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(Research Article)

Annual Rainfall Prediction using Holt-Winters Models for Junagadh (Gujarat-India) Region

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Abstract

The Rainfall is a crucial hydro meteorological variable in arid and semi-arid region due to its yawning impact on agriculture, drinking water and energy sectors. Junagadh (Gujarat-India) region reels under rainfall uncertainties and thereby water resources and crop production suffer a lot. Rainfall is highly complex, nonlinear, and dynamic in nature and affected by many interrelated meteorological parameters. Further the temporal and spatial variability causes more uncertainty in its occurrence. Despite significant contribution of advance computing techniques, the rainfall prediction yet remains a tough challenge. Holt-Winters model is a time series model and it relies on three aspects of the time series: a typical value (average), a slope (trend) over time, and a cyclical repeating pattern (seasonality). Annual rainfall data often exhibits trend and seasonality and hence, the Holt-Winters models could be the best choice for its prediction. This study examined ability of three different types of time series models (Holt-Winters model (HW), Multiplicative Holt-Winters (MHW) and Additive Holt-Winters (AHW)) in predicting annual rainfall for Junagadh (Gujarat-India) region. Performances of the models were evaluated by using refined Willmott's index (d_r) and mean absolute error (MAE) evaluation measures. All the three models performed better and are recommended for forecasting annual rainfall of the selected region and the similar hydro-meteorological regions.

Keywords: Annual Rainfall, Time Series Model, Holt-Winters Model, Willmott's Index, Mean Absolute Error.

1. Introduction

Rainfall becomes the predominant risk factor because of its erratic nature and spatiotemporal variation that has a direct or indirect effect on yield production. The farmers of arid and semi-arid regions are always worried about yield losses due to extreme climate fluctuations. The crop production and economy in the region mainly depend on the amount of annual rainfall. Further, irregular, insufficient and unpredictable nature of the rainfall resulted in unequal economic growth in the region. Knowledge of rainfall trend in the region is pre-requisite for effective decision-making system. Therefore, predicting the annual rainfall has a great socio-economic importance in such region.

Rainfall forecasting in India was begun in 1886 by Sir Henry Blanford. [1 – 4] studied variability and trend of annual rainfall data over India. [5] has reported that there is no distinct change observed in trend of mean annual rainfall. However, [6] and [7] have noted an increasing trend in rainfall while [8] and [9] have found significant decreasing trends of rainfall over India. Extensive research works on rainfall prediction were carried out by Indian Meteorological Department (IMD) using advanced empirical models since 1932, albeit with limited success. However, [10 - 15] demonstrated that the time-series analysis was extensively used for predicting hydrological variables, flooding and environmental events.

In these present studies, three different forms of the Holt-Winters time series models (Holt-Winters model (HW), Multiplicative Holt-Winters (MHW) and Additive Holt-Winters (AHW)) are applied to predict annual rainfall for Junagadh region.

2. Study Region and Data Collection

Geographical region of Junagadh (Gujarat-India) is located between 20° 26' to 21° 24' North latitudes and 69° 24' to71° 03' East longitudes (Figure 1). Junagadh District has the population of about 27.4 lakh and it is the 7th most populous district of Gujarat state (India). Total geographical area of Junagadh district is 8831 km^2. Junagadh region is characterized by its insufficient, non-uniform rainfall pattern and inadequate aquifer water storage capacity. Natural water conservation and water scarcity are the prime factors influencing water resource management, selection of crops, irrigation scheduling and environmental assessment in this region.

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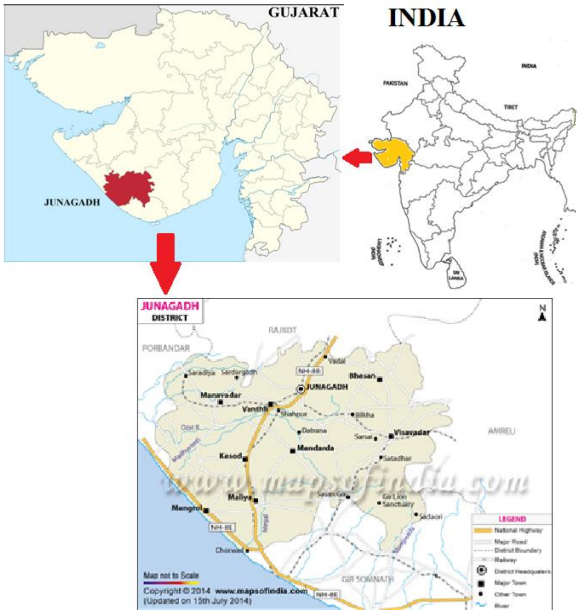

Figure 1. Junagadh (Gujarat-India) region
(Source: www.mapsofindia.com)

Annual rainfall data were collected from Junagadh Agro-meteorological Cell for 39 years (1984-2022) and was used in the analysis. Junagadh weather station is located at an altitude of 61m from mean sea level and lies between latitude of 21°31’ N and longitude of 70°33’ E. The weather parameters are recorded at the Agro meteorological observatory; Department of Agronomy affiliated with Junagadh Agricultural University, Junagadh and published annually.

Microsoft Excel worksheets were used to analyse the annual rainfall records.

3. Models and Methodology

Holt-Winters (HW) is a one of the attractive time series models characterised by three basic features a typical value (average), a slope (trend) over time, and a cyclical repeating pattern (seasonality) and used to predict the future values of the parameters based on its existing attributes. (HW) is more suitable when the seasonal variability of the series synchronized with the level of the series. (MHW) is preferred when time series data exhibits multiplicative seasonality and the amplitude of the seasonal pattern is proportional to the average level. In the multiplicative model, the sum of the seasonality components is fixed as 1 for c consecutive periods of time. The original HW model initialized the trend value with 0 while in MHW the same is initialized with 1. Additive Holt Winters Model (AHW) is quite useful when additive seasonality noticed in the time series data. These models permit calibration of its smoothing parameters based on weighted average of past and present observations. The prediction was carried out using calibrated smoothing constants.

HW model relies on four equations viz. level equation (01), trend equation (02), seasonal term equation (03) and forecast equation (04) [16].

Time series base (level) equation:

$$L_t = \alpha\left(\frac{Y_t}{S_{t-s}}\right) + (1-\alpha)(L_{t-1} + T_{t-1}) \text{ .... (1)}$$

Where Y_t = Observed rainfall data at time t, L_{t-1} = Smoothed base value for period t-1, T_{t-1} = Trend estimate for period t-1, S_{t-s} = Sum of seasonality components for s consecutive periods of time, length of the seasonality is s and α = Exponential smoothing parameter for the data ($0<\alpha<1$).

Time series trend equation:

$$T_t = \beta(L_t - L_{t-1}) + (1-\beta)T_{t-1} \text{ ....(2)}$$

Where β = Smoothing constant for the trend estimate ($0<\beta<1$).

Time series season equation:

$$S_t = \gamma\left(\frac{Y_t}{L_t}\right) + (1-\gamma)S_{t-s} \text{ .... (3)}$$

Where γ = Smoothing constant for the seasonality estimate ($0<\gamma<1$).

The rainfall for a stipulated time future period is estimated by using equation (04):

$$P_{t+m} = (L_t + mT_t)S_{t-s+m} \text{ ....(4)}$$

To calculate the level, $L_s = (Y_1 + Y_2 + \ldots + Y_n) / s$ (in our case s = 3) is used. For initializing the trend, we used $T_s = (Y_s + 1 – Y_1) / s$ while seasonal index was initialized by using $S_p = Y_p / L_s$, p = 1, 2,……, s.

The forecasted value was computed by summing up the baseline, trend and seasonality components. The seasonal indices were divided and multiplied in (MHW) model, while they added and subtracted in the (AHW). The seasonal indices were initialized by using $S_p = Y_p – L_s$, p = 1, 2, 3…, s. The sum of the seasonality components for c consecutive periods of time is about c (not 1 as in the multiplicative model).

The forecast value at t periods is given by:

$$P_p = (F_t + mT_t) + S_{t-s+m} \text{ ....(5)}$$

Where $P_P = P_{(t+m-i)}$=Population of m steps ahead to get predictions decade (i=1, 2, …, m).

The initial value of the trend is taken equal to zero.

$$S_t = \gamma(Y_t - T_t) + (1-\gamma)S_{t-s} \text{ ....(6)}$$

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4. Results and Discussion

In this study, the HW, AHW and MHW models are applied on database from the year 1984 to 2022 to predict the annual rainfall for Junagadh region. The data of the 35 years (1984-2019) were used for calibration of models' parameters. The values of these parameters were kept constant during model validation and forecasting procedures. Models were validated by comparing data of the remaining three years (2020-2022) and forecasts were made for the next three years (2022-2025).

The model parameters require to be optimized as the meteorological time series are very dynamic in nature. Once the values of the smoothing constants i.e., α, β, and γ were calibrated, they kept constant. Microsoft Excel add-in program Solver was used for calibration and optimization of the smoothing constants (α, β, and γ). Microsoft Excel spread sheets was used for statistical analysis, evaluation and graph preparation.

Models were evaluated by employing refined Willmott's index (d_r) (Dimensionless statistic) and mean absolute error (MAE) (error index statistic) statistical criteria. d_r indicates the degree of similarity between the predicted and observed deviations about the observed mean comparative to the sum of the magnitudes of the perfect model and observed deviations about the observed mean. d_r varies from -1.0 to 1.0. d_r=0 implies that the sum of the magnitudes of the errors and the sum of the perfect model deviation and observed deviation magnitudes are alike. d_r=1.0 indicates perfect agreement between modeled value and observation and a d_r of -1. 0 shows either lack of agreement between the modeled value and observation or insufficient variation in observations to adequately test the model. MAE is the most natural and unambiguous measure of average error scale. It provides more robust measure of average model error, since it is not influenced by extreme outliers and estimates model error in the units of the variable. A higher MAE value indicates poor model performance and vice versa. MAE=0 indicates a perfect fit.

Table shows performance of all the three models at annual time scale along with calibration values of smoothing constants. The results indicate that HW (d_r=0.64 and MAE =26.54 mm) and MHW (d_r=0.64 and MAE =26.53 mm) models performed slightly better than AHW (d_r=0.63 and MAE =27.05 mm) model at annual time scale. This explicates that the annual rainfall does not exhibit additive seasonality. The results are in good agreement with results obtained by [16] in their study for forecasting the ionosphere delay. Predicted annual rainfalls for the year 2023 to 2025 by these models are also presented in Table. All the models predicted highest rainfall (1452.53 mm, 1459.08 mm, and 1464.15 mm) in the year 2025 which is more than 1.5 times the average annual rainfall (AAR) 953.59 mm (1984-2022) of the region. It was revealed from (Figure 2) that all the three methods overestimated annual rainfall in the year 2023 and 2025 while they underestimated the rainfall in the year 2024.The trend smoothing constant calibrated values (β=1) showed the growing trend in annual rainfall. The values of smoothing constant α obtained nearly zero which indicates no significant contribution of average (level) value of series in forecasting the annual rainfall. The rainfall prediction is a complicated job and there will not be one correct model for all datasets. The rainfall is highly complex natural phenomenon influenced by many meteorological factors and hence does not follow any deterministic trend, pattern and seasonality. However, all the three models explicitly performed well and predict the annual rainfall satisfactorily.

Table 1. Performance of HW, AHW and MHW models at annual time scale

Years	Observed Rainfall in mm	Predicted Rainfall in mm		
		HW	AHW	MHW
2020	1758.00	1086.83	1090.56	1098.35
2021	1344.80	899.50	909.69	917.52
2022	1089.10	1511.29	1511.26	1511.50
2023	AAR = 953.59 (1984-2022)	1342.46	1336.39	1335.30
2024		1073.29	1074.65	1077.35
2025		1452.53	1459.08	1464.15
Statistical measures	d_r	0.64	0.63	0.64
	MAE (mm)	26.54	27.05	26.53
Smoothing constants	α	0.0097	0.0190	0.0095
	β	1.0000	1.0000	1.0000
	γ	0.0509	0.0466	0.0511

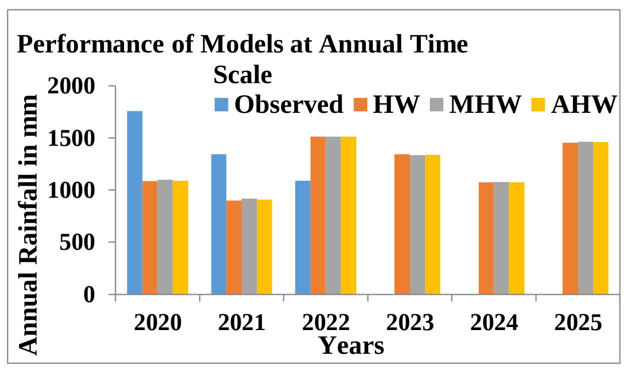

Figure 2. Performance of HW, MHW and AHW models at annual time scale

5. Conclusions

In the present study, the predictive ability of the HW, AHW and MHW models is investigated to forecast the annual rainfall for Junagadh (Gujarat-India) region. Annual rainfall data from 1984 to 2022 were used to analyze the models. The models' performances were evaluated on annual time scales with two statistical measured and MAE. The results indicated that the HW and MHW performed slightly better than the AHW model. Nearly zero values of smoothing constant α indicate a little contribution of average (level) value of series in forecasting the annual rainfall.The trend smoothing constant calibrated value (β=1) pointed out a significant rising trend has been shown in annual rainfall data. It is recommended that for a practical point of view, all the three models can be used to predict the annual rainfall of Junagadh region and other similar hydro-meteorological regions.

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References

1. Chand R., Singh U.P., Singh V.P., Siddique L.A. and Kore P.A., Analysis of weekly rainfall of different period during rainy season over Safdarjung airport of Delhi for 20thcentury - A study on trend, decile and decadal analysis, *Mausam*, Vol. 62, No. 2, pp. 197-204, 2011.
2. Jain S.K., Kumar V. and Saharia M., Analysis of rainfall and temperature trends in northeast India, *International Journal of Climatology*, DOI: 10.1002/joc.3483, 2012.
3. Pingale S., Khare D., Jat M. and Adamowski J., Spatial and temporal trends of mean and extreme rainfall and temperature for the 33 urban centres of the arid and semi-arid state of Rajasthan, India, *Atmospheric Research*, Vol. 138, pp. 73-90, 2014.
4. Rani Arthi, Manikandan and Maragathan N., Trend analysis of rainfall and frequency of rainy days over Coimbatore, *Mausam*, Vol.65, No 3, pp. 379-384, 2014.
5. Das J. and Bhattacharya S.K., Trend analysis of long-term climatic parameters in Dinhata of Koch Bihar district, West Bengal, *Spatial Information Research*, DOI: 10.1007/s41324-018-0173-3, 2018.
6. Goswami B.N., Venugopal V., Sengupta D., Madhusoodanam M.S. and Xavier P.K., Increasing trends of extreme rain events over India in a warming environment, *Current Science*, Vol, 314, pp. 1442-1445, 2006.
7. Jaswal A.K., Roa P.C.S. and Singh V., Climatology and trends of summer high temperature days in India during 1969–2013, *J Earth SystSci*, DOI: 10.1007/s12040-014-0535-8, 2015.
8. Meshram S.G., Singh S.K., Meshram C., Deo R.C. and AmbadeB., Statistical evaluation of rainfall time series in concurrence with agriculture and water resource of Ken River Basin, Central India (1901-2010), *Theoretical and Applied Climatology*, DOI: 10.1007/ s00704-0172335-y, 2017.
9. Yin Y., Xu C.Y., Chen H., Li L., Xu H., Li H. and Jain S.K., Trend and concentration characteristics of precipitation and related climatic telecommunications from 1982 to 2010 in the Beas River basin, India, *Global and Planetary Change*, Vol. 145, pp. 116-129, 2016.
10. Bernal J.L., Cummins S. and Gasparrini A., Interrupted time series regression for the evaluation of public health interventions: a tutorial, *International Journal of Epidemiology*, Vol. 46, No 1, pp. 348, 2017.
11. Faust K., Lahti L., Gonze D., De VosVos W.M. and Raes J., Metagenomics meets time series analysis: unraveling microbial community dynamics. *Current Opinion in Microbiology*, DOI: 10.1016/j.mib.2015.04.004, Vol. 25, pp. 56-66, 2015.
12. Gocheva-Ilieva S.G., Ivanov A.V., Voynikova D.S. and Boyadzhiev D.T., Time series analysis and forecasting for air pollution in small urban area: an SARIMA and factor analysis approach, *Stochastic Environmental Research and Risk Assessment*,Vol. 28. No 4, pp. 1045, 2014.
13. Montgomery D.C., Jennings C.L. and Kulahci M., Introduction to time series analysis and forecasting, *John Wiley & Sons*, 2015.
14. Komornik J., Komornikova M., Mesiar R., Szokeova D. and Szolgay J., Comparison of forecasting performance of nonlinear models of hydrological time series, *Physics and Chemistry of the Earth*,DOI: 10.1016/j.pce.2006.05.006. Vol. 31, No. 18, pp. 1127-1145, 2006.
15. Rossi M. and Brunelli, Forecasting data centers power consumption with the Holt-Wintersmethod, In Environmental, Energy and Structural Monitoring Systems (EESMS), IEEE Workshop, pp. 210-214, 2015.
16. Elmunim N.A., Abdullah M., Hasbi A.M. and Bahari S.A., The Comparison of Statistical Holt-Winter Models for Forecasting the Ionospheric Delay Using GPS Observation, *Indian Journal of Radio and Space Physics*, Vol. 44, pp. 28-34, 2015.

Biographical notes

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