	2.93	1.61	1.58	1.58
		⋮		

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