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Forecasting models for seasonal rainfall for different regions of Gujarat

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ABSTRACT

The large spatial variability in monsoon rainfall over India demands for regional models for predicting the seasonal rainfall. Hence, models were developed for predicting seasonal (June-September) rainfall of three regions (north, middle and south) of Gujarat using multiple regression technique. The monthly weather data of 30 years of Anand (1980-2009), 22 years (1987-2009) of Navsari and 27 years (1983-2009) of SK Nagar were used. The models were validated with independent data set of four year (2006-2009). The best models were selected based on higher R^2 and lower model error. Four models were obtained; 2 for Anand (middle Gujarat) and one each for SK Nagar (north Gujarat) and Navsari (south Gujarat). Different models explained 74 to 93% variability in seasonal rainfall with models error ranging between -2.5 to 5.1%. During the validation period the performance of model was quite satisfactory with model error rainging between -12.6 to 2.6%. All the models were used to predict the rainfall for 2010 season. Results suggested that the rainfall would be higher than the normal rainfall in all the three regions. Navsari (south Gujarat) is expected to receive 1529.0 mm (14.5% higher than the normal), Anand (middle Gujarat) is expected to get 1294.0 to 1363.0 mm (62-71% higher) and SK Nagar (north Gujarat) is expected to receive 770.0 mm (40% above normal) rainfall during June to September period of year 2010.

Key words: Rainfall prediction, monsoon rainfall, seasonal, regression model

A major portion of annual rainfall over India is received during the southwest monsoon season (June–September) which is more or less stable with the mean seasonal rainfall (based on 1941–1990 data) of 89 cm and CV % of 10 (Rajeevan *et al.,* 2006). However, even small fluctuation in the seasonal rainfall can have devastating impacts on agricultural sector at regional level. Thus forecasting of seasonal mean rainfall is therefore in great demand by the country's policy makers. In the past, attempts were been made to predict the total summer monsoon rainfall using empirical techniques involving local and global antecedent parameters that correlate with the monsoon rainfall. In the beginning of this century, Walker (1924) introduced an object technique of co-relation for long range forecast and identified a few predictors from different parts of the world. Subsequently several antecedent meteorological parameters were identified and used for prediction (Jagannathan, 1960; Thapliyal and Kulshreshtha, 1992). In all these attempts a limited number of parameters were used, utilizing multiple linear regression technique. The accuracy of models was not always very satisfactory. The 16-parameter power regression and parametric models developed by Gowariker *et al*., (1991) were introduced operationally by IMD in 1988. The year 2002 turned out to be an all-India drought year with an overall rainfall deficiency of 19%, while model had predicted a normal monsoon, resulting in a lot of attention being focused on IMD's prediction methodology. The long-range forecasts models were subsequently modified and now IMD follows a two-stage forecasting strategy for long range forecasting of the south-west monsoon rainfall. The first stage forecast is issued in April for the south-west monsoon season (June-September) rainfall for country as a whole, while the second stage is issued in June for four broad geographical regions of India using separate multiple regression models (IMD, 2010).

Although at many a times the SW-monsoon rainfall of country as a whole had been normal but there have been quite large variation in regional rainfall distribution. IMD has predicted 828 mm rainfall in 2006 for country as a whole (93% of normal), but Gujarat received 1072.8 mm rainfall which was 151.2 % as compared to the normal. While, in 2009 IMD predicted 881.1 mm (99% of normal) rainfall, but Gujarat received 613.7 mm (86.4% of normal) rainfall which was a deficit year. So, it was felt necessary to give regional prediction/local station by using statistical techniques. Thus, there is need to develop models for predicting regional rainfall. In this paper attempts have been made to predict the south-west monsoon rainfall of three different regions of Gujarat.

MATERIALS AND METHODS

For the present study three stations viz. Anand (latitude - 22° 35' N, longitude- 72° 58' E), Navsari (latitude- 20° 57' N, longitude- 72° 54' E) and Sardar Krushinagar (latitude - 24° 19' N, longitude- 72° 19' E) representing middle Gujarat, south Gujarat and north Gujarat respectively were selected, mainly because of availability of sufficiently long period weather data. These three stations vary considerably in terms of rainfall receipt. Navsari receives rainfall of 1335.6 mm followed by Anand 797.0 mm and SK Nagar 570.5 mm during monsoon season (June to September).The weekly weather data of 30 years (1980-2009) of Anand, 22 years (1987-2009) of Navsari

Table 1: Mean monthly weather data at three locations.

Station	Months	Rainfall (mm)	Tmax (°C)	Tmin (°C)	RH-I (%)	RH-II (%)	BSS (h)	Epan (mm day^{-1})
Anand (1980-2009) Middle Gujarat	January	1.3	28.2	11.4	80	36	9.3	3.5
	February	0.9	31.1	12.8	76	29	9.8	4.9
	March	0.1	35.6	17.3	67	23	9.4	6.9
	April	0.9	38.7	21.7	69	25	10.4	8.3
	May	11.8	39.3	25.7	76	36	10.5	9.0
	June	125.8	36.6	27.0	81	52	7.8	7.6
	July	349.4	32.3	25.7	90	71	4.0	4.3
	August	211.4	31.4	25.0	92	72	4.2	3.7
	September	110.8	33.3	24.5	90	60	7.4	4.6
	October	23.4	35.3	20.5	81	37	9.3	5.0
	November	9.9	32.4	15.4	77	32	9.3	4.1
	December	1.5	29.6	12.6	80	36	9.1	3.3
S.K.Nagar (1983-2009) (North Gujarat)	January	0.9	26.9	9.5	71	32	8.5	3.7
	February	0.8	29.6	11.2	67	27	9.4	5.3
	March	0.3	34.6	16.3	58	22	9.4	7.6
	April	1.4	38.4	20.7	58	20	10.2	10.0
	May	4.8	40.0	24.8	71	30	9.8	11.4
	June	75.1	38.5	25.9	75	42	7.5	10.4
	July	216.8	33.9	24.6	84	61	4.1	5.9
	August	194.3	32.2	23.6	88	70	3.8	4.6
	September	84.3	34.5	23.0	87	52	7.4	5.8
	October	19.5	35.9	19.3	73	30	9.3	5.9
	November	1.1	32.8	13.9	68	26	9.0	4.4
	December	1.2	27.8	10.3	73	32	8.4	3.4
Navsari (1987-2009) (South Gujarat)	January	6.5	30.0	13.0	79	37	9.3	3.6
	February	0.2	31.8	14.4	79	33	10.1	4.5
	March	0.5	34.0	18.4	80	36	9.0	5.5
	April	0.6	33.4	21.5	84	47	9.6	6.2
	May	5.7	33.1	25.5	88	57	9.5	6.5
	June	243.0	31.0	25.4	86	70	5.8	4.7
	July	605.0	30.1	25.9	88	81	3.3	2.9
	August	302.5	29.1	23.6	93	79	3.7	2.8
	September	185.1	28.9	22.7	89	74	5.7	2.8
	October	24.8	31.6	20.5	86	54	8.2	3.5
	November	4.6	28.2	16.3	80	45	8.2	3.2
	December	0.3	27.6	13.2	79	43	7.9	2.8

and 27 years (1983-2009) of SK Nagar available at Department of Agricultural Meteorology, BACA, AAU, Anand were used to develop prediction models for S-W monsoon seasonal (June to September) rainfall using multiple regression techniques. The data up to 2005 were used for model development while data of 2006 to 2009 were used for validating the models.

The weekly weather data of maximum temperature (Tmax), minimum temperature (Tmin), morning relative humidity (RH–I), afternoon relative humidity (RH-II), wind speed (WS), bright sunshine hours (BSS), pan evaporation (Epan) and rainfall were converted into monthly values (period wise) as per defined by IMD. The data pertaining to November to May period were used for development of models because these periods are very crucial for the development of monsoon currents. Co-relations were worked out between predictors (monthly weather data) with seasonal (June to September) rainfall. Based on significant co-relations the multiple regression analysis was performed by trial and error method to obtain the best combination of predictor parameters as decided by highest R^2 and lowest percent error. The models were validated with independent data set (2006-2009) and predictions were made for year 2010.

The performance of the models were studied in terms

Table 2: Statistical Models for Anand, SK Nagar and Navsari

Model No	Equation	R^2	Model Error
Anand (Model 1) Middle Gujarat	Y = 691.78+28.32*RH-II (Nov.) -143.2* WS (Nov.) -266.77* Tmax (Dec.) -178.91* BSS (Dec.) -155.79*WS (Dec.) +77.87* Tmax (Jan.) +170.08* Tmin (Jan.) -31.35 * RH-II (Jan.) +153.29*Tmax (Feb.) -202.40* Tmin(Feb.) + 41.030* RH-II (Feb.) - 205.95*BSS (Feb.) + 126.95*WS (Feb.) -102.92* Tmax(Mar.) + 313.11*Tmin (Mar) + 309.4334*BSS (Mar.)	0.74	5.1%
Anand (Model 2) Middle Gujarat	Y= -12405.43 -204.19*Tmax (Mar.) + 377.06* Tmin (Mar.) -20.63* RH-II(Mar.) +19.58 *BSS (Mar.) - 403.62*WS(Mar.) + 286.14*Tmax (Apr.) -399.88*Tmin(Apr.) +101.23*RH-II (Apr.) - 358.75*BSS (Apr.) + 191.63* WS (Apr.) + 143.13* Tmax (May) +71.59*Tmin (May) - 14.5 *RH-II (May) -65.98*BSS(May) + 87.82*WS (May)	0.85	-2.5 %
S.K.Nagar (North Gujarat)	Y= 4207.37 - 96.38*WS(Nov.) -0.74*RH-II (Nov.) -115.09* WS (Dec.) -73.46*Tmax (Dec.) -13.96*RH-I (Dec.) + 18.12*RH-II (Dec.) + 39.89*WS (Jan) - 411.37*Epan (Jan.) -32.70*RH-I (Jan.) + 14.81*RH-II(Jan.) -19.90*Epan (Feb.) + 26.96*RH-I (Feb.) + 5.61*RH-II (Feb.) + 193.58*WS (Mar.) + 14.93*RH-II (Mar.)	0.84	1.4%
Navsari (South Gujarat)	Y = -26212.60 + 239.13*Epan (Mar.) -39.37*BSS (Mar.) + (87.49* RH-I (Mar.) + 15.45*RH-II (Mar.) + 673.44*BSS (Apr.) + 831.13*Tmin (Apr.) -20.00*RH-I (Apr.) - 82.75*RH-II (Apr.) -33.55*BSS (May) + 125.66*Tmax (May) -412.8*Tmin (May) + 13.27*RH-I (May) +76.57* RH-II (May)	0.93	0.4%

of error analysis like mean absolute error (MAE), mean bias error (MBE), root mean square error (RMSE), percent error (PE) and average error (%) following statistical techniques given by Wilmot (1982) and Varshneya and Karande (1998).

RESULTS AND DISCUSSION

Climatic conditions

The climatic conditions of the three stations (Anand, SK Nagar and Navsari) varied considerably. The annual rainfall of Anand is 846.3 mm out of which 797.0 mm is recorded during June to September (Table 1). At SK Nagar the annual rainfall is 600.5 mm, out of which 570.5 mm is received during SW monsoon. In south Gujarat region at Navsari annual and seasonal rainfall are 1378.8 and 1335.6 mm respectively. In all the three regions, July receives the highest monthly rainfall followed by August.

In north Gujarat the mean monthly maximum temperatures varied much more (26.9 to 40.0°C) than that in south Gujarat (27.6 to 34.0°C) while in middle Gujarat it varied in between (28.2 to 39.3°C). The lowest minimum temperatures is observed at SK Nagar (9.5°C) in north Gujarat while in south Gujarat it is higher (13°C).The mean monthly morning relative humidity ranged between 67% to 92% at Anand, while afternoon relative humidity ranged between 23% to 72%. At SK Nagar the morning relative humidity ranged between 58% to 87% while afternoon relative humidity ranged between 20% to 70%. At Navsari, the morning relative humidity was ranged between 79% to 93% while afternoon relative humidity ranged between 33% to 80%. Large spatial variation is also seen in all the other climatic parameters (Table 1).

Rainfall prediction models

As stated earlier that the monthly weather data from November to May period were used to develop the models for three stations (Anand, Navsari and SK Nagar) by trial and error method for obtaining highest R^2 and lowest model error. Two sets of models were obtained for Anand while one each for Navsari and SK Nagar (Table 2). The Model 1 for Anand uses predictors (monthly weather data) from November to March period while Model 2 for Anand uses data from March to May period. The updated model (Model 2) has better R^2 (0.85**) and model error (-2.5%) than these of Model 1(R^2 =0.75 and ME = 5.1%). The total number of predictors in Model 1 were 16 while in Model 2 they were 15 in number. For Navsari the best model obtained has 13 predictors from March to May period only. This model gave highest R^2 (0.93) and least model error (0.4%). For north Gujarat region, the model developed for SK Nagar with 15 predictors were from November to March period which could produce R^2 of (0.84) with model error of 1.4%.

The models thus developed were used to predict the rainfall in different years. The observed and predicted rainfall

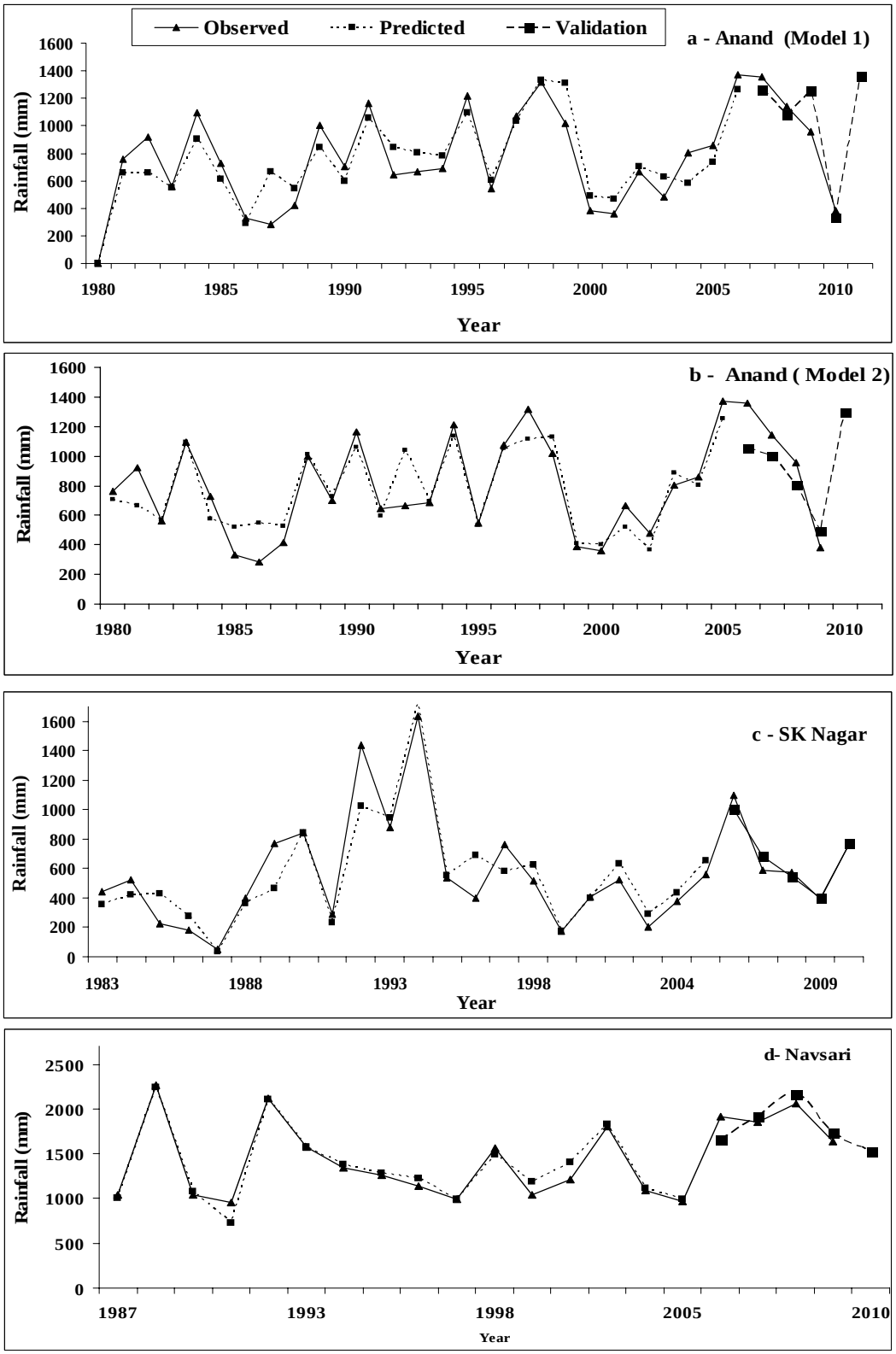

Fig. 1: Observed and predicted seasonal rainfall at different stations

Table 3: Validation of models and prediction for 2010

Station	Rainfall (mm)	2006	2007	2008	2009	Prediction for year 2010
Anand	Observed	1358.2	1140.7	957.4	380.9	922.3
(Model 1)	Predicted	1266.6	1079.5	1251.6	338.4	1363.0
	Deviation (%)	-6.7	-5.4	30.7	-11.1	
Anand	Observed	1358.2	1140.7	957.4	380.9	922.3
(Model 2)	Predicted	1050.7	1004.9	804.5	492.9	1294.0
	Deviation (%)	-22.6	-11.9	-15.9	29.4	
	Observed	1094.9	585.0	574.0	391.6	947.0
S.K.Nagar	Predicted	1001.7	680.8	546.1	403.9	770.0
	Deviation (%)	-8.5	16.4	-4.9	3.1	
	Observed	1916.2	1852.6	2063.2	1638.7	2033.0
Navsari	Predicted	1657.5	1913.8	2170.5	1732.3	1529.0
	Deviation (%)	-13.5	3.3	5.2	5.7	

are given in Fig 1(a-d). It may be seen that model 1 for Anand (Fig 1a) is able to predict rainfall variability very well from year to year. The observed and predicted are very close to each other except in year 1986 and 2003 when these are in opposite phase. Fig. 1b (Model 2 for Anand) also shows good agreement between observed and predicted rainfall. Although, it has depicted rainfall fluctuations very well but there are few years (1986, 1987 and 1992) of mismatch.

For SK Nagar, the observed and predicted rainfall (Fig. 1c) have good match particularly in the years of extreme rainfall. The model correctly predicted the drought years 1987, 1999 and 2002 and excess rainfall year 1994. However, out of phase is observed in year 1996 and 1997. The model developed for heavy rainfall region of Gujarat (Navsari) has predicted rainfall very close to observed rainfall (Fig. 1d). The observed and predicted have prefect match in almost all the years.

Validation of models

The models were validated with the four years (2006-2009) of independent data set. The observed and predicted rainfall for validation period (2006-2009) are depicted in Fig 1 (a-d) for all the stations. The data presented in Table 3 show that for Anand the rainfall predicted by model 1 deviated -11.1 to 30.7% from the observed rainfall in different years while that by Model 2 deviated from -22.6 to 29.4 %. The predicted rainfall for SK Nagar deviated from -8.5 to 16.4%. The percent deviation of rainfall predicted for Navsari was found to vary between -13.5 to 5.7% only. This may be noted that during validation period the observed rainfall also varied much. In middle Gujarat it varied between 380.9 to 1358.2 mm, in north Gujarat it varied between 391.6 to 1094.9 mm while in south Gujarat it varied between 1638.7 to 2063.22 mm. Thus all the models performed very well under diverse conditions.

The performance of models were also evaluated in terms of various error analysis as given in Table 4. The results revealed that the MAE, MBE and RMSE of model 1 were 4.1 mm, 5.9mm and ± 156.3 mm respectively. Even with independent data the RMSE is ± 158.5 mm. The model error of 5.1 % and 2.6% with two data sets revealed the well acceptability of the model. Thus the model (Model 1 for Anand) can be used to predict the seasonal rainfall of Anand using predictors up to March only.

The error analysis of model 2 for Anand (Table 4) which uses data up to May month revealed that the absolute errors were higher than that of model 1. The MBE of -20.0 mm and -16.1 mm indicated that model slightly underestimated the rainfall, however, the average error is low (-2.5%). Thus model can be used as updated model for Anand, although the average for validation period is more (-12.6%).

For SK Nagar the model's performance as evaluated by error analysis revealed that the MAE, MBE and RMSE for data set period were 22.2 mm, 6.1 mm and ± 142.3 mm respectively, while with validated data these were 57.1, -0.53 and ± 68.5 mm respectively. The average errors were quite low (1.4 and -0.53%) which revealed that this model can be used for forecasting rainfall in north Gujarat (SK Nagar) using data up to March.

The model developed for Navsari (south Gujarat) was found to be the best among all the models developed. All parameters of error analysis were low with average error of only 0.43 and 0.05% respectively for whole data set and validated data. Thus it can be used to predict rainfall using data up to May.

Table 4: Error analysis of forecasting models for Anand, SK Nagar and Navsari

Station	Error analysis	All data set	Independent data (2006-2009)
Anand	MAE (mm)	4.1	122.4
(Model 1)	MBE (mm)	5.9	3.3
	RMSE (mm)	156.3	158.5
	PE (%)	19.6	16.5
	Average Error (%)	5.1	2.6
Anand	MAE (mm)	109.3	177.1
(Model 2)	MBE (mm)	-20.0	-16.1
	RMSE (mm)	144.0	192.9
	PE (%)	18.1	24.2
	Average Error (%)	-2.5	-12.6
S.K.Nagar	MAE (mm)	22.2	57.1
	MBE (mm)	6.1	-0.53
	RMSE (mm)	142.3	68.5
	PE (%)	25.0	10.4
	Average Error (%)	1.4	-0.53
Navsari	MAE (mm)	5.8	130.2
	MBE (mm)	1.1	0.17
	RMSE (mm)	105.1	150.8
	PE (%)	7.3	8.1
	Average Error (%)	0.43	0.05

Forecast for year 2010

The validated models were used to forecast, the seasonal rainfall (June-September) for year 2010 (Table 3). It may be seen that both the models for Anand predicted higher than the normal rainfall. Model 1 predicted 71% higher rainfall (1363.0 mm) while Model 2 predicted 62% higher rainfall (1294.0 mm). For north Gujarat the model predicted 770.0 mm of rainfall which is about 40% above the normal rainfall of SK Nagar. In south Gujarat also the predicted rainfall (1529.0 mm) is 14.5% higher than the normal rainfall. Thus all the three regions of Gujarat are expected to received 14.5 to 71 % higher than the normal rainfall. The actual rainfall received at Anand, SK Nagar and Navsari stations were 922.3, 947.0 and 2033.0 mm, which were higher than the normal but 40.3, 18.7 and 24.8% less than predicted values.

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