AN ECONOMETRIC ASSESSMENT OF WATER CONSUMPTION: A CASE STUDY OF NEW NORTH ZONE OF SURAT CITY

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Abstract

When water is plentiful and easily available, we tend to take it for granted and overuse it but when water availability is limited or its use is being monitored by water meters, it results in reduced water contamination and non-revenue water as well as uninterrupted water supply to the cities. As the 24 x 7 water supply scheme is at its very initial stage in Gujarat state, data from New North zone in Surat Municipal Corporation of monthly water consumption which is metered had been collected and analyzed to forecast the water consumption. After applying various econometric techniques to collected data, results of the study revealed that the Holt model performed better and can be used for modeling and forecasting the water consumption.

Keywords: *24 x 7 water supply scheme, Metered water consumption, forecasting, and Holt model.*

Water is considered as lifeline of all living things especially humans; hence its availability is a critical component in the measurement of human wellbeing through the Human Development Index (HDI)[1].With the growing demand for water in urban areas and our increased concern regarding the environment, we have to develop and use institutional arrangements and mechanisms to reduce the growth in demand. At initial stage, it is required to study the water consumption in which normal variation around the average water consumption can be predicted with statistical methods[2]. Usually, the subject of the forecast is water delivered to the systems, not water used by any particular category of customer. Generally, Water supply agencies maintain records of the quantity of water delivered to the water distribution network. Where customers are metered, recorded water meter readings provide a history of customer water use. For various reasons including leakage, unmetered use & meter mis-registration the total of customer water use is expected to be smaller than the quantity of water supplied. These historical records of water deliveries and metered use are essential for any study of operations, system capacity, or supply cost[3]. According to the requirement of the water resources management purpose, average annual use, total monthly use, daily use can be forecasted.

The majority of research project have focused on highlighting the current water shortages and the increased use by the residential sector in urban area. So far, research into residential water consumption is restricted to the only one variable i.e. population assuming that it contains all the relevant information regarding water use. While Per capita water use varies widely from place to place; it can be observed to rise and fall over time for any particular location. This kind of variation suggests that results based on this per capita method are an inadequate explanation of urban water use[4]. While residential water use may be moderately well correlated with population (it is actually better correlated with number of housing units), the same cannot be said for commercial, institutional or public uses of water. When monthly water consumption is monitored based on number of housing units through water meters statistical analysis should be carried out by analyzing the trend and seasonality of the data.

Objective of the study

As per the need of the water resources management sector , it is necessary to analyze the review of 24 x 7water supply scheme to understand how it will succeed and helpful to the policy makers as well as consumers in India. The main objective of the study is to get the best fit model to the data and to forecast water consumption for future, which can be useful to decisions makers, researchers, policy makers and government officials of water sector.

As per the knowledge based on literature review from various sources, this is the first attempt of statistical analysis of the metered water consumption data of cities in the state of Gujarat using various statistical tools and techniques.

Literature Review: Hiroshi Yamauchi and Wen-yuan Huang (1977) concluded that An improved understanding of the behavior of the various time series components for both aggregate and disaggregate data should allow the more effective extension of analysis into economic incentive effects of alternative policy measures and closer integration of water supply and demand management. Ben Dziegielewski et al.(2002) prepared An Analytical Bibliography on Predictive models of water use. Cosmos Agbe Kwame Todoko (2013) analyzed time series of water consumption in Hohoe municipality of Volta Region in Ghana. Emmanuel.A.Donker et al. (2013) had reviewed the literature on urban water demand forecasting published from 2000 to 2010 in order to identify methods and models useful for specific water utility decision making problems. Results showed that although a wide variety of methods and models have attracted attention, applications of these models differ, depending on the forecast variable, its periodicity and the future horizon. Keval Jodhani & Dipak Madalani (2015) studied water supply scenario of Ahmedabad city and identified myths which running in India about 24 x 7 water supply and tried to provide resolving measures. Amit Kumar. R. Chauhan & Prof. B.M. Vadher (2015) studied existing water supply network for 24 x 7 water supplies in

[1] Time series analysis of water consumption in the Hohoe municipality of the Volta region of Ghana by Cosmos Agbe Kwame todoko, p.16
[2] K. William Easter:" The Urban water environment of cities", Ch.13, p. 260.
[3] "Urban water demand management and planning", Dane D Baumann, John J. Boland, W. Michael, Hanemann, ch.3, p.77
[4] Urban water demand management and planning, ch.3, p.86

Mogarawadi of Valsad city through pipe network analysis using EPANET 2.0. Pantelis Chronis et al. (2016) discussed on "Open issues and challenges on Time series forecasting for water consumption.

Research Design: Forecasting is an important part of econometric analysis and ultimate objective of any research study. While a moving average is a very useful form of forecasting, it suffers from the disadvantage of assigning the same weight of importance to older data that it does to more recent values. Exponential smoothing can be used to avoid this dilemma by conferring more significance to more recent data[5]. Exponential smoothing method can capture that advantage. The influence of the observations on the parameter estimates diminishes with the age of the observations. An adaptation of single double and triple exponential smoothing is based on trends and seasonality of the data. In this paper we discuss Exponential smoothing methods and its real life application in urban water consumption data which is untouched application area so far in Gujarat state as well as statistical analysis of water consumption. After studying the trend and seasonality of the data set, double exponential smoothing (Holt) method is used for the analysis in this study.

Study area: Among all the cities of Gujarat state, Surat is the second largest city which is spread over 325.51 square kilometers having population of 4.46 million according to census 2011. It continues to be among India's fastest developing cities in the country by providing all the necessary utilities to the residents of the city. Water Supply scheme (Part) for Amroli, Kosad, Chhaprabhatha area of New North Zone of Surat was commissioned and inaugurated by Honorable chief minister of Gujarat, Shri Narendrabhai Modi on 27thMay, 2012[6].

Cluster Sampling: Surat Municipal Corporation(SMC) has initiated and implemented 24x 7 water supply scheme in one cluster of New North zone and east zone of the city, under which water meters were installed and maintained monthly water consumption readings.SMC has been installing water meters in New North Zone area of Surat since 2013.For this research paper cluster sampling used in which, among all the piped water connections in this cluster, data of monthly water consumption readings of each metered water connection from March 2014 to January 2017 in New north zone were collected. (Source: Kosad water works department of New North Zone area of SMC.)

Variables: Over the past so many years, the per capita requirement (Liters per capita per day)method has been used for the explanation of urban water use by considering only one relevant variable i.e. population. But if water use per connections is being monitored, water use or consumption should be analyzed to get the better explanation. In this context, data of monthly water consumption of each metered connection had been collected. From this raw data, Total water consumption of all the metered water connections were calculated for all 35 months and considered as study variable for Univariate forecasting.

Methodology

All the smoothing methods Simple, Holt and winter all are nonparametric methods against Regression models. Double exponential smoothing employs a level component and a trend component at each period. It uses two smoothing parameters, to update the components at each period for update the components at each period.For a series of observations Y_1, Y_2 Y_3,..., Y_n. The double exponential smoothing equations are as follows:

L_t = á Y_t + (1-á) [L_{t-1} + T_{t-1}]

T_t = ã [L_t – L_{t-1}] + (1- ã) T_{t-1}

$\hat{Y}_t = L_{t-1} + T_{t-1}$

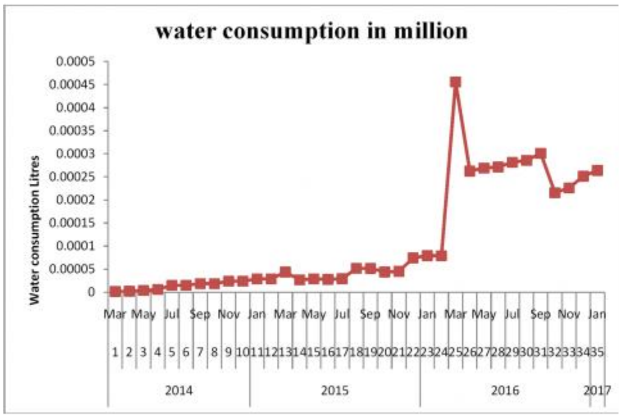
Where L_t is the level at time t, á is the weight for the level, T_t is the trend at time t, ã is the weight for the trend, Y_t is the data value at time t and is the fitted value or one period ahead forecast at time t. If the first observation is numbered one, then level and trend estimates at time zero must be initialized in order to proceed. The initialization method used to determine how the smoothed values are obtained in one of two ways; with optimal weights or weights or with specified weights[7]. Data up to the forecast origin time will be used for smoothing. The forecast for m periods ahead from a point of time t is (L_t + mT_t). The study seeks to examine the trend and seasonality in the data to select the best fit model to the data. Outlier detection procedure is also carried out to deal with distortion of the trend. Applying exponential smoothing techniques forecasting for next 10 months water consumption have been obtained through best fit model.

Tools and Techniques: For statistical Analysis, analytical softwares such as Microsoft Excel, Minitab 16 and SPSS 22 were used to obtain necessary results and plots.

Analysis & Interpretation

Visual inspection of a time series can often be a powerful guide in choosing an appropriate exponential smoothing model. Fig 1 shows a graph of total metered water consumption of all the households of the new North zone, Surat from March 2014 to January 2017 (i.e. 35 months).

Figure 1 - Scatter plot of monthly Total water consumption; 2014 -2017.

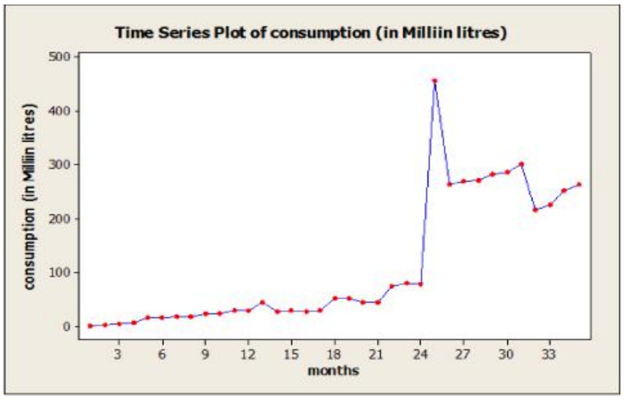


[5] Introductory regression analysis with computer application business & economics by Allen Webster, ch.11, p.385

[6]https://www.suratmunicipal.gov.in/Departments/HydraulicHome

[7]Statistics for Business and Economics by Anderson Sweeny Williams,11th edition, ch 18 pp.767-74

Figure 2 - Time series plot of Total water consumption; 2014-2017.



At first look on time series plot (Fig 2.) observation 25 which is March 2016 is unusual observation. By rechecking this extreme value, it is found that it is neither wrong reading nor typing error but it is due to exceptional increase in no of connections in this month. Statistically to check influence of this observation on the model by outlier detecting processes, standard error of this observation is found to be 3.89 which is higher than 2 indicating the presence of outlier. Leverage value of this observation is h_{25} =0.2559 > 0.1714 ($h_{\text{tabulated}}$). According to F distribution ($F_{0.50}$)test & Rule of thumb for Cook's distance D_{25}= 0.334865< 2.82 & D_{25}< 1 respectively.

In order to taper off the upper tail of our data in Fig 2 and to get the better fit of the model, we have considered logarithmic transformation. Fig 3, 4 shows scatter plot & plots of the residuals respectively for log transformed variable.

Figure 3 - Time series plot of Log transformed variable

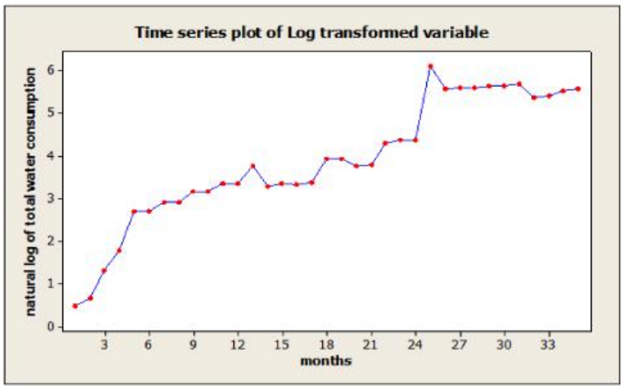
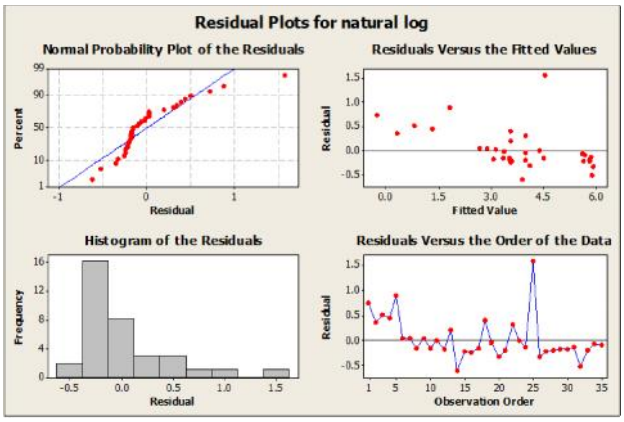


Figure 4 - Residual plots for Log transformed variable



The null hypothesis is that no significant correlation exists between residuals. A correlogram that graphs theses correlations shown in figure 5 & 6.The autocorrelation and Partial autocorrelation of the residuals up to the order 9 is observed to be within the range of -0.4 to 0.4 indicating the no autocorrelation in error terms.

Figure 5 - Autocorrelation function of Residuals for water consumption

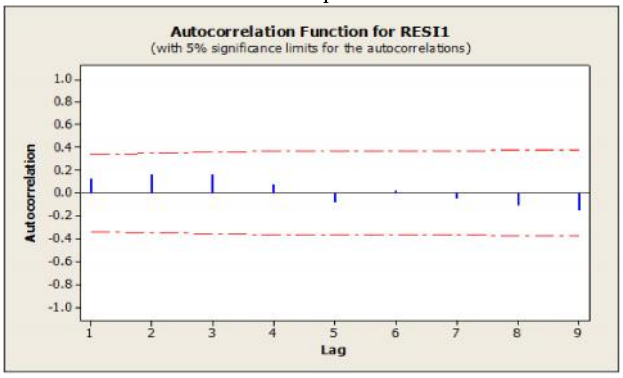
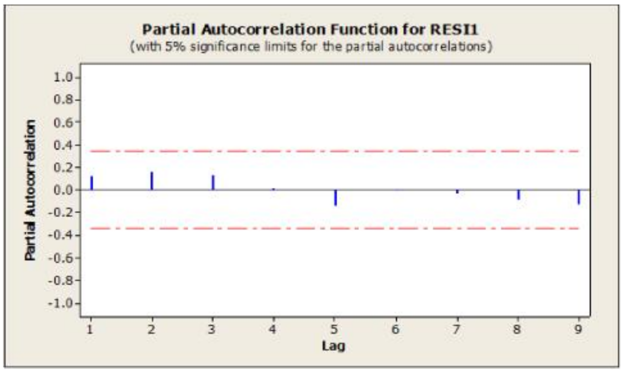
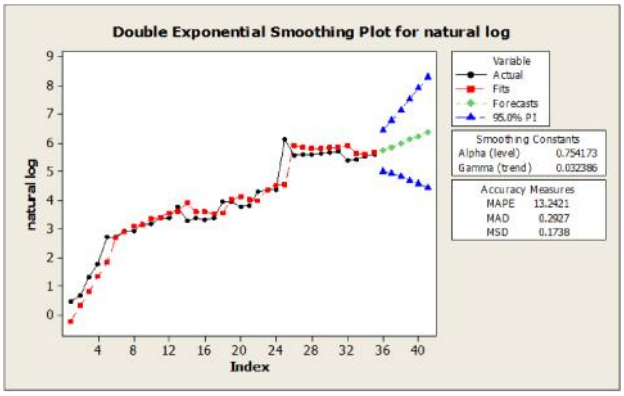


Figure 6 - Autocorrelation function of Residuals for water consumption



From the above analysis, it has been decided to use Holt model to forecast the total water consumption for the year 2017.The process involves a smoothing constant á, such that 0< á <1 and ã. These smoothing parameters were chosen by MINITAB software which are á (level) = 0.754173 and ã(trend)=0.032386. A Plot of double exponential smoothing is constructed with smoothing parameters á and ã which results in following accuracy measures. Mean Absolute Percentage Error (13.2421), Mean Absolute Deviation (0.2927) and Mean square deviation (0.1738).

Figure 7. Double Exponential Smoothing plot for log transformed variable.



This analysis has been carried out with SPSS 18 software also, it showed that Expert modeler of the SPSS also chosen Holt model with á = 0.802 and ã=0.03which results in very good R^2=0.929, Root mean square error (RMSE)=0.399, and MAPE=7.622.

Forecasted values from February to November for year 2017 are depicted in Table 1.

Table 1 - Forecasted values from February to November for year 2017.

	Minitab	SPSS
Month of 2017	Forecast	Forecast
February	306.9516	308.2466
March	348.3438	352.9054
April	395.3178	404.0344
May	448.6262	462.5710
June	509.1283	529.6413
July	577.7839	606.3758
August	655.6978	694.2277
September	744.1183	794.8075
October	844.4622	910.0504
November	958.3375	1041.8987

Results and Discussion

A visual analysis of the data shows that there is an upward trend movement and almost no seasonality in the data indicating increase in total water consumption month by month but not so much effect of seasons on Total water consumption. In some situations using only high leverage to identify influential observation can lead to wrong conclusions, So Cook's distance measure has been used to determine whether the observation is influential. In essence, considering the outlier, high leverage, large residuals and cook's distance measures for unusual observation we can ignore the impact of presence of unusual observation in this case and Holt method is used to forecast the total water consumption for the year 2017.As apparent, Residual analysis from the plots in fig 4, the behavior of the residuals is quite in confirmation with the objective of estimation of the said model. A correlogram reveals the significance of the Autocorrelation coefficient. The plot of double exponential smoothing shows that for given smoothing parameters the predicted values is much closer to the observed values with less error. All the above models are highly converging towards a definite result.

Recommendations

The Surat Municipal Corporation should use the Holt model in determining the Total water consumption by residents, institutions and commercials for better planning purpose; In case of low water production, the corporation should priorities area according to records of water consumption and essential service providers, such as hospitals, urban health centers, schools, colleges in the city; Municipal Corporation through the water works officials must put in effective and efficient water production and distribution strategies in the city since its population is increasing and lifestyle of the urban population is changing due to urbanization.

Conclusion

The objective of the research was to develop a time series model and to forecast monthly water consumption by residents and commercials. For that, time series data of Total metered water consumption for 35 months (March 2014 to January 2016) on monthly bases were collected from New North Zone water works department. Several exponential smoothing models including Simple, Holt and winter incorporating different assumptions and hypothesis about trend and seasonality model accuracy have been tested. The initial plot of the time series and all the results of the analysis indicate that the Holt (Double Exponential smoothing) model is truly the best fit forecasting model for total water consumption data of new north zone, Surat Municipal Corporation. This analysis can be carried out for more time series data in future which can be useful for decision makers, researchers, Policy makers and Government officials in Water Resources Management sector.

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