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The Holt-Winters' method for forecasting water discharge in Attanagalu Oya

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Abstract

Forecasting river water discharge is significant in developing flood and agriculture management plans. Annual flood events damage properties, agricultural field, and infrastructures, etc. can be observed in Attanagalu Oya catchment area in Sri Lanka. Therefore, the aim of this study is to forecast water discharge rates (m^3/s) at the Dunamale gauging station of Attanagalu Oya using Holt-Winter's method. Holt-Winter's method was chosen because of its' ability to model trend and seasonal fluctuations, less data requirements and simplicity. Time series models were fitted using the Holt-Winter's method to daily water discharge rates for the period of 2015 –2019 and water discharge was forecasted for the year 2020. The accuracy of the fitted time series models was tested using root mean squares error (RMSE) and mean absolute error (MAE) values. Results showed that the additive Holt-Winters' method is more appropriate for future forecasting which gave the minimum RMSE and MAE values. Forecasted results will be useful to identify future flood events in advanced to take necessary actions to mitigate damages.

Keywords

Attanagalu Oya, Flood, Holt Winters' Methods, Time Series Analysis, Water Discharge

Introduction

Time series analysis is widely used in hydrological and meteorological applications. Time series is a series of data points that are measured over a regular time interval and most of the series can be decomposed into three main components, namely trend, seasonality, and random. The trend exists when there is a long term up or down in the data. Seasonal variations are fluctuations in a time series that occur at regular short intervals such as daily, weekly, monthly, quarterly, etc. Seasonality may be caused by various factors such as weather, seasons etc. Random components do not comply with any of the above components and they are uncontrollable and unpredictable. Most of the water discharge rates contain above three components due to climatic variations such as rainfall, temperature and humidity.

Time series forecasting methods predict the future occurrences based on historical data. Even though many time series forecasting methods are available in literature, the choice of the method depends on the nature of the data series. Traditional time series methods like naive method, drift method, simple exponential smoothing method, Holt-Winters' method, and ARIMA method are successfully used to model univariate time series. Real-world data has many seasonality and trends. When forecasting data in such cases, it is required to handle both seasonality and trends. Holt-Winters' method can handle many seasonality and trends using triple exponential smoothing. This method is popular, because it is simple and requires low data-storage. Holt-Winters' method has two variations namely, additive and multiplicative. An appropriate variation is selected according to the nature of the seasonal and trend component. Additive method is selected when the seasonal variation of the time series is roughly constant over time and multiplicative method is selected when the seasonal variations are changing proportional to the level of the series (Kalekar, 2004).

Literature showed that Holt-Winters' method has been used widely for forecasting in different fields. Szmit, M., and Szmit, A. (2011) have used the Holt-Winters' method to analyze network traffic data. Veiga *et al.* (2014) have used Holt-Winters' method and ARIMA method for forecasting food retail and they have shown that better forecasting was obtained from the Holt-Winters' method. Puah *et al.* (2016) have examined the rainfall patterns using additive Holt-Winters' method. Dantas *et al.* (2017) have also used the Holt-Winters' method for forecasting air transportation demand.

Further, forecasting river water discharge is applicable in various water resource applications, such as flood forecasting, drought management, operation of water supply utilities and building mathematical models for future predictions. According to the literature, Tamagnone *et al.* (2019) have analyzed water discharge of the Sirba river in western Africa to identify the river behavior and developed a flood mitigation procedure. Pelletier and Turcotte (1997) have used water discharge for drought hazard assessment. Trepanier *et al.* (1996) have used the time series analysis of water discharge for controlling the upstream migration of adult salmonids to their spawning areas. Wang *et al.* (2006) have explained a connection between decreasing water discharges, global weather patterns and anthropogenic impacts in the drainage basin using datasets of river water discharge, water consumption and regional precipitation. Albostan and Onoz (2015) have used water discharge pattern to investigate whether all stations of river basin exhibit chaotic behavior. Accordingly, forecasting of water discharge can be applied in different applications in flood and agriculture management activities. Therefore, the study aims to forecast water discharge rates (m^3/s) at the Dunamale gauging station of Attanagalu Oya for year 2020 using the Holt-Winters' method.

Methodology

Study area

Attanagalu Oya, which is situated in Gampaha district, was selected for the study. Total catchment area of the Attanagalu Oya is about $727km^2$ and the basin has an elevation of about 30m MSL (mean sea level) at its highest according to Wijesekara and Perera (2012).

Data collection

Daily water discharge rates (m^3 /s) for the period of 1st January 2015 – 31st December 2019 at the Dunamale gauging station in Attanagalu Oya were used for the analysis and required data were collected from the Department of Irrigation. Statistical analysis was carried out using R statistical software.

Holt-Winters' method

Augmented Dickey-Fuller (ADF) test was used to determine the stationarity of the time series. This test can handle more complex models than other tests. *adf.test()* function in R was used to check stationary of the time series and when series is stationary, p-value (out-put of *adf.test()*) is less than or similar to 0.05. Then, both additive and multiplicative

Holt-Winters' methods were fitted to the time series and predict the daily water discharge rates for the period of 1st January 2020 – 31st December 2020. *HoltWinters()* function in R was used to fit the both models and Table 1 shows the model equations. Holt-Winters' method has three smoothing factors, namely alpha (α) : data smoothing factor, beta (β) : trend smoothing factor and gamma (γ) : seasonal change smoothing factor. Adequacy of the methods were examined by calculating RMSE (Equation 1) and MAE (Equation 2) values for the period of 2015-2019. The best fitted method shows the minimum RMSE and MAE values (Szmit, M., and Szmit, A., 2011).

Table 1. *Model equations of additive and multiplicative Holt-Winters method (Lima, S. et al., 2019)*

Additive Holt-Winters' method	**Multiplicative Holt-Winters' method**
$S_t = \alpha(X_t - C_{t-L}) + (1-\alpha)(S_{t-1} + B_{t-1})$	$S_t = \alpha \dfrac{X_t}{C_{t-L}} + (1-\alpha)(S_{t-1} + B_{t-1})$
$B_t = \beta(S_t - S_{t-1}) + (1-\beta)B_{t-1}$	$B_t = \beta(S_t - S_{t-1}) + (1-\beta)B_{t-1}$
$C_t = \gamma(X_t - S_t) + (1-\gamma)C_{t-L}$	$C_t = \gamma \dfrac{X_t}{S_t} + (1-\gamma)C_{t-L}$
$F_{t+m} = S_t + mB_t + C_{t-L+h}$	$F_{t+m} = (S_t + mB_t)C_{t-L+h}$

S_t is the smoothed observation at time t, X_t is the observed data at time t, α is the data smoothing factor i.e. $0 \leq \alpha \leq 1$, β is the trend smoothing factor i.e. $0 \leq \beta \leq 1$, γ is the seasonal change smoothing factor i.e. $0 \leq \gamma \leq 1$, B_t is trend factor at time t, C_t is seasonal index at time t, F_{t+m} is the forecast at m periods ahead of time t, L is the length of the seasonality, m is the number of forecast ahead, t is time period and $h = \big((m-1) mod\ L\big) + 1$.

$$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n} |e_t{}^2|} \qquad (1)$$

$$MAE = \frac{\sum_{t=1}^{n} |e_t|}{n} \qquad (2)$$

where e_t is the error at time *t and n* is the number of observations.

Results and Discussion

Time series was prepared using daily water discharge rates (m^3 /s) of the period of 1st January 2015 – 31st December 2019. There were no any missing values observed. Figure 1 shows the seasonal and trend components of the water discharge time series and ADF test (p value = 0.01) stated that the time series is stationary. The trend is not specifically increasing or decreasing (Figure 1B) and complex consistent seasonal pattern and two peaks can be observed in each year (Figure 1C).

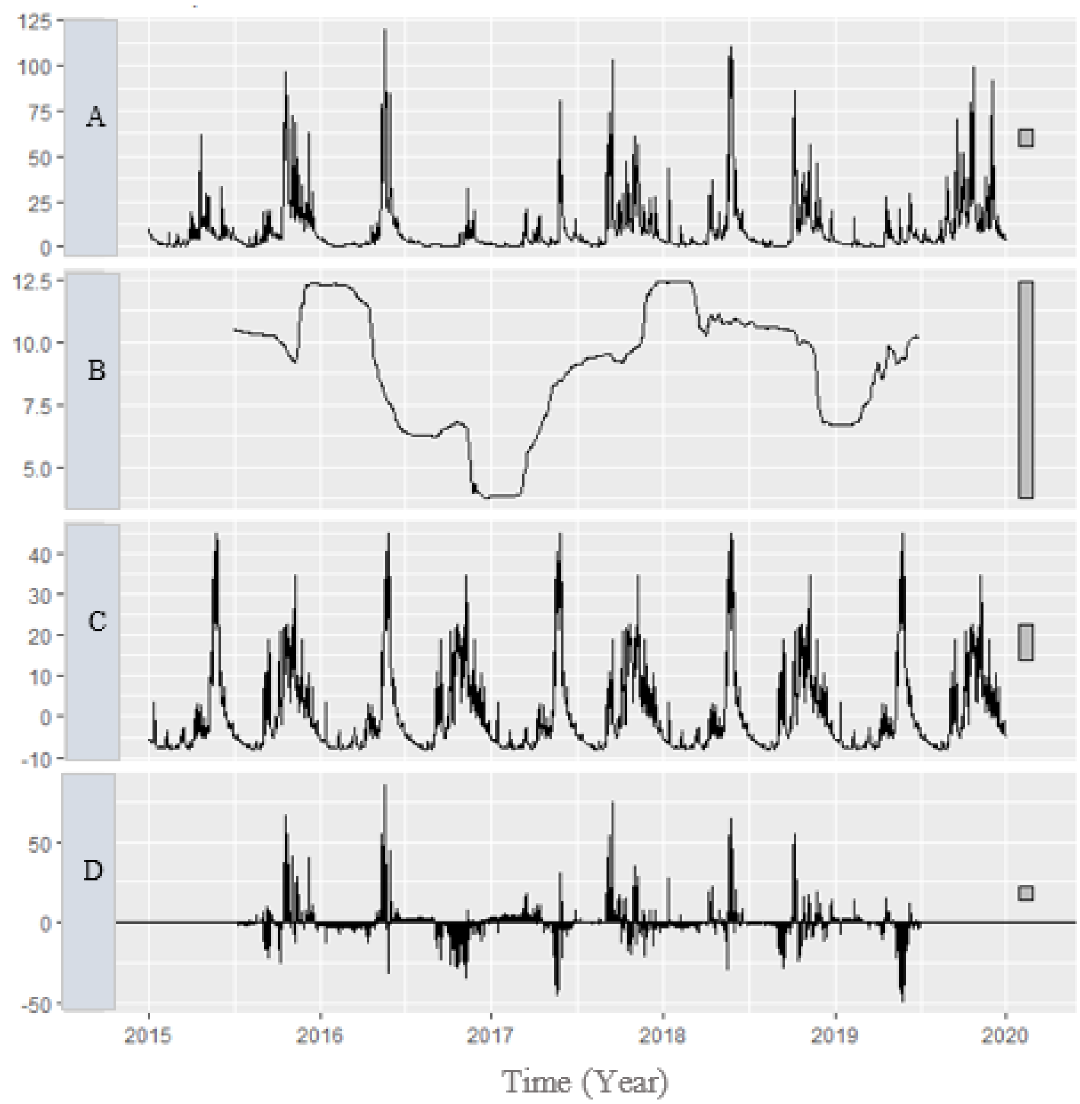

Figure 1. *Decomposition of time series of water discharge for the period of 2015-2019, A: Data, B: Trend, C: Seasonal variation, D: Remainder.*

Table 2. *Error values and smoothing parameters of the additive and multiplicative Holt-Winters' method for the period of 2015-2019.*

Method	RMSE	MAE
Additive method α : 0.7665214 β : 0 γ : 1	11.70029	5.472673
Multiplicative method α : 0.2947401 β : 0.1034771 γ : 0.09994384	23.58825	8.165856

Table 2 shows the optimal smoothing parameters (α, β, γ) and error values (RMSE and MAE) of both fitted additive and multiplicative Holt-Winters' method. For additive Holt-Winters' method, $\alpha = 0.7665214$ indicates that the forecasts are more responsive to more recent observations, $\beta = 0$ indicates that the initial trend component is the trend component for all periods and $\gamma = 1$ indicates that seasonality at each time period is estimated as the difference between the corresponding level and trend components at each time period. For multiplicative Holt-Winters' method, all smoothing parameters α, β and γ are closed to 0, that indicates forecasts are more response to older values of each components. The results show that the forecasted errors have approximately constant variance over time, and normally distributed with mean zero for both additive and multiplicative methods. Therefore, both methods are suitable for forecasting water discharge rates. But according to the error values (Table 2), the additive Holt-Winters' method has the minimum RMSE and MAE values, which implies the additive Holt-Winters' method is much better than the multiplicative Holt-Winters' method.

Figure 2 shows the forecasted data of the additive method. Predicted values are shown in blue line and prediction intervals are shown in gray. Two peaks were identified in the forecasted data. The highest water discharge rate was observed as 115.09 m^3 in May 2020. The second period which has increment of water discharge was observed in mid of October, 2020.

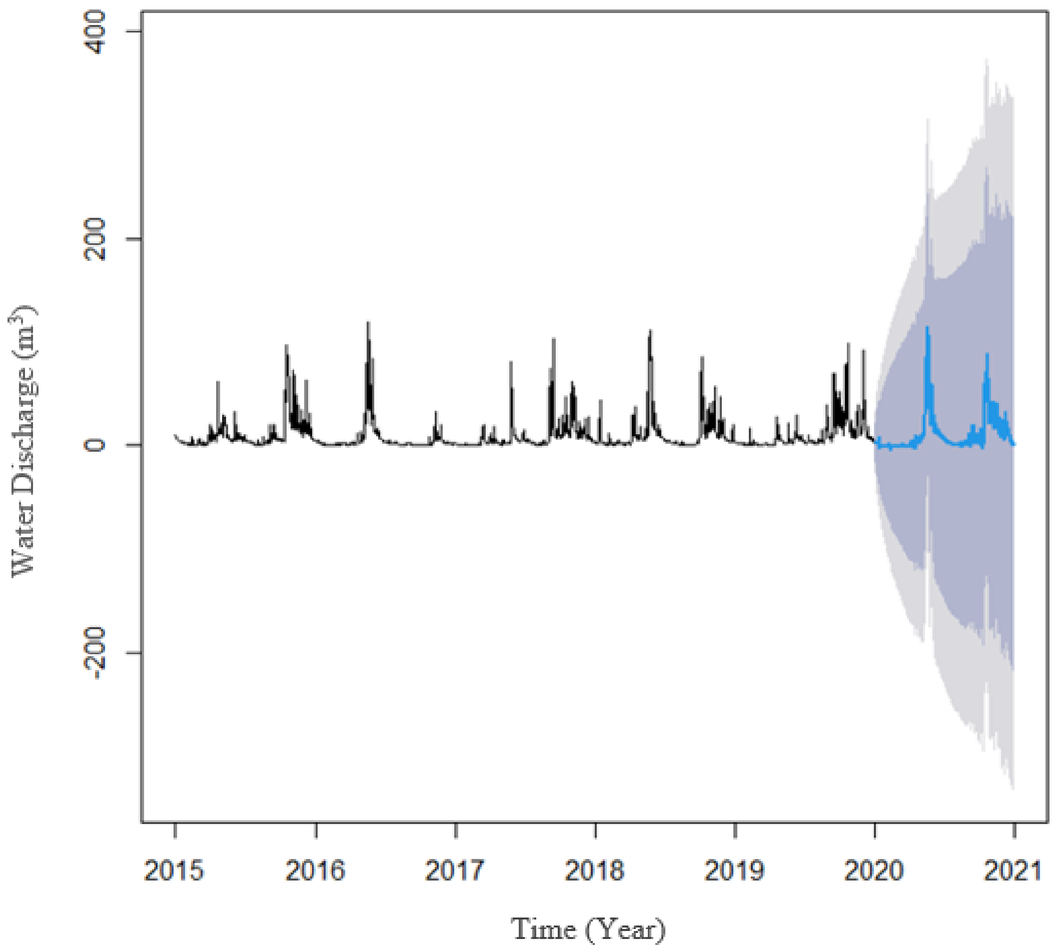

Figure 2. *Forecasted water discharge data for 2020 using additive Holt-Winters' method.*

Conclusion

The water discharge is an important factor for identifying flood incidents and flood inundation areas. It is worth to observe variations in water discharge series changes in future to have better agricultural management procedure such as crop selection, identifying suitable harvesting time. Based on the results, the additive Holt-Winters' method is more appropriate than the multiplicative Holt-Winters' method for forecasting water discharge. The forecasted values will be useful to identify the future flood events and to measure the intensity of flood. Moreover, it will also helpful to farmers and residencies of Attanagalu Oya basin to take precautionary steps to mitigate flood damages. Further, this study will be extended to simulate future flood prone areas of Attanagalu Oya basin using Hydrologic Engineering Center's Hydrologic Modelling System (HEC-HMS) and Hydrologic Engineering Center's River Analysis System (HEC-RAS).

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References

Albostan, A., and Onoz, B. (2015). Implementation of chaotic analysis on river discharge time series. *Energy and Power Engineering,* 7(03), 81. https://doi.org/10.4236/epe.2015.73008.

Charles C. H. (1957). Forecasting seasonals and trends by exponentially weighted moving averages. *International Journal of Forecasting.* 20(1), 5-10. https://doi.org/10.1016/j.ijforecast.2003.09.015.

Chatfield, C. (1978). The Holt-winters forecasting procedure. *Journal of the Royal Statistical Society: Series C (Applied Statistics),* 27(3), 264-279. https://doi.org/10.2307/2347162.

Dantas, T. M., Oliveira, F. L. C., & Repolho, H. M. V. (2017). Air transportation demand forecast through Bagging Holt Winters methods. *Journal of Air Transport Management*, 59, 116-123. https://doi.org/10.1016/j.jairtraman.2016.12.006.

Dikkubura, H.K.S., and Weerasinghe, V.P.A. (2016). Rainfall-Runoff-Inundation (RRI) model for flood analysis in Attanagalu Oya basin, Sri Lanka. *International Symposium of ICT for Sustainable Development.*

Kalekar, P.S. (2004). Time series forecasting using holt-winters exponential smoothing. *Kanwal Rekhi school of information Technology*, 4329008(13),1-13. https://doi.org/10.1063/1.5137999.

Lima, S., Gonçalves, A. M., & Costa, M. (2019). Time series forecasting using Holt-Winters exponential smoothing: An application to economic data. *In AIP Conference Proceedings. AIP Publishing LLC.* 2186(1), 090003.

Pelletier, J.D., and Turcotte, D.L., (1997). Long-range persistence in climatological and hydrological time series: analysis, modeling and application to drought hazard assessment. *Journal of hydrology,* 203(1-4), 198-208. https://doi.org/10.1016/S0022-1694(97)00102-9.

Puah, Y. J., Huang, Y. F., Chua, K. C., & Lee, T. S. (2016). River catchment rainfall series analysis using additive Holt–Winters method. *Journal of Earth System Science*, 125(2), 269-283. http://dx.doi.org/10.1007/s12040-016-0661-6

Pushpakumara, T.D.C., and Isuru, T.V.A. (2018). Flood modeling and analyzing of Attanagalu Oya river basin using geographic information system. *International Journal of Advanced Remote Sensing and GIS*, 7(1), 2712-2718. https://doi.org/10.23953/cloud.ijarsg.366.

Szmit, M., and Szmit, A. (2011). Use of holt-winters method in the analysis of network traffic: case study. *International Conference on Computer Networks*, 224-231. http://dx.doi.org/10.1007/978-3-642-21771-5_24.

Tamagnone, P., Massazza, G., Pezzoli, A., and Rosso, M. (2019). Hydrology of the Sirba river: Updating and analysis of discharge time series. *Water*, 11(1),156. https://doi.org/10.3390/w11010156.

Thushari, N.H., and Manawadu, L. (2008). Flood monitoring in Gampaha district using SAR data as a case study in the lower basin in Attanagalu Oya (river).

Trepanier, S., Rodriguez, M.A., and Magnan, P. (1996). Spawning migrations in landlocked Atlantic salmon: time series modelling of river discharge and water temperature effects. *Journal of Fish Biology*, 925-936. https://doi.org/10.1111/j.1095-8649.1996.tb01487.x.

Veiga, C.P.D., Veiga, C.R.P.D, and Catapan, A.,Tortato, U., and Silva, W.V.D. (2014). Demand forecasting in food retail: A comparison between the Holt-Winters and ARIMA models. *WSEAS transactions on business and economics*, 11(1), 608-614. https://doi.org/10.17559/TV-20160615204011.

Wang, H., Yang, Z., Saito, Y., Liu, J.P., and Sun. X. (2006). Interannual and seasonal variation of the Huanghe (Yellow River) water discharge over the past 50 years: connections to impacts from ENSO events and dams. *Global and Planetary Change*, 50(3-4), 212-225. https://doi.org/10.1016/j.gloplacha.2006.01.005.

Wijesekara, N.T.S., and Perera, L.R. H. (2012). Key issues of data and data checking for hydrological analysis- case study of rainfall data in Attanagalu Oya basin of Sri Lanka. *Engineer Journal of the Institution of Engineer, Sri Lanka*,45(2). http://dx.doi.org/10.4038/engineer.v45i2.6936.

Winters, Peter R. (1960) Forecasting sales by exponentially weighted moving averages. *Management science*, 6(3), 324–342. https://doi.org/10.1287/mnsc.6.3.324.