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Mathematical forecasting simulation of salinity intrusion in Chao Phraya River

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Abstract

At present, at two water stations along Chao Phraya River, the main river of the central region of Thailand, the salinity in the river exceeds the raw water salinity standard for tap water production that must be lower than 0.25 g/L. During December to May, since 2013, the salinity value exceeded the raw water standard, strongly affecting the raw water management of Metropolitan Waterworks Authority. Surveillance and prediction of salinity level at the river mouth at Klong Lat Pho Water Quality Monitoring Station, downriver from Sam Lae station, in advance, will be beneficial to the Metropolitan Waterworks Authority's raw water management. The purpose of this study was to forecast the hourly salinity levels at Khlong Lat Pho Water Quality Monitoring Station. The methods used were Exponential Smoothing and Winter's Linear and Seasonal and Exponential Smoothing (EXPOW). Both forecasting methods showed a very low mean of square error (MSE): 0.1551 when the exponential smoothing method was used with alpha= 0.9995 and 0.4869 when the EXPOW was used with alpha = 0.0618, gamma = 0.9995, and beta = 0. 0001. Nevertheless, the exponential smooth method fell out of favor since, for long-term prediction, its predicted value converged to a constant value, 0.2405, useless for predicting seasonal variation. On the other hand, the EXPOW method, even though less effective in terms of MSE, produced more reliable short and long-term forecasts for salinity at Khlong Lad Pho Water Quality Monitoring Station.

Subject Classification: *90C46.*

Keywords: *Salinity intrusion, Mathematical forecasting models, Chao Phraya River.*

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1. Introduction [1, 2]

1.1 *Saltwater intrusion*

Saltwater intrusion is a natural phenomenon in estuary tidal river network regions. Currently, there is an increasing trend of shortage of fresh water for various population activities caused by global warming—drought conditions and intermittent rain. These conditions, in turn, affect the problem of saltwater intrusion into freshwater area at the mouth of the Chao Phraya River Basin, the main river of the central region of Thailand. People along the river rely on the water in it to support their agriculture and industry. In 2017, Chao Phraya River experienced a state of saltwater intrusion earlier than usual, and the salinity value was severely higher than the standard because of unusually low level of freshwater in the river; the saltwater rose up where the sea water rose through Samut Prakan Province and went up all the way to Phra Nakhon Si Ayutthaya Province as shown in Figure 1. A serious impact on tap water production occurs when the salinity exceeds the value of raw water salinity standard, lower than 0.25 grams per liter, with an average volume of raw water pumping about 4.5 million cubic meters per day. The highest salinity observed was 1.92 g/L at Khlong Lat Pho Water Quality Monitoring Station and Sam Lae Raw Water Pumping Station, as shown in Figure 2. Surveillance threshold was 0.25 g/l for producing tap water not more than 0.50 g/L and salinity control criteria for agriculture was not more than 2.00 g/L. Therefore, a consistent salinity forecast in the downstream area at the Khlong Lat Pho water quality monitoring station and Sam Lae raw water pumping station predicted in advance will benefit the raw water management of the Metropolitan Waterworks Authority, especially from December to May of every year [1,2,3].

1.2 *Study area and data*

Chao Phraya river originates at Pak Nam Pho, Nakhon Sawan Province. It flows to the Gulf of Thailand through the central plain out to the sea at Samut Prakan. The length of Chao Phraya River down to the mouth of the Gulf of Thailand is about 379 kilometers. In this study, the area downstream of the Chao Phraya Dam was investigated, starting from Khlong Lat Pho Water Quality Monitoring Station and Sam Lae Pumping Station, in Figure 1 and Figure 2, respectively [1,2,3].

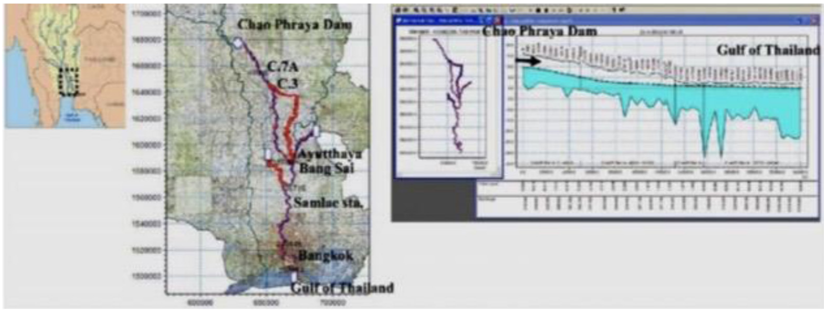


Figure 1

Lower Chao Phraya River and levels of seawater intrusion along the river [1,2,3]

Figure 2

Real-time map of the monitoring stations focused in this study [1,2,3]

The data used in this study were hourly salinity water quality data. Covering the years 2020-2022, all data were collected from the Metropolitan Waterworks Authority, for a total of 730 days and a total of 17,520 data points.

There have been many researchers who investigated water-quality models used for streams and rivers. In [4], the study used salinity data at Sam-Lae pumping station as a target variable to predict salinity level at any time of year. The predicted values 24-hour in advance were close to the actual values. In [5], this study was to predict hourly salinity values at Sam-Lae pumping station with an artificial neural network model. It was found that the model was satisfactory. In [6], hourly salinity values at Sam-Lae stations were predicted using artificial neural network model trained by Levenberg-Marquardt correlation of such data during the years 2013-2014. The predicted values were found to be close to the actual values. In [7], a model was developed to forecast saltwater intrusion for Thachin River using Multilayer Perceptron Neural Network. It was able to give good prediction for 7 days in advance. In [8], two machine learning approaches to forecast salinity time series data for multistep times: random forest (RF) models and extreme learning machine (ELM) model were successfully developed. In [9], the study was conducted to develop a hybrid model coupling the techniques of wavelet transform (WT) and artificial neural network (ANN) for forecasting estuarine salinity in the Pearl River Estuary, China. The resulting forecast lead time was extended from 1 to 3 days. In [10], it was suggested that the simple Exponential Smoothing method (SES) model is an easy-to-use modeling tool for water resource managers to obtain a quick preliminary assessment of salinity intrusion. In [11], the study investigated uncertainty in salinity forecasts imposed by limitations on data available to calibrate and apply a mass balance salinity model in the Barataria basin, Louisiana, and the authors suggested that data need to be validated before an analysis. In [12], five forecasting techniques were applied on two data sets gained from the Palestinian Water Authority of Deir El-Balah City: salinity rates and groundwater levels (GL). The used forecasting algorithms were: exponential smoothing (ETS), state space model with Box–Cox transformation, ARMA errors, trend and seasonal components (TBATS), auto-regressive integrated moving average (ARIMA), ARIMA combined with: neural network (NN), ETS, and TBATS model. The most effective model was ARIMA. In [13], The authors explored a number of model candidates based on two common fitting methods: multiple linear regression and the artificial neural network. According to the test results, the salinity can be accurately forecasted with an RMSE of 0.054 g L–1 at a forecast period of 24 h and up to 0.107 g L–1 at a forecast period of 120 h.

The objective of this study was to develop simple salinity forecasting model that would be able to give accurate prediction instantly. Specifically, the purpose of this study was to forecast hourly salinity values at Khlong Lad Pho Water Quality Monitoring Station as a preliminary guideline for early warning with Exponential Smoothing and Winter's Linear and Seasonal and Exponential Smoothing (EXPOW) models.

2. Mathematical Forecasting Models [14,15]

In forecasting the data $t+1$, observations of time t, $t-1$, $t-2$, $t-3$, ..., $t-n$ collected in large numbers can be taken advantage of. Weather forecast system, meteorological department warning, and water resource warning will know the time period to forecast in advance [15].

These techniques can be used to forecast monthly rainfall [4,5,6,7] and salinity encroachment in the Chao Phraya River due to sea level rise, by studying the hourly salinity data report from Khlong Lat Pho Water Quality Monitoring Station [16]. Forecasting salinity levels is vital to the metropolitan Waterworks Authority as a whole, as it provides the basic inputs for the planning and control of all water management.

Causal forecasting methods attempt to forecast future values of a variable (called the dependent variable) by using past data to estimate the relationship between the dependent variable and one or more independent variables. Two causal forecasting models were used in this study. They are explained below.

2.1 *Exponential Smoothing [14,15]*

Exponential smoothing is a time-series mathematical forecasting technique from past data. The formula is simple and most suitable for short-term prediction. However, it is not suitable for long-term prediction. The size of the data set (i.e., how far the record is) does not strongly affect the prediction outcomes. Below describes this method in detail.

2.1.1 Single Exponential Smoothing

Single exponential smoothing model is a forecasting model that is suitable for modeling linear trend data points with no seasonal variance. It is most suitable for short to medium-term prediction. To make a prediction, at least 5 data points at different time periods of the day needed to be processed. The model can make predictions for any and more than one time period. Initially, a parameter α for each time period needs to be optimized separately.

From the forecast equation of the moving average method,

$$F_{t+1} = (X_t + X_{t-1} + \ldots + X_{t-N+1}) / N,$$

$$F_{t+1} = (X_t / N) + (X_{t-1} + X_{t-2} + \ldots + X_{t-N+1}) / N,$$

and from $$F_t = (X_{t-1} + X_{t-2} + \ldots + X_{t-N+1} + X_{t-N}) / N,$$

$$F_{t+1} = (X / N) + (F_t - X_{t-N}) / N, \tag{1}$$

but since X_{t-N} cannot be determined directly, time series datasets are stationary, and there was no pattern in the data, so X_{t-N} is estimated from F_{t+1}. From equation (1),

$$F_{t+1} = (X / N) + F_t - (F_t / N)$$

$$F_{t+1} = (1 / N) X_t + (1 - (1 / N)) F_t$$

Set the weighted value $1/N$ for the most current data value and weight $(1-(1/N))$ for the most current forecast value, given $\alpha = 1/N$ and $0 < \alpha < 1$ The forecasting equation is

$$F_{t+1} = \alpha X_t + (1-\alpha) F_t \tag{2}$$

This equation is the basic model used for calculating future salinity level. Equation (2) can be distributed in the form of historical data values, which are

$$F_{t+1} = \alpha X_t + (1-\alpha)[\alpha X_{t-1} + (1-\alpha) F_{t-1}],$$

$$F_{t+1} = \alpha X_t + \alpha(1-\alpha) X_{t-1} + (1-\alpha)^2 F_{t-1},$$

$$F_{t+1} = \alpha X_t + \alpha(1-\alpha) X_{t-1} + (1-\alpha)^2 [\alpha X_{t-2} + (1-\alpha) F_{t-2}],$$

$$F_{t+1} = \alpha X_t + \alpha(1-\alpha) X_{t-1} + \alpha(1-\alpha)^2 X_{t-2} + (1-\alpha)^3 X_{t-3} + \ldots . \tag{3}$$

Equation (2) can also be distributed as,

$$F_{t+1} = \alpha X_t + F_t - \alpha F_t = F_t + \alpha [X_t - F_t], \tag{4}$$

and $e_t = X_t - F_t$ is the discrepancy in the agenda *t* (residual),

$$F_{t+1} = F_t + \alpha e_t . \tag{5}$$

An input can be a time series of some variables at given times, and the output will be a predicted value for a future time. For example, in this study, the input is a collection of hourly salinity data at a given period, and the output is the salinity level at a future time period.

2.1.2 Winter's Linear and Seasonal Exponential Smoothing (EXPOW) [15]

Winter's Linear and Seasonal Exponential Smoothing model, modified from Holt's Exponential Smoothing Method, is a forecasting model that is suitable for time series data points that vary with seasonal trend. It is most suitable for short to medium-term prediction. The data points should be collected on hourly, daily, weekly, monthly, or quarterly basis. For hourly data, there should be sufficient data points for at least 72 hours; for daily data, at least 365 days; for monthly data, at least 36 months, and for quarterly data, at least 12 quarters. The principal equations of this model are equations for determining smoothing value, St, and trend value, and an auxiliary equation is an equation for estimating seasonal variance.

This forecasting method operates similarly to the double exponential smoothing method but has the unique advantage of combining the adjusted seasonal factors as well as the double exponential smoothing method. With the adjusted trend factor, this method can forecast time series data with seasonal factors and trend factors. The related equations are as follows,

Smoothing equation: $S_t = \alpha[X_t / I_{t-L}] + (1-\alpha)(S_{t-1} + b_{t-1}),$

Trend determination equation: $b_t = \gamma(S_t - S_{t-1}) + (1-\gamma)b_{t-1},$

Seasonal equation: $I_t = \beta(X_t - S_t) + (1-\beta)I_{t-L}.$

The prediction equation is

$$F_{t+m} = (S_t + b_t m)I_{t-L+m}, \tag{6}$$

where $0 < \alpha < 1,\ 0 < \beta < 1,$ and $0 < \gamma < 1.$

In the equations above, L is the length of the season

I It is an adjusted season factor (seasonal adjustment factor)

S_t = smoothing value at t,

b_t = trend value at t,

I_t = seasonal estimate at t,

α = smoothing constant, $0 < \alpha < 1$,

γ = slope constant, $0 < \beta < 1$,

β = seasonal constant, $0 < \gamma < 1$,

X_t = observed value at t,

m = future prediction time period, $m = 1, 2, 3, \ldots$

F_{t+m} = predicted value at $t + m$.

2.1.3 Prediction error [14,15]

Accuracy and reliability are most important in forecasting. The higher the prediction accuracy, the more likely that a water management scheme will be effective and on time. However, prediction error is inevitable.

Prediction error is the difference between actual measured value and predicted value, expressed mathematically as

$$e_t = \left| X_t - F_t \right|, \tag{7}$$

where F_t = predicted forecast salinity level at

X_t = actual measured salinity level at

e_t = error at

In this study, Mean Square Error (MSE) is the selected error measure,

$$MSE = \sum_{t=1}^{n} \frac{(actual - forecast)^2}{n} = \frac{\sum_{t=1}^{n} (e_t)^2}{n}. \tag{8}$$

3. Methodology

3.1 *Time Series Analysis of Hourly Salinity for Forecasting a Case Study of the Chao Phraya River at Khlong Lat Pho Water Quality Monitoring Station. The researcher conducted the research in 4 steps as follows.*

1. Extracting information from the system (Export Data)
2. Determining lost data: by good data management, it was found that no data was lost. Officials of the Metropolitan Waterworks Authority at Khlong Lat Pho Water Quality Monitoring Station Data on salinity in the Chao Phraya River had collected hourly data daily from July 1, 2020 to June 30, 2022 in its entirety. Therefore, the data format suited the forecasting models.
3. Salinity analysis and forecasting by the exponential smoothing method (Exponential Smoothing Method) and Winter's exponential

smoothing method (Winter's Exponential Smoothing Method). The two forecasting models were compared based on Mean Square Error.

4. From the more effective technique, predictions for future time was processed, at 24-hour, 72-hour, and 120-hour in the future.

3.2 *Graphs of salinity level*

The hourly salinity data of the Chao Phraya River at the Khlong Lat Pho Water Quality Monitoring Station for 730 days, totaling 17,520 data points, were used to construct a forecasting model suitable for the movement of the data. It started from plotting the data as a line graph showing the salinity and time data (Figure 3). The trend of the data tended to repeat in every 24-hour period. Between 13:00 and 16:00 was the time when the salinity level in the Chao Phraya River was lower than other times. Then, it would gradually increase until 20.00 - 21.00. The salinity level in the Chao Phraya River would be the highest. Then, it would gradually decrease to a low during 01.00 - 02.00 hrs and then increase to its highest value during 04.00 - 06.00 hrs. each day (Figure 4).

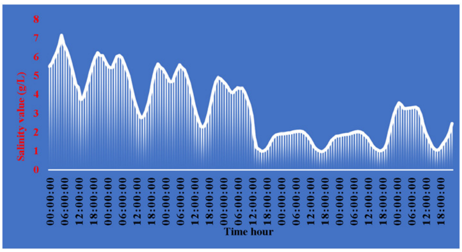


Figure 3

Graph showing hourly salinity at Khlong Lat Pho Water Quality Monitoring Station since 1 July 2020 – 30 June 2022 (720 hours)

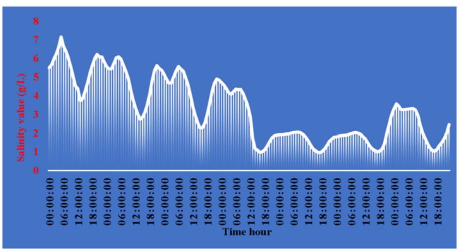


Figure 4

Graph showing hourly salinity at Khlong Lat Pho Water Quality Monitoring Station since 1 July 2020 – 30 June 2022 (168 hours)

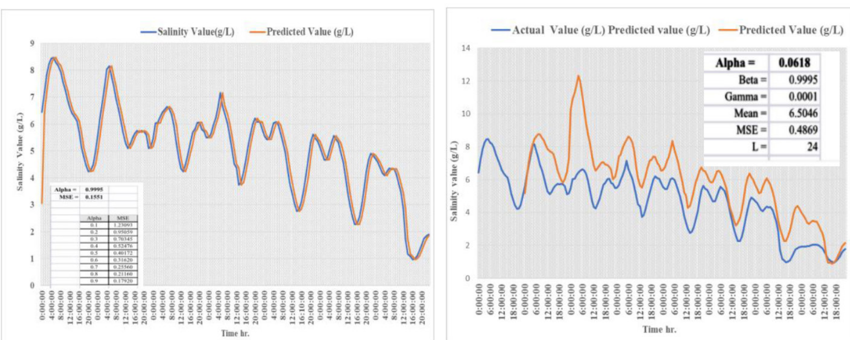
3.3 *Comparison of single exponential smooth versus EXPOW*

Time series prediction of this data set using exponential smoothing method using alpha = 0.9995 obtained MSE = 0.1551, and when using Winter's exponential smoothing method, with alpha = 0.0618, gamma = 0.9995, beta = 0.0001, the MSE was 0.4869, as shown in Table 1 and Figure 5 and 6. Both forecasting methods showed very low mean squared error.

Table 1

The mean squared error (MSE.) of the salinity of the Chao Phraya River at Khlong Lat Pho Water Quality Monitoring Station according to both forecasting models.

Forecasting	MSE. (N=17,520, L=24)
Exponential Smoothing Method	0.1551
Winter's Exponential Smoothing Method	0.4869



(a) (b)

Figure 5

Graphs (a) and (b) show time series analysis of salinity values for Exponential Smoothing and Method and Winter's Exponential Smoothing Method in the Chao Phraya River at Khlong Lat Pho Quality Monitoring Station

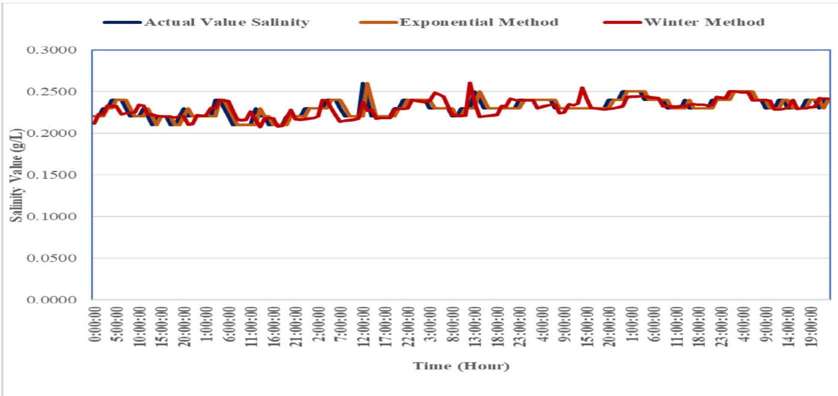


Figure 6

Compare Salinity Actual value (g/L) and Predicted value by Exponential Model and Winter Model period 24-30/06/2022

3.4 *Hourly Salinity Forecast*

Although, single exponential smoothing seemed to be more accurate with the lower MSE of 0.1551, in making prediction, it failed to give robust results. when forecasting 24 hours in advance, the predictions were found to converge to a constant value of 0.2405. On the other hand, the EXPOW which can deal with seasonal changes well provided more reliable forecast values. (Figure 3, 4, 7, 8, 9 and Table 2, 3).

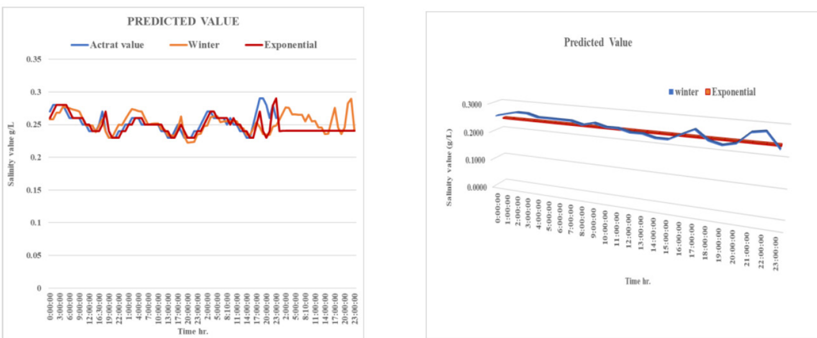
Table 2

Hourly Salinity Forecast of Khlong Lat Pho Water Quality Monitoring Station for 24 hours, 03/07/2022

Time	Predicted value	
	Winter's Exponential Smoothing Method (g/L)	Single exponential Smoothing Method (g/L)
0:00:00	0.2578	0.2402
1:00:00	0.2673	0.2405
2:00:00	0.2762	0.2405
3:00:00	0.2756	0.2405
4:00:00	0.2655	0.2405
5:00:00	0.2657	0.2405

Contd...

6:00:00	0.2653	0.2405
7:00:00	0.2650	0.2405
8:00:00	0.2551	0.2405
9:00:00	0.2650	0.2405
10:00:00	0.2551	0.2405
11:00:00	0.2554	0.2405
12:00:00	0.2455	0.2405
13:00:00	0.2458	0.2405
14:00:00	0.2358	0.2405
15:00:00	0.2361	0.2405
16:00:00	0.2562	0.2405
17:00:00	0.2757	0.2405
18:00:00	0.2454	0.2405
19:00:00	0.2355	0.2405
20:00:00	0.2454	0.2405
21:00:00	0.2829	0.2405
22:00:00	0.2899	0.2405
23:00:00	0.2404	0.2405



(a) (b)

Figure 7

Graph showing hourly salinity forecast of Khlong Lat Pho 24-hour water quality monitoring station 03/07/2022

Table 3

Hourly salinity value and hourly salinity forecast value of Khlong Lat Pho 24-hour water quality monitoring station 01/07/2022

Time	Actual Value (g/L)	Predicted value	
		Winter's Exponential Smoothing Method (g/L)	Exponential Smoothing Method (g/L)
0:00:00	0.24	0.2414	0.2400
1:00:00	0.25	0.2515	0.2400
2:00:00	0.25	0.2514	0.2400
3:00:00	0.26	0.2514	0.2400
4:00:00	0.26	0.2514	0.2400
5:00:00	0.25	0.2513	0.2400
6:00:00	0.26	0.2412	0.2400
7:00:00	0.25	0.2412	0.2400
8:00:00	0.24	0.2411	0.2400
9:00:00	0.24	0.2317	0.2400
10:00:00	0.25	0.2322	0.2400
11:00:00	0.24	0.2321	0.2400
12:00:00	0.24	0.2414	0.2400
13:00:00	0.24	0.2408	0.2400
14:00:00	0.24	0.2307	0.2400
15:00:00	0.24	0.2313	0.2400
16:00:00	0.24	0.2313	0.2400
17:00:00	0.24	0.2313	0.2400
18:00:00	0.27	0.2407	0.2400
19:00:00	0.24	0.2401	0.2400
20:00:00	0.23	0.2396	0.2400
21:00:00	0.23	0.2303	0.2400
22:00:00	0.23	0.2404	0.2400
23:00:00	0.24	0.2404	0.2400

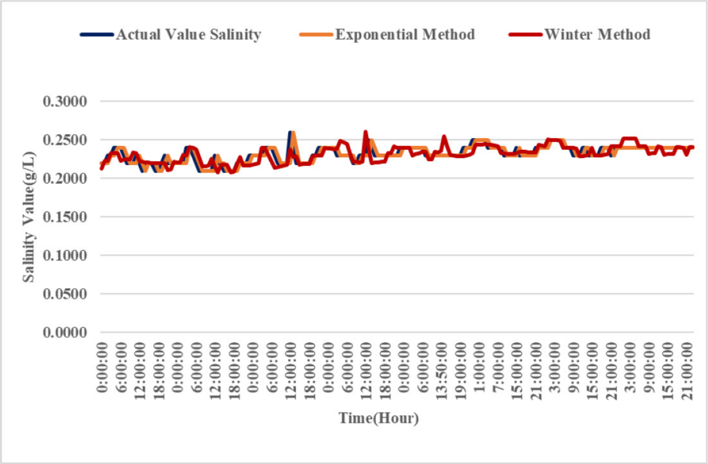


Figure 8

Graph comparing Actual value(g/L) and Predicted value(g/L) by Exponential Model and Winter Model and hourly salinity forecast of Khlong Lat Pho Water Quality Monitoring Station 24 hours in advance salinity forecast (24-30/6/2022 and Predicted value 01/07/2022 (24 Hours)).

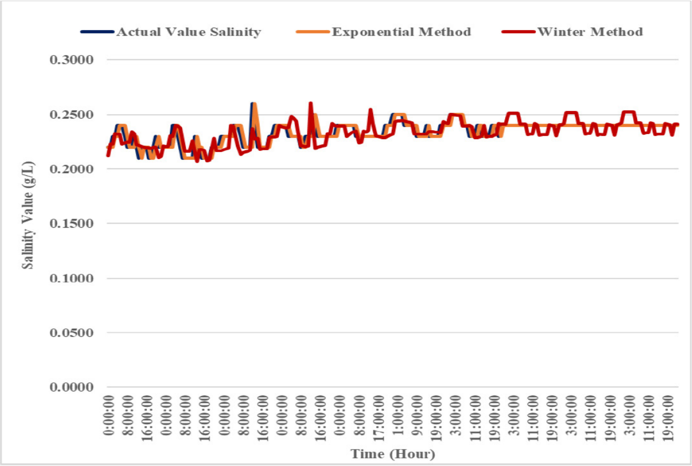


Figure 9

Graph showing Compare Actual value(g/L) and Predicted value(g/L) by Exponential Model and Winter Model and hourly salinity forecast of Khlong Lat Pho Water Quality Monitoring Station 72 hours in advance salinity forecast (24-30/6/2022 and Predicted value 1-3/7/2022 (72 Hours)).

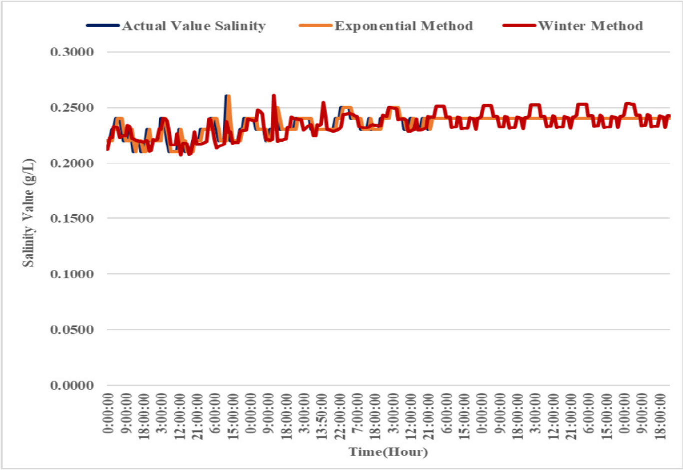
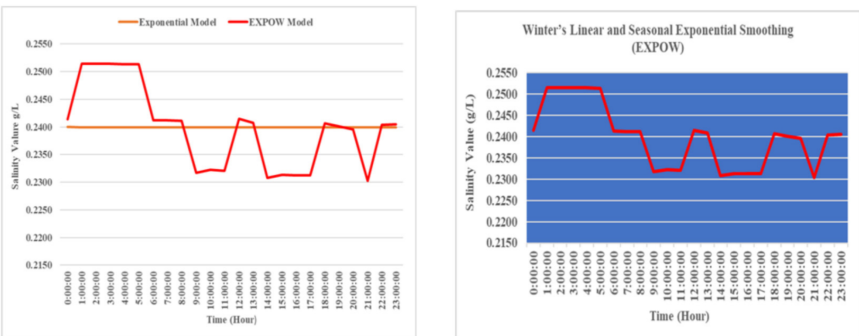


Figure 10

Graph comparing Actual value(g/L) and Predicted value(g/L) by Exponential Model and Winter Model and hourly salinity forecast of Khlong Lat Pho Water Quality Monitoring Station 120 hours in advance salinity forecast (24-30/6/2022 (and Predicted value 1-5/7/2022 (120 Hours)).

To show our final forecast clearly, Figure 10, Figure 11, Figure 12 and Figure 13 show the forecast made by EXPOW, the technique of choice.



(a) (b)

Figure 11

In advance salinity forecast by Winter Model (24 Hr.) 01/07/2022

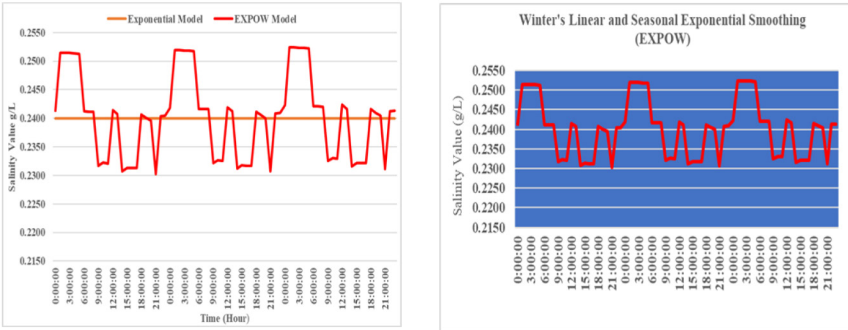


Figure 12

In advance salinity forecast by Winter Model (72 hr.) 01-03/07/2022

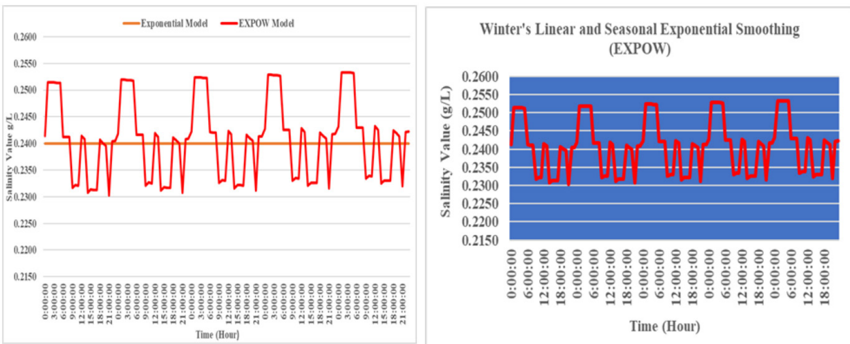


Figure 13

In advance salinity forecast by Winter Model (120 hr.) 01-05/07/2022

5. Discussion and conclusion

Two points are discussed in this section: comparison of techniques and suitable time for pumping the water at the pumping station. Regarding the two techniques, the single exponential smoothing model provided the lowest mean squared error but failed to make robust forecast—the predicted value always converged to a constant. On the other hand, the EXPOW model was able to make reliable predictions. Regarding suitable pumping time, to produce good quality tap water, the Metropolitan Waterworks Authority Pumping should arrange pumping during the period of minimum salinity because pumping water during this time will make the production of tap water cost less to produce than during other times According to the 24-hour forecast results, the most suitable water pumping time for agriculture or tap water production was between 7:00 p.m. and 8:00 p.m., when the water salinity level was the lowest at 0.2355 g/l. and during 2:00 p.m. – 4:00 p.m., which had a salinity value of 0.2358 – 0.2361 g/l. The next suitable time was between 12:00 - 14:00, which had the salinity of water at 0.2455 - 0.2458 g/L during the period from 21:00 to 23:00.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Reference

[1] K. Kulmart, and N. Pochai. : Numerical simulation for salinity intrusion measurement models using the MacCormack finite difference method with Lagrange interpolation. *Journal of Interdisciplinary Mathematics*, vol. 23(6), pp. 1157-1185 (2020).

[2] K. Kulmart, and N. Pochai. : Simulation of Salinity Intrusion in Chao Phraya River by a Developed Mathematical Model and MacCormack Scheme with Cubic Spline Interpolation. *Universal Journal of Mechanical Engineering,* Vol.7(6), pp. 386-397 (2019).

[3] K. Kulmart, and N. Pochai. : A Numerical Model for Salinity Intrusion Measurement and Control Based on MacCormack Finite Difference Method and Cubic Spline Interpolation (2020). doi:10.5013/IJSSST.a.21.01.01.

[4] P. Lamjuan, C. Changklom, and A. Prommin. : Time series analysis of salinity for forecasting as a preliminary guideline to early warning: A case study of the Chao Phraya River basin *[Online Conference].* The 26th National Convention on Civil Engineering. Thailand (2021, 23-25 June).

[5] C. Lapnimitchai, W. Thaisiam, and J. Kanasut. Hourly Salinity Prediction at Sum-Lae Pumping Station. [Unpublished Manuscript]. *E-mail: active_save@hotmail.*

[6] S. Lapnimitchai. The Application of Artificial Neural Network Model for Hourly Prediction Sum-Lae Pumping Station. [Unpublished Manuscript]. E-mail: active_save@hotmail.

[7] P. Palwisut, A. Junkorn, and M. Rodjan. : Saltwater Intrusion Forecast System for Thachin River using Multilayer Perceptron Neural Network. *Information Technology Journal.* Vol. 16(1) (2020).

[8] J. Hu, B. Liu, and S. Peng. : Forecasting salinity time series using RF and ELM approaches coupled with decomposition techniques. *Springer-Verlag Germany, part of Springer Nature.* Vol. 2019. https://doi.org/10.1007/s00477-019-0169-1.

[9] F. Zhoua, B. Liua, and K. Duana. : Coupling wavelet transform and artificial neural network for forecasting estuarine salinity. *Journal of Hydrology.* Vol. 2020, https://doi.org/10.1016/j.jhydrol.2020.125127.

[10] T. Thai Thanh, N. Quang Xuan1, H. Hieu Hoang, and N. Nhan Phan. Short-term forecasting of salinity intrusion in Ham Luong river, Ben Tre province using Simple Exponential Smoothing method. *Journal of Vietnamese Environment.* Vol.11(2), pp. 43-50 (2019).

[11] E. Habib, William K. Nuttle, Victor H. Rivera-Monroy, S., Jing Wang, Ehab Meselhe. and Robert R. Twilley. : Assessing Effects of Data Limitations on Salinity Forecasting in Barataria Basin, Louisiana, with a Bayesian Analysis. *Journal of Coastal Research*. Vol. 23(3), pp. 749-763 (2007).

[12] Ihsan A. Abuamra, Ashraf Y. A. Maghari, and Hussam F. Abushawish. : Medium-term forecasts for salinity rates and groundwater levels. *Springer Nature Switzerland AG.* Vol.7, pp. 485-494 (2020).

[13] J. Changklom, P. Lamchuan and A. Pornprommin. : Salinity Forecasting on RawWater forWater Supply in the Chao Phraya River. *Water 2022*, Vol.14, pp. 741 (2022). doi.org:10.3390/w14050741.

[14] Wayne, L. Winston. : *Operations Research: Applications and Algorithms*, Fourth Edition. Wayne L. Winston (2004).

[15] S. Ruang Peerakul. : *Statistical Forecasting Methods*, Two Edition. [Bangkok]: Department static and computer Faculty of Science Ramkhamhaeng University. Thailand (1999).

[16] Department. : Metropolitan Waterworks Authority. Bangkok: Bureau of Water Management and Hydrology. Thailand (2020).

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