Autoregressive Model Development of Some Rainfall Stations of Assam

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ABSTRACT

The study is concerned with the development of a time series model for predictions of the South West Monsoon (SWM) rainfall in three rainfall stations, namely Barpeta, Digboi and Goalpara spread over plain and hilly areas of Assam. The SWM rainfall data of 60 years (1900-1960) are collected and are used for the development of the model. Autoregressive (AR) models of different orders are progressively tried to fit the model. It is observed that the AR model of order one can be used efficiently for the future prediction of rainfall at these stations. The goodness of fit and adequacy of the model are tested with the help of Akaike information criteria and other tests such as residual analysis. The graphical comparisons of historical and generated data are in close agreement.

Keywords: *South West Monsoon, Autoregressive model, Akaike Information Criteria, Residual analysis, Mean Forecast Error, Root Mean Square error.*

1. Introduction

The South West Monsoon (SWM) is an important phenomenon connected with the weather and agriculture throughout the states of East and North East regions of India including Assam. The state of Assam is traditionally dependent on agriculture as about 75% of the population is engaged in farming. Study of the management of water resources is an important and significant. SWM rainfall modeling is an important aspect of weather study and some research activities are in progress. Some studies are available at the all India level (eg. Iyenger and Basak, 1994; Sengupta and Basak, 1998; Iyenger and Raghukant, 2003; Iyenger and Raghukant, 2005); in some states (eg. Iyenger, 1991; Basak, 2014; Basu et al., 2004). Most of the analysis attempts for advanced statistical approach and physical process that occurs.

The principal aim of time series analysis is to describe the history of moments in some variables at a particular place. For a comprehensive review of time series used in climatology and weather study, it is suggested to identify the presence of any stationarity and trend that may be present in time series. Whilst, a few rainfall stations series have both deterministic and stochastic component, stochastic time series model such as Autoregressive (AR) (Thomas and Fiering, 1962; Yevjevich, 1963), Moving Average (MA) and Autoregressive Moving Average (ARMA) (Carlson, 1970) are used to predict the series. Salas and Smith (1981) demonstrated few physical considerations of the models. Rai and Sherring (2007) demonstrated some other aspects of a model, namely, AR model is mainly suitable for certain region of climate.

Few models fit in a data set analyzed for a certain range. It is noticed that multivariate autoregressive (MAR) and univariate autoregressive (AR) are suitable for regional scale rainfall modeling (Tomsaz, 2006) and also model found applicable in a particular zone such as temperate zone (Iyenger, 1982).

In the present study, a time series model of SWM rainfall applicable to three stations, namely, Barpeta, Digboi and Goalpara located at the three regional end of Assam, India has been organized. The objectives of the study are to,

- Generate a stochastic time series model for prediction of SWM rainfall at the three stations.
- Estimate parameters of the autoregressive model.
- Test the validity of the predicted model and evaluate the performance of the model.

2. Materials and Methods

The rainfall stations of plains and hills of Assam spread over Barpeta, Digboi and Goalpara are depicted in the Fig. 1. The data set used to develop proposed model consists of yearly SWM rainfall provided by Indian Meteorological Department, Pune. Time series of the SWM rainfall are presented in Figs. 2-4.

2.1 Stochastic time series model

A mathematical model representing a stochastic process is stochastic time series models. Whilst the time series models represent different structure and set of parameters, a simple time series model could be represented by single probability distribution function f(X; Θ) with parameters $\Theta=(\Theta_1, \Theta_2, \ldots.)$ valid for all time points t=1,2,….,n and without any dependence between $X_1, X_2, \ldots, X_n$ subsequently.

A time series model with dependent structure can be formed as (Box and Jenkins 1970)

$$Y_t = \Theta . Y_{t-1} + \epsilon_t \qquad (1)$$

Where, ϵ_t = a_n independent series with mean zero and variance $(1-\Theta^2)$

Y_t = A dependent series

Θ =Parameter of the model

2.2 Autoregressive (AR) model

In an Autoregressive model, the current value of a variable (say, rainfall) is equated to the weighted sum of a pre-assigned number of part values and a variable that is random of the previous process and shock (white noise). The p-th order Autoregressive model AR (p), representing the variable Y_t is in general represented as

$$Y_t = Y' + \sum_{j=1}^{p} \Theta j (Y_{t-j} - Y') + \epsilon_t \qquad (2)$$

where, Y_t=The time dependent series variable (say SWM rainfall)

ϵ_t = The time dependent series which is independent of Y_t and is normally distributed with mean zero and variance σ^2,

Y' = Mean value of the variable (rainfall)

and $\Theta_1, \Theta_2, \ldots, \Theta_p$ are Autoregressive parameters.

2.3 Estimation of autoregressive parameters (Θ_j): Maximum likelihood estimate

For estimation of the model parameter, method of maximum likelihood is utilized (Anderson 1972). Considering the sum of cross-products,

$$Z_i z_j + Z_{i+1} z_{j+1} + \ldots + Z_{n+i-i} z_{n+i-j}$$

the model parameters are estimated as follows. In particular, for AR(1) model, $X_t = \phi . X_{t-1} + e_t$, (t=1,2,….n),

estimate of ϕ is computed as $\phi = \dfrac{\sum_{t=2}^{n} X_{t-1} . X_t}{\sum_{t=1}^{n-1} X_{t-1}^2}$

and also, for AR(2) model, $X_t = a_1 . X_{t-1} + a_2 . X_{t-2} + e_t$, (t=1,2,….n),

the corresponding a_1 and a_2 are computed as

$a_1 =$

$$\frac{\left(\sum_{t=2}^{n-1} x_t x_{t-1}\right)*\left(\sum_{t=1}^{n-2}(x_t^2)\right) - \left(\sum_{t=2}^{n-1} x_t x_{t-1}\right)*\left(\sum_{t=3}^{n} x_t x_{t-2}\right)}{\left(\sum_{t=1}^{n-2} x_t^2\right)^2 - \left(\sum_{t=2}^{n-1} x_t x_{t-1}\right)^2}$$

and

$a_2 =$

$$\frac{\left(\sum_{t=3}^{n} x_t x_{t-2}\right)\left(\sum_{t=1}^{n-2}(x_t)^2\right) - \left(\sum_{t=2}^{n-1} x_t x_{t-1}\right)^2}{\left(\left(\sum_{t=1}^{n-2}(x_t)^2\right)^2\right) - \left(\sum_{t=2}^{n-1} x_t x_{t-1}\right)^2}$$

2.4 Autocorrelation function

The autocorrelation function r_k at lag k of the variable Y_t of equation (2) is obtained by multiplying both sides of the equation (2) by y_{t+k} and taking expectation term by term as proposed by Kottegoda and Horder (1980)

$$r_k = \frac{\sum_{t=1}^{n-k}(Y_t - \bar{Y})(Y_{t+k} - \bar{Y})}{\sum_{t=1}^{n}(Y_t - \bar{Y})^2}$$

where,

r_k = Autocorrelation function of time series Y_t at lag k

Y_t = Historical SWM rainfall series

$\underline{Y}$'= Mean of time series Y_t

k = Lag of k time unit

n = Total number of discrete values of time series Y_t

The 95% probability of level of autocorrelation is determined as (Anderson, 1942)

$$r_k\,(95\%) = \frac{-1 + 1.645\sqrt{N-K-1}}{N-K}$$

2.5 Partial autocorrelation function

The following equation was used to calculate the partial autocorrelation function of lag k (Durbin, 1960),

$$PC_{k,k} = \frac{r_k - \sum_{j=1}^{k-1} PC_{k-1,j}\, r_{k-j}}{1 - \sum_{j=1}^{k-1} PC_{k-1,j}\, r_j}$$

Where, PC_{kk} = Partial autocorrelation at lag k

r_k = Autocorrelation function at lag k

The 95% probability limit for partial autocorrelation function are calculated using the following equation,

$$PC_{kk}\,(95\%) = 1.96/\sqrt{n}$$

3. Statistical Characteristics and Analytical Procedure

Stationarity

The presence of linear or nonlinear trend in the data series is tested using the Mann-Kendall rank statistic test (WMO1966b). The test statistic is computed as

$$T = \frac{4\sum_{i=1}^{N} ni}{N(N-1)} - 1$$

Here n_i is the number of values larger than the i^{th} in the series subsequent to its position in the time series and N is the length of the time series. For N≥ 10; T is distributed normally with zero mean and variance (4N + 10)/(9N(N-1)).

The statistic T is significant, if

$|T| \geq (T)_t$

Here, $(T)_t$ =±t_g. Sqrt((4N+10)/(9N(N-1),

t_g being the desired probability level of the Gaussian distribution (say, 5% level).

Akaike information criterion

The Akaike Information Criteria (Akaike, 1974) was used for checking whether the order of the fitted model is adequate compared with the order of dependence model. Akaike Information Criteria for AR(p) models, are computed using the following equation.

$$AIC(p) = n.\ln(\sigma_\epsilon^2) + 2.(P)$$

where n=Number of observation

σ_ϵ^2 = Residual variance

and p=Order of the model

A comparison was made between the AIC(p), AIC(p-1) and AIC(p+1); then the AR(p) model is the best otherwise, the model which gives minimum AIC value is the one to be selected.

4. Evaluation of Quality of Model

In order to evaluate quality of the autoregressive (AR) models, we utilized the several criteria as follows

Mean forecast error

Mean forecast error (MFE) is calculated to evaluate the performance of autoregressive models fitted to time series of rainfall. The MFE is computed for the SWM rainfall series by the following equation (Raghuwanshi and Wallender, 2000).

$$MFE = \frac{\sum_{i=1}^{n} rc(i)}{n} - \frac{\sum_{i=1}^{n} ro(i)}{n}$$

where rc(t) = Computed SWM rainfall value

ro(t) = Observed SWM rainfall value

n = Number of observations

Mean absolute error

Mean absolute error (MAE) is calculated to evaluate the performance of AR models fitted to time series of rainfall. The MAE is computed for the SWM rainfall series by the following equation

$$MFE = \frac{\sum_{i=1}^{n} |rc(i)-ro(i)|}{n}$$

Root mean square error

Root mean square error (RMSE) is calculated as per the following formula

$$MFE = \frac{\sum_{i=1}^{n} [rc(i)-ro(i)]2}{n}$$

Residual analysis

The residuals of the model, $r_t = x_t - x_1$, where x_t and x_1 are the actual value and predicted value respectively of SWM rainfall.

The mean, variance and standard deviation of the residuals are computed. Moreover, standard errors of the residuals are computed. For a good model, the statistics are expected to be small and the statistics reduces as far as the model matches the observations.

5. Development of the Forecasting Model

The SWM rainfall series of the subjected stations, namely Barpeta, Digboi and Goalpara were tested for stationarity (WMO, 1966b) and the station rainfall series of the subjected stations are found stationary.

The standardized SWM series were modeled through the AR model. The modeling procedure of the data series involved various steps like preliminary analysis and identification, estimation of model parameters and diagnostic checking for the adequacy of the model (Salas and Smith, 1980). Autocorrelation and Partial autocorrelation are used for identification of the models. The identification generally depends on the overall rainfall system, the characteristic of the time series and the model inputs. Salas and Smith (1981), Iyenger (1982) and Iyenger and Basak (1994) demonstrated these physical considerations of the type of model. The

Autocorrelation function and Partial autocorrelation functions with 95% probability limits up to lag 4 of the series (lag k) were computed and AR model of first order, AR(1) is selected for further analysis for all the stations.

Akaike Information criteria (AIC) for the respected stations are tested to check the adequacy of the AR (0), AR (1) and AR (2) models for SWM rainfall and the tests reveal that all three models are good fit and are acceptable but AIC values of AR (1) are lying between AR (2) and AR (0) for the respective stations. Consequently, AR (1) model is considered for models of SWM rainfall for the subjected stations.

6. Results and Discussion

The parameters of AR model were computed for SWM rainfall of Barpeta, Digboi and Goalpara (Tables1-3). The predicted values of SWM rainfall were compared with the observed values (fig.s 1-3). It was observed that AR (p) model up to order 1 have shows the good fit and correlation between the observed and predicted values.

The autoregressive model for Barpeta is as follows:

$$AR(1): Y_t=1601.7286+0.7876(Y_{t-1}-1601.7286)+e_t$$

The autoregressive model for Digboi is as follows:

$$AR\ (1): Y_t=872.5832+\ 0.9592(Y_{t-1}-872.5832)+e_t$$

The autoregressive model for Goalpara is as follows:

$$AR(1): Y_t=1228.4518+0.6991(Y_{t-1}-28.4518)+e_t$$

6.1 Statistical characteristics of the models

The mean, standard deviation and skewness of historical and model data was calculated to evaluate the fitting of the model in moment preservation. The results clearly indicates that the skewness of model data by AR (1) model and historical data is lying between -1 to +1 and therefore AR (1) model preserved the mean and skewness better. Performances of the models are estimated with the statistical characteristic such as AIC, MFE, MAE and RMSE. The details are presented in Table 1. All the errors are less attesting efficiency of AR (1) models of SWM rainfalls in the respective stations.

We observe that all evaluation criteria support the quality of the proposed model for SWM rainfall.

6.2 Residual analysis of the model

It may be observed that the overall quality of the model is good. We proceed to calculate the residuals , $r_t = x_t - x_1$, where x_t and x_1 are the actual value and predicted value respectively of SWM rainfall at the stations and results are graphically presented in Fig. 1-3 for Barpeta, Digboi and Goalpara respectively.

We observe that the residuals are quite small and fluctuating around zero axes as expected. The mean, standard deviation and MSE of the residuals are also found to be reasonably small (Table 2). This attests that the proposed model is capable of forecasting the SWM rainfall for the respective stations.

7. Conclusions

We have developed a stationary time series model to predict future estimates of SWM rainfall relevant over stations of Assam. We use actual SWM rainfall recording in both the situations to develop subject statistical model. The developed process is evaluated to attest the degree of quality by using various statistical criteria. Finally, we test the accuracy of the proposed model by predicting and analyzing the SWM rainfall. The result appears encouraging.

The developed AR (1) models were evaluated to attest the degree of quality by using various statistical criteria. On the basis of estimated errors, statistical characteristics and correlation between the observed and predicted values, it is concluded that the proposed autoregressive AR (1) model can be used to predict the future estimates of SWM rainfall at three spatially distributed stations of Assam, namely Barpeta, Digboi and Goalpara.

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Table 1 Statistical parameters of first order autoregressive (AR (1)) model for SWM rainfall for Barpeta, Digboi and Goalpara.

Station Name	AR(1) parameter	Akaike information Criteria (AIC)	Mean Observed/ Predicted	Standard Deviation Observed/Predicted	Mean Forecast Error (Predicted)	Mean Absolute Error (Predicted)	Root Mean Square Error (Predicted)
Barpeta	0.7876	195.5562	1601.7286/1578.1541	151.1449/148.2563	-49.7152	280.3129	397.8725
Digboi	0.9592	181.0817	872.5832/868.2541	214.8285/211.2982	-30.5315	204.3481	253.1050
Goalpara	0.6991	184.6894	1228.4518/1230.5819	516.0526/518.0185	-11.9633	227.7025	203.3108

Table 2 Residual analysis of model and observed SWM rainfall of stations, Digboi, Goalpara and Barpeta

Barpeta				Digboi			Goalpara		
Year	Observed SWM rainfall	Model SWM rainfall	Residual	Observed SWM rainfall	Model SWM rainfall	Residual	Observed SWM rainfall	Model SWM rainfall	Residual
1901	1492.79	1492.79	0.00	1141.90	1141.90	0.00	1660.00	1660.00	0.00
1902	1655.90	1363.50	292.4	1059.89	1093.92	-34.02	1784.99	1612.01	172.98
1903	1533.40	1511.38	22.02	1141.90	1016.08	125.81	1454.69	1732.65	-277.95
1904	1184.49	1400.31	-215.82	1184.40	1093.92	90.48	1414.09	1413.88	0.21
1905	1836.19	1083.97	752.22	964.29	1134.26	-169.96	1412.60	1374.70	37.89
1906	1427.29	1674.86	247.57	1162.19	925.33	236.86	1219.79	1373.25	-153.45
1907	1531.10	1304.11	226.99	1145.89	1113.18	32.71	1286.49	1187.19	99.30
1908	1149.5	1398.23	-248.73	848.19	1097.71	-249.51	1629.09	1251.56	377.53
1909	1498.90	1052.23	446.67	1021.59	815.13	206.46	1306.69	1582.19	-275.49
1910	1248.59	1369.03	-120.44	763.49	979.72	-216.22	1906.00	1271.05	634.94
1911	1742.40	1142.09	600.31	1096.09	734.73	361.36	2020.79	1849.42	171.37
1912	1893.89	1589.81	304.08	1076.80	1050.44	26.35	1389.50	1960.21	-570.71
1913	1318.90	1727.17	-408.27	850.79	1032.12	-181.32	1576.00	1350.96	225.03
1914	1175.90	1205.83	-29.93	979.39	817.60	16.79	1774.00	1530.95	243.04
1915	2000.50	1076.17	924.33	903.79	939.67	-35.87	1343.69	1722.03	-378.33
1916	1475.39	1823.62	-348.23	796.09	867.91	-71.80	1388.99	1306.76	82.23
1917	1104.09	1347.72	-243.63	1428.30	765.67	662.62	1864.80	1350.48	514.31
1918	2000.6	1011.07	989.53	1250.30	1365.77	-115.47	1843.49	1809.66	33.83
1919	937.29	2168.46	-1231.17	904.39	1196.81	-292.41	1515.30	1789.10	-273.80
1920	1423.59	859.83	563.76	805.09	868.47	-63.37	1201.40	1472.37	-270.97
1921	1055.39	1300.76	-245.37	1034.99	774.22	260.77	1736.40	1169.43	566.96
1922	753.39	1003.18	-249.79	1010.59	992.44	18.15	1610.89	1685.74	-74.84
1923	624.3	693.09	-68.79	630.69	969.28	-338.58	1667.09	1564.63	102.46
1924	1382.10	576.04	806.06	971.09	608.67	362.42	1751.20	1618.87	132.32
1925	906.39	1263.13	-356.74	834.99	931.79	-96.79	1769.10	1700.03	69.06
1926	787.19	741.15	46.04	602.4	802.60	-200.20	1791.89	1717.30	74.59
1927	626.83	723.74	-96.91	1016.79	581.81	434.98	1770.19	1739.31	30.88
1928	934.89	850.41	84.48	727.79	975.17	-247.37	2456.30	1718.36	737.93
1929	873.19	857.66	15.53	749.79	700.84	49.95	1822.80	2380.50	-557.70
1930	777.6	801.30	-23.7	946.09	721.72	224.37	1494.20	1769.13	-234.93
1931	959.59	715.04	244.55	1184.59	908.06	276.53	1145.30	1452.00	-306.70
1932	1087.99	880.05	207.94	649.09	1134.45	-485.35	1389.50	1115.29	274.20
1933	851.59	996.47	-144.88	705.19	626.14	79.05	1092.00	1350.96	-258.96
1934	1062.40	782.13	280.27	1207.70	679.39	528.30	1592.40	1063.85	528.54
1935	736.3	973.26	-236.96	590.00	1156.37	-566.37	1065.49	1546.77	-481.27
1936	517.39	677.59	-160.2	872.20	570.04	302. 15	1338.60	1038.2832	300.31
1937	634.7	479.12	155.58	1182.50	837.91	344. 58	1286.59	1301.84	-15.24
1938	316.29	585.47	-269.18	1023.99	1132.45	-108 .45	1034.59	1251.66	-217.06

1939	343.50	296.78	46.72	917.59	982.00	-64.40	1106.09	1008.46	97.63
1940	250.79	321.44	-70.65	891.99	881.00	10.99	769.69	1077.46	-307.76
1941	385.58	281.32	104.26	621.99	856.70	-234.70	1057.00	752.81	304.18
1942	354.58	540.35	-185.77	959.89	600.41	359.48	756.69	1030.08	-273.38
1943	384.33	335.41	48.92	824.59	921.16	-96.56	980.79	740.26	240.53
1944	341.69	355.53	-13.84	444.29	792.73	-348.43	1235.20	956.54	278.65
1945	363.00	314.80	48.2	630.90	431.74	199.15	1282.69	1202.05	80.64
1946	367.99	339.12	28.87	639.49	608.86	30.63	1028.39	1247.89	-219.49
1947	906.49	343.47	563.02	769.89	617.02	152.87	725.10	1002.47	-277.37
1948	675.99	904.44	-228.45	642.99	740.80	-97.80	791.70	709.77	81.92
1949	1010.80	622.92	387.88	960.79	620.35	340.44	471.89	774.04	-302.14
1950	310.79	926.57	-615.78	642.69	922.01	-279.31	406.79	465.41	-58.61
1951	381.80	291.79	90.01	59.39	620.06	-60.66	475.80	402.59	73.20
1952	845.90	356.17	489.73	890.39	540.99	349.40	634.50	469.18	165.31
1953	608.59	776.96	-168.37	546.59	855.18	-308.58	435.89	622.33	-186.43
1954	194.10	561.82	-367.72	738.10	528.84	209.25	282.60	430.67	-148.07
1955	268.99	185.98	83.01	592.79	710.62	-117.82	444.69	282.72	161.97
1956	108.5	253.89	-145.39	744.99	572.70	172.29	337.90	439.16	-101.26
1957	253.6	108.37	145.23	606.79	717.17	-110.37	255.10	336.09	-80.99
1958	108.5	239.93	-131.43	678.20	585.98	92.21	468.20	256.18	212.01
1959	104.42	108.37	-3.95	63.09	653.76	-22.66	545.70	461.84	83.85
1960	27.5	104.93	-77.43	953.90	609.05	344.84	407.50	536.63	-129.13
	Mean of residual 49.71			30.59			11.96		
	Std.dev.of residual (SD) 398.08			253.37			285.44		
	Std.err. of residual (SE) 19.98			15.91			16.89		
	Mean Square Error (MSE)								

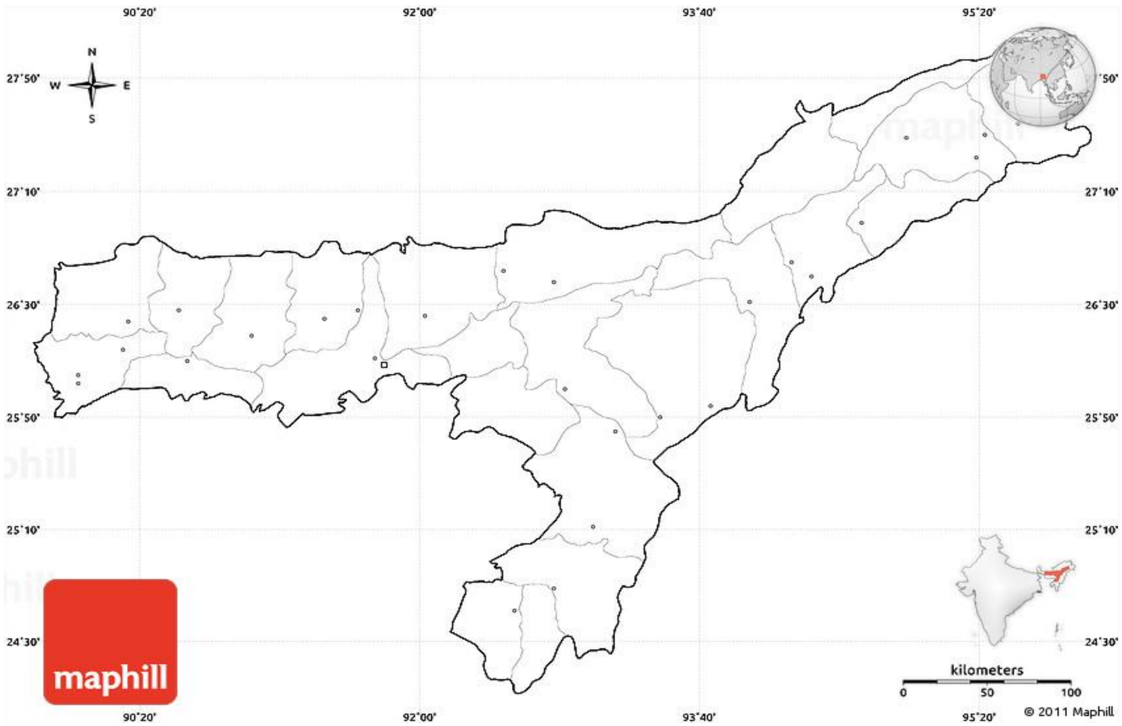

Fig. 1: Location of stations of Assam: Barpeta (1), Goalpara (2), Digboi (3) (Courtsey: Maphill)

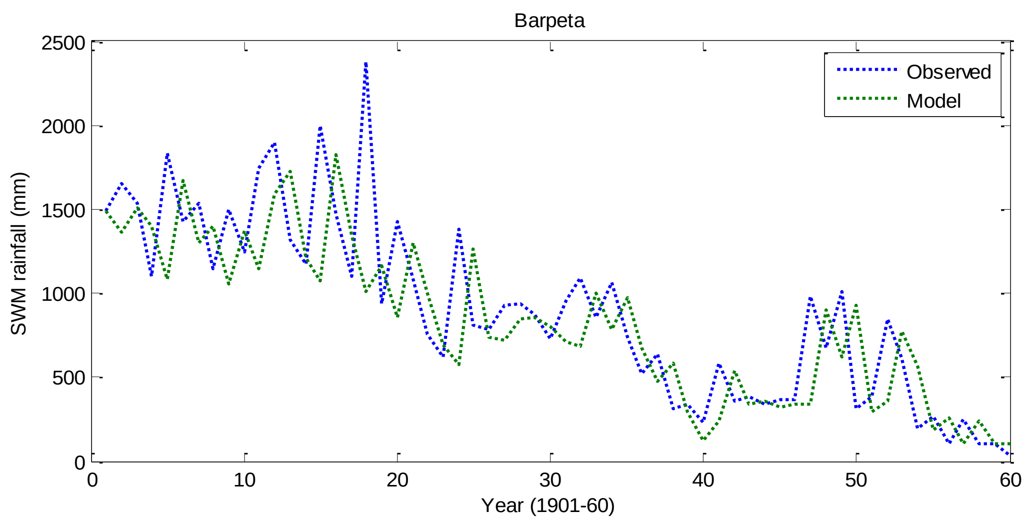

Fig. 2: Yearly SWM rainfall vs. model values for the station Barpeta.

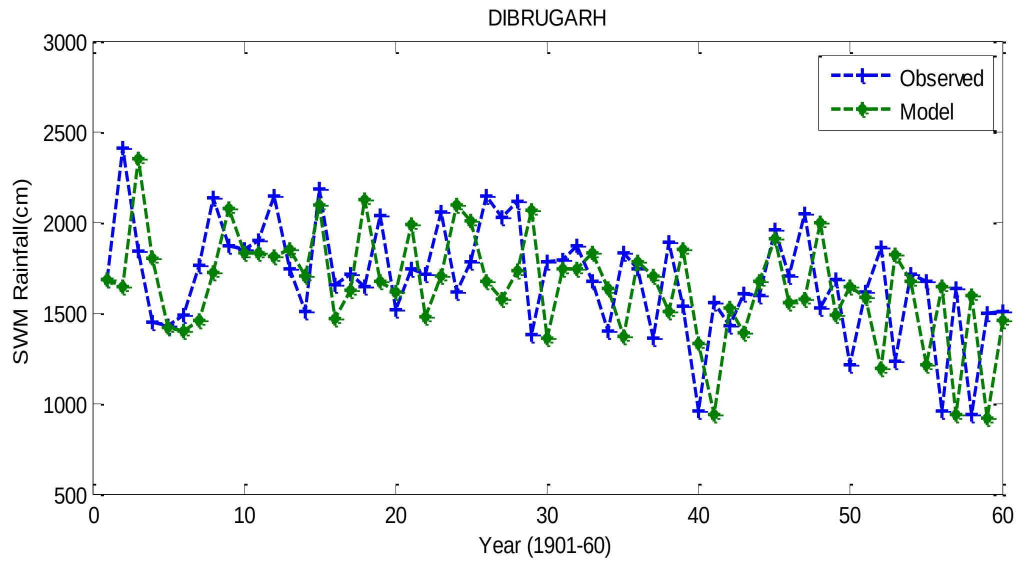

Fig. 3: Yearly SWM rainfall vs. model values for the station Digboi.

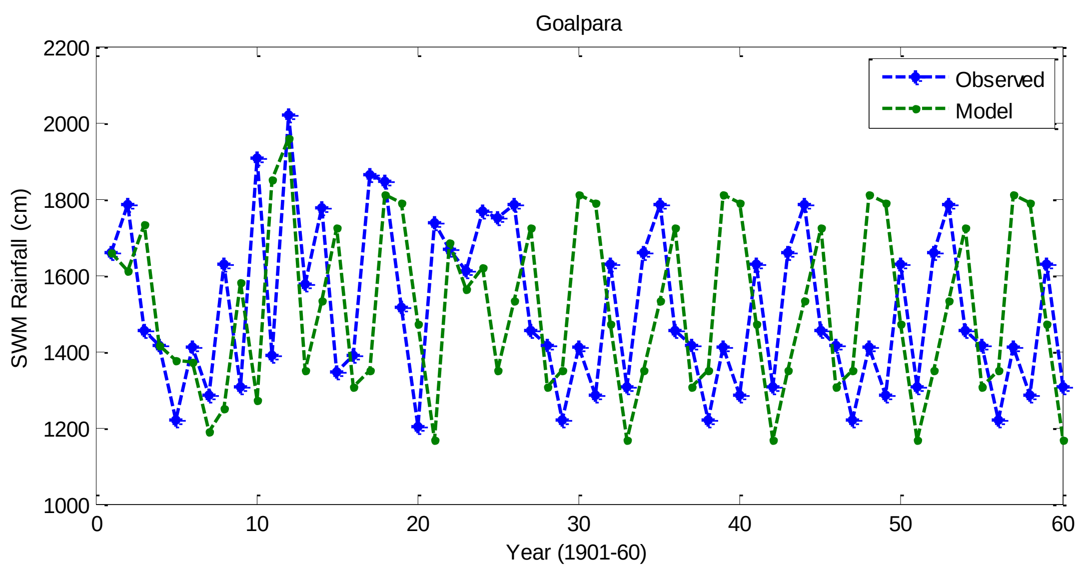

Fig. 4: Yearly SWM rainfall vs. model values for the station Goalpara.