Rainfall Forecast for Agricultural Water Allocation Planning in Thailand

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Abstract

Rain water is an important water resource for agricultural purposes, particularly for paddy cultivation. Accurate forecast of rainfall is necessary for agricultural water allocation planning. The study aims to develop a mathematical model for forecasting annual rainfall in Thailand. ARMA and ARIMA model were used to fit the time series of annual rainfall during 1951 to 1990 of 31 rainfall stations distributed in all regions of Thailand. It has been found that ARIMA model is more suitable to describe inter-annual variation of annual rainfall in Thailand, i.e. most of the rainfall stations are better fitted with ARIMA model, while only 8 stations are better fitted with ARMA model. The models proposed in the study are able to forecast annual rainfall for all regions of Thailand, providing an acceptable accuracy for planning purposes, i.e. with mean relative error ranging from 8% to 27% during the verification period(1991-2003).

Keyword: ARMA model, ARIMA model, rainfall forecast, agricultural water allocation

1. Introduction

Rain water is an essential water resource for the agricultural water supply in Thailand, particularly for paddy cultivation, which requires high water consumption compared to other crop water requirements. Therefore, an accurate rainfall forecast is useful for agricultural water allocation planning, for appropriate cropping patterns which are suitable for natural and irrigated available water. Thailand is located in a tropical zone whose climate is influenced by monsoons, i.e. Southwest and Northeast monsoons as shown in Figure 1. Occurrences of rainfall in Thailand are caused by the Southwest monsoon and tropical cyclones[Fig 1]. High inter-annual variation of monsoon rainfall results in many water-related problems such as flooding and drought, which can sometime damage crop production[3]. Hence, an accurate rainfall forecast can also help to alleviate such problems by planning for appropriate cropping patterns corresponding to available water.

Over hundreds of years since the Sukhothai era, Thai farmers believe in the rainfall prediction annually conducted in the traditional ceremony on Royal Ploughing Day. In this Royal Ploughing ceremony "a man", so called "Praya Ragna", and "Royal cows", so called "Phra-co", conduct Rainfall prediction, consisting of two processes. Firstly, "Praya Ragna" chooses one of three panungs(lower clothing made of a wide strip of cloth are end fastened) which has 3 different sizes, which are used to predict the different amounts of rainfall. Secondly "Phra-co" selects one or more amongst 7 kinds of grains and drinks, which are corn, paddy, nut, sesame seed, grass, water and liquor. The combination of there selections is used to predict abundance of food, water and level of commerce in the country.

So far, there is no mathematical model which can be used for prediction of annual rainfall over all regions in Thailand. However, several studies concerning forecast of rainfall in Thailand have been conducted. For example, Rusamee(1999) developed a rainfall forecast model by using monthly rainfall data in 19 provinces in the northeastern region of Thailand, during the period of 1986-1996. Four methods of forecasting were investigated in the study, which are Constant Mean Model, Decomposition Method, Winter's Forecast Method and Box-Jenkins Technique. Rainfall data in 1997 were used to test the performance of such models. The results revealed that the Decomposition Method is the most suitable one for the forecasting of monthly rainfall in northeast Thailand[7].

Another approach of monthly rainfall forecast was developed by Manusthiparom et al (2003), using the Chao Phraya river basin (located in north and central region of Thailand) as the study area. In the study, the correlations between Southern Oscillation Index(SOI), sea surface temperature (SST) and monthly rainfall were investigated using data during 1960-2000. The predictable period of the model predictable for rainfall prediction was determined. The quantitative predictability of monthly rainfall was evaluated utilizing predominant climatic indices as predictors in an Artificial Neural Network(ANN) model. The result of study showed that the developed model was able to predict monthly rainfall in the Chao Phraya river basin one year ahead with tolerable accuracy, even during the long drought period of 1991-1994.

Otarig(2000) examined the impact of EI-Nino on the amount of rainfall at 31 rainfall stations distributed in all region of Thailand, during 1951-2000. The study reveals that EI-Nino has no statistically significant impact on annual rainfall in Thailand.

Review of literature reveals that there is no model developed for practical use, to forecast annual rainfall for all regions of Thailand. This study, aimes to develop a mathematical model which is able to forecast annual rainfall in all regions of Thailand. It is expected that the developed model could provide forecasted annual rainfall with acceptable accuracy, which is able to fulfill the requirement for agricultural water allocation planning.

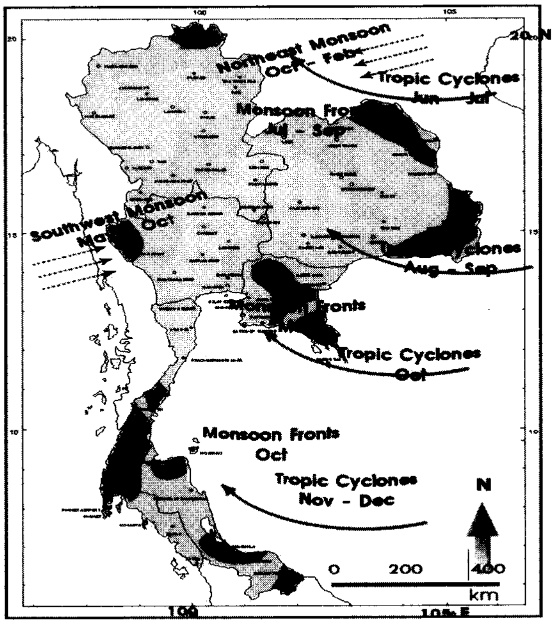

Figure 1. Monsoon winds and Tropical Cyclones influence the occurrence of rainfall in Thailand

2. Data Collection and Analysis

Annual rainfall data from 31 synoptic rainfall stations distributed in all regions over Thailand were collected as shown in Figure 2 and Table 1. There are 7 stations representing rainfall in the northern part, 6 stations representing rainfall in the northeastern part, 4 stations representing rainfall in the central part, 5 stations representing rainfall in the eastern part and 9 stations representing rainfall in the southern part. Annual rainfall at these 31 stations were collected during the period of 53 years i.e. from 1951 to 2003. This data was used in the study and the time series was divided into 2 periods. The first one is from 1951 to 1990, where data was used for analysis of characteristics of rainfall and selection of most appropriate rainfall forecast models at each location. The time series in second period, starting from 1991 to 2003 was used for evaluation of performance of selected models at each station.

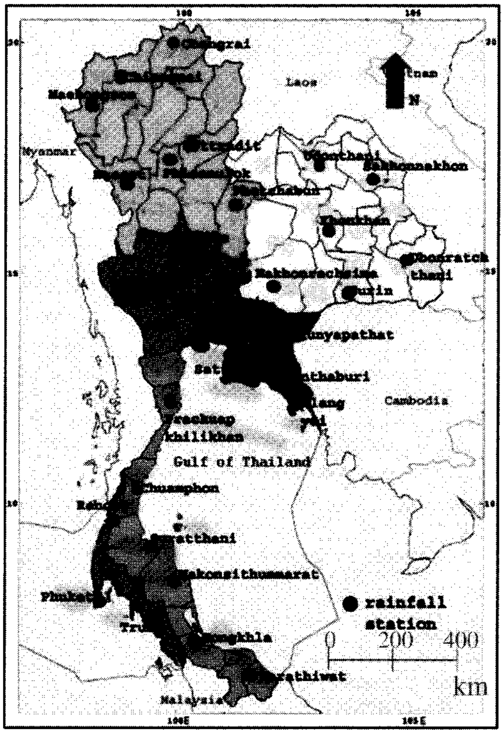

Figure 2. Location of rainfall stations

Table 1 summarizes statistics of annual rainfall in each region of Thailand. Average annual rainfall in Thailand during the period of 1951 to 1990 varied from 1071 mm. to 4616 mm. with the coefficient of variation varying from 0.12 to 0.27. Considering spatial distribution of annual rainfall, statistics reveal that low to moderate rainfall occurs in the north, northeast and central parts while moderate to heavy rainfall occurs in the eastern and southern regions. Coefficients of variation indicate that there is quite a large inter-annual variation of rainfall, particularly in the northern , central and southern parts of Thailand.

In this study, a time series analysis was adopted as a technique for forecasting of annual rainfall. Autoregressive Moving Average (ARMA) and Autoregressive Integrated Moving Average(ARIMA) methods [1],[5],[6] were used to fit these time series of annual rainfall at each rainfall station during the period of 1951-1990. Several combinations of ARMA and ARIMA were tested at each station to find the most appropriate model that can describe inter-annual variation of rainfall at that station.

ARMA and ARIMA models are mathematical models of the persistence, or autocorrelation in a time series. Modeling can contribute to understanding the physical system by revealing something about the physical process that builds persistence into the series. ARMA models can also be used to predict behavior of a time series from past values alone.

Generally the ARIMA model is written as:

$$\hat{R}_{t+1} = \alpha + \frac{\theta(B)}{\phi(B)}\varepsilon_t \qquad (1)$$

where

t indexes time

$\hat{R}_{t+1}$ is the response series R_t or difference of the response series

α is the mean term

B is the backshift operator ;that is $BR_t = R_{t-1}$

$\phi(B)$ is the autoregressive operator, represented as a polynomial in the back shift operator:

$$\phi(B) = 1 - \phi_1 B - \ldots - \phi_p B^q$$

$\theta(B)$ is the moving-average operator, represented as a polynomial in the back shift operator:

$$\theta(B) = 1 - \theta_1 B - ... - \theta_p B^q$$

ε_t is the independent disturbance, also called the random error.

In order to simplify differencing terms, $\hat{R}_{t+1}$ can be defined as $(1-B)^d R_{t+1}$, where "d" is the degree of non-seasonal differencing.

In this study, ARMA and ARIMA models are modified to forecast annual rainfall at times "$t+1$" "$\hat{R}_{t+1}$". As an example, in the case of ARMA(1,1) model, the general equation is modified and can be written as:

$$\hat{R}_{t+1} = \alpha + \frac{(R_t - \theta_1 R_{t-1})}{(R_t - \phi_1 R_{t-1})}\varepsilon_t \qquad (2)$$

where

$\hat{R}_{t+1}$ is the annual rainfall to be forecasted at time "$t+1$",(next year)

R_t is the annual rainfall at time "t", (this year)

R_{t-1} is the annual rainfall at time "$t-1$", (last year)

ε_t is the random error at time t

α, ϕ, θ are coefficients to be determined.

For ARIMA(1,1,1) model, which is used to forecast annual rainfall at time $t+1$, a general equation is modified and can be written as:

$$(1 - \frac{\hat{R}_{t+1}}{R_t}) = \alpha + \frac{(R_t - \theta_1 R_{t-1})}{(R_t - \phi_1 R_{t-1})}\varepsilon_t \qquad (3)$$

where

$\hat{R}_{t+1}$ is the rainfall to be forecasted at time "$t+1$",(next year)

R_t is the rainfall at time "t",(this year)

R_{t-1} is the rainfall at time "$t-1$",(last year)

ε_t is the random error at time t

α, ϕ, θ are coefficients to be determined.

These ARMA and ARIMA models were used to fit the time series of annual rainfall at each station using data during 1951 to 1990. The most appropriate model for each station was selected as shown in Table 1.

In order to evaluate the performance of selected models at each station, the relative error (RE) was adopted as an indicator, which can be written as:

$$RE = \sqrt{\frac{\sum_{t=1}^{n}\left(R_t - \hat{R}\right)^2}{\left(\sum_{t=1}^{n} R_t^2\right)}} x100 \qquad (4)$$

where

R_t is the observed Rainfall at time t.

$\hat{R}_t$ is the Forecasted Rainfall at time t.

n is the number of data points

Table 1. Statistics of Annual Rainfall during the calibration period

REGION	RAINFALL STATION	Period 1951-1990			
		μ (mm.)	σ (mm.)	$\frac{\sigma}{\mu}$	Relative Error %
NORTHERN	Mae Hong Son	1180	186	0.16	15.3
	Chiang Rai	1506	340	0.23	17.1
	Chiang Mai	1191	214	0.18	16.4
	Maesot	1436	337	0.23	21.4
	Phetchabun	1073	215	0.20	17.7
	Phitsanulok	1071	228	0.21	15.4
	Uttradit	1425	207	0.15	13.6
NORTHEASTERN	Khon Kaen	1203	162	0.13	11.1
	Sakon Na Khon	1529	270	0.18	18.2
	Surin	1274	255	0.20	11.1
	Ubon Ratcha Thani	1589	225	0.14	14.6
	Udon Thani	1449	276	0.19	21.1
	Na Khon Ratchasima	1123	215	0.19	18.2
CENTRAL	Bangkok	1505	319	0.21	14.5
	Nakhon Sawan	1139	222	0.19	20.4
	Lop Buri	1249	229	0.18	18.7
	Kanchanaburi	1303	319	0.24	23.4
EASTERN	Khlongyai	4616	778	0.17	18.2
	Arunyapathet	1485	197	0.13	12.2
	Chanthaburi	2982	496	0.17	14.8
	Chon Buri	1352	249	0.18	20.3
	Satthahip	1305	299	0.23	20.3
SOUTHERN	Prachuap Khili Khan	1141	278	0.24	26.7
	Songkhla	2036	433	0.21	20.6
	Surat Thani	1666	333	0.20	16.7
	Chuamphon	1904	431	0.23	15.1
	Ranong	4220	494	0.12	10.4
	Narathiwat	2490	639	0.26	27.4
	Nakon Si Thammarat	2321	625	0.27	24.2
	Trang	2272	385	0.17	14.9
	Phuket	2314	340	0.15	14.3
	Average	1753	329	0.19	17.6

Table 2. Values of Model Parameters during the calibration and verification period

REGION	RAINFALL STATION	MODEL	DIF	model parameters in calibration period(1951-1990)						results in verification period 1991-2003			
				α	θ		ϕ		Relative error (%)	μ (mm.)	σ (mm.)	$\frac{\sigma}{\mu}$	Relative Error %
					θ_1	θ_2	ϕ_1	ϕ_2					
NORTHERN	Mae Hong Son	ARIMA(1,1,1)	1	-0.2	0.62		-0.02		15.3	1216	239	0.20	16.8
	Chiang Rai	ARIMA(1,1,1)	1	23.6	0.68		0.27		17.1	1672	279	0.17	7.5
	Chiang Mai	ARMA(1,1)	-	1193.9	0.18		0.49		16.4	1109	208	0.19	17.3
	Maesot	ARIMA(1,1,1)	1	-13.7	0.29		-0.64		21.4	1453	339	0.23	24.7
	Phetchabun	ARIMA(1,1,1)	1	24.7	0.55		0.14		17.7	1127	230	0.20	18.5
	Phitsanulok	ARIMA(1,1,1)	1	24.3	0.59		0.19		15.4	1104	192	0.17	18.6
	Uttradit	ARIMA(1,1,1)	1	-7.3	0.78		0.16		13.6	1412	229	0.16	15.2
NORTHEASTERN	Khon Khen	ARMA(2,1)	-	1203.2	-0.62		-0.63	0.10	11.1	1261	226	0.18	17.2
	Sakon Na Khon	ARMA(1,1)	-	7.8	1.00		0.50		18.2	1612	234	0.15	17.2
	Surin	ARMA(1,1)	-	1275.6	-0.16		-0.24		11.1	1462	256	0.17	14.3
	Ubon Ratchathani	ARIMA(1,1,1)	1	-18.4	0.29		-0.64		14.6	1543	203	0.13	10.7
	Udon Thani	ARIMA(1,1,1)	1	-11.1	0.96		0.17		21.1	1484	263	0.18	16.1
	Na Khon Ratchasima	ARIMA(2,1,2)	1	-10.8	0.07	-0.07	0.52	-0.38	18.2	1020	224	0.22	18.9
CENTRAL	Bangkok	ARIMA(1,1,1)	1	-2.8	0.91		-0.01		14.5	1597	281	0.18	23.3
	Nakhon Sawan	ARIMA(1,1,1)	1	-8.1	0.85		0.10		20.4	1108	231	0.21	16.7
	Lop Buri	ARIMA(1,1,1)	1	-6.8	-		-0.54		18.7	1057	168	0.16	19.6
	Kanchanaburi	ARMA(1,1)	-	1084.7	0.44		0.54		23.4	1438	283	0.20	13.2
EASTERN	Khlongyai	ARIMA(1,1,1)	1	-17.5	1.00		0.83		18.2	4752	829	0.17	12.9
	Arunyapathet	ARIMA(1,1,1)	1	-11.5	0.95		0.16		12.2	1313	149	0.11	10.3
	Chanthaburi	ARMA(1,1)	-	2993.0	0.72		0.80		14.8	2864	428	0.15	13.2
	Chon Buri	ARIMA(1,1,1)	1	-9.6	0.78		-0.07		20.3	1246	234	0.19	18.9
	Satthahip	ARMA(1,1)	-	1297.4	0.43		0.63		20.3	1298	185	0.14	9.1
SOUTHERN	Prachuap Khili Khan	ARIMA(2,1,2)	1	-11.7	1.34	0.96	0.68	0.55	26.7	1141	314	0.27	26.9
	Songkhla	ARIMA(2,1,1)	1	0.6			-0.12	0.41	20.6	2113	344	0.16	17.4
	Surat Thani	ARIMA(1,1,1)	1	-12.4	0.89		-0.13		16.7	2009	455	0.23	21.7
	Chumphon	ARIMA(1,1,2)	1	-3.7	0.02	0.98	-0.86		15.1	1998	301	0.15	12.9
	Ranong	ARIMA(1,1,1)	1	0.7			-0.35		10.4	4150	609	0.15	14.1
	Narathiwat	ARMA(1,1)	-	2476.0	-0.93		-0.65		27.4	2726	562	0.21	14.1
	Nakon Si Thammarat	ARIMA(1,1,1)	1	38.6	0.62		0.14		24.2	2627	395	0.15	11.4
	Trang	ARIMA(1,1,1)	1	-28.1	0.72		0.12		14.9	2232	327	0.15	14.3
	Phuket	ARIMA(1,1,1)	1	-15.2	1.00		0.46		14.3	2169	404	0.19	17.7
		Average		Average					17.6	1784.3	310.3	0.2	16.2

Table 2 summarizes selected results of the best ARMA and ARIMA models at each location. It reveals that ARIMA and ARMA models can be used to describe inter-annual variation of annual rainfall in all regions of Thailand with acceptable error of forecast, ranging from 10.4% to 27.4%.

3. Results and Discussion

ARIMA and ARMA models were then selected as rainfall forecast models. In order to verify whether they are applicable for the forecasting of annual rainfall or not, simulation at each station was conducted. By supposing that the present time is in year 1990 and then a rainfall forecast was done for next year i.e. 1991. Then the error of the forecast value in 1991 was calculated by comparing the observed rainfall in 1991 with the forecast value in 1991. The procedure of simulation of rainfall forecast was repeated like this from 1991 to 2003, as shown in Table 2.

Table 2 summarizes results of rainfall forecasts during 1991 to 2003 on 31 stations over Thailand. It has been revealed that ARIMA and ARMA models proposed for forecasting of annual rainfall in Thailand are applicable for the purpose of agricultural water allocation planning with relative error ranging from 7.5% to 26.9% as shown in Table 2 and Figures 3 to 8. Less inter-annual variation of rainfall in the northeastern region provides more accuracy of forecast than ones in the northern, central and southern parts, where annual rainfall has higher annual variation due to the influence of uncertain tropical cyclones which are the dominant cause of rainfall in that area, particularly in Prachuap Khiri Khan and Phuket as shown in Figures 7 and 8.

4. Conclusion

Time series of annual rainfall at 31 rainfall stations, distributed in all regions of the Thailand, were analyzed to formulate appropriate model for prediction of the annual rainfall. It has been found that ARIMA model is more appropriate for rainfall forecast for all of the cases. However, stochastic models including more climate variables should be considered in the development of models for future studies in order to improve the accuracy of forecast. The models proposed, here, are applicable for annual rainfall forecast for agricultural water allocation planning purposes with mean relative error of about 20%.

5. Acknowledgements

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6. References

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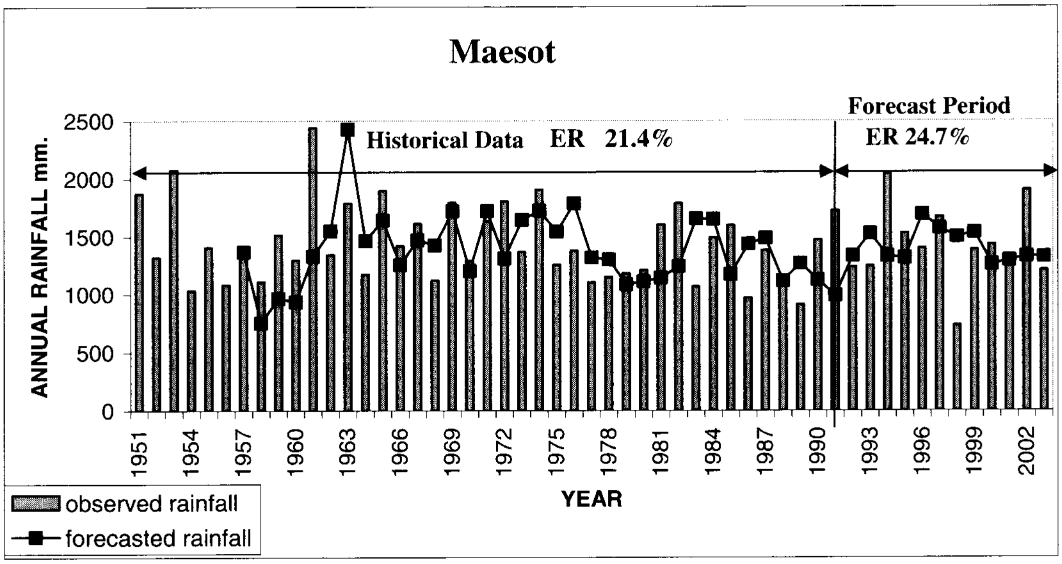

Figure 3. Forecast of annual rainfall by ARIMA(1,1,1) model at Mae sot station

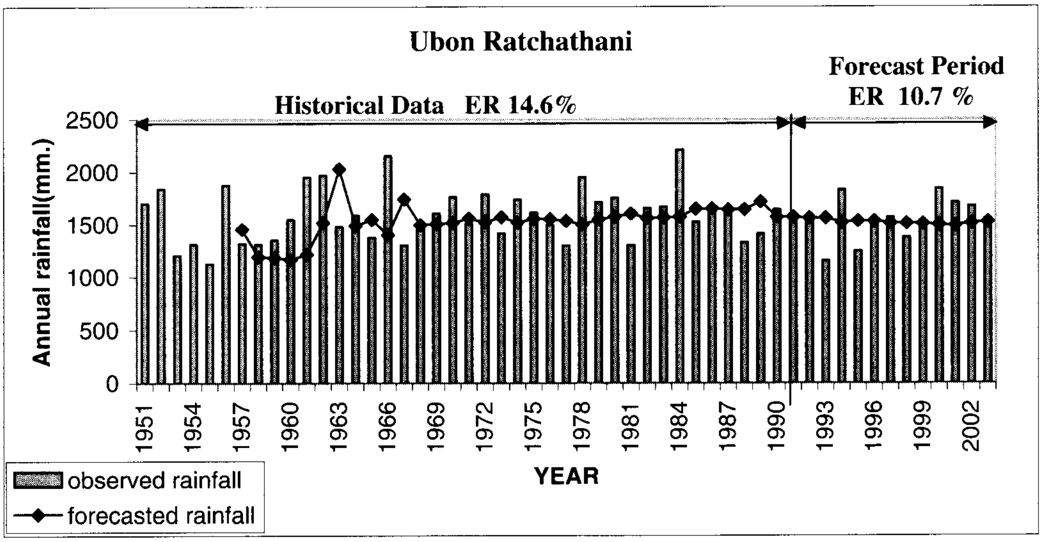

Figure 4. Forecast of annual rainfall by ARIMA(1,1,1) model at Ubon Ratchthani station.

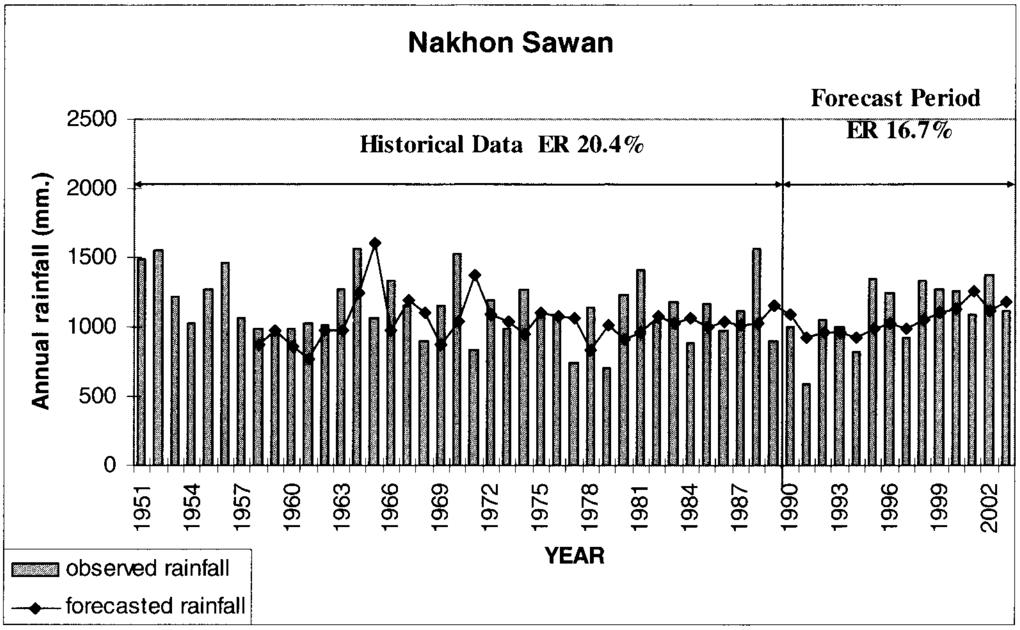

Figure 5. Forecast of annual rainfall by ARIMA(1,1,1) model at Nakhon Sawan station.

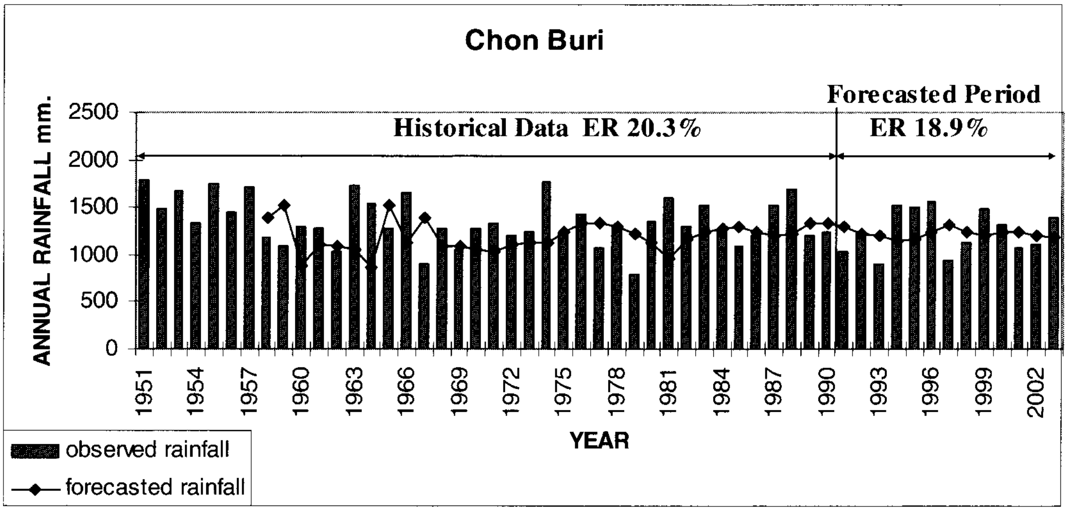

Figure 6. Forecast of annual rainfall by ARIMA(1,1,1) model at Chon Buri station.

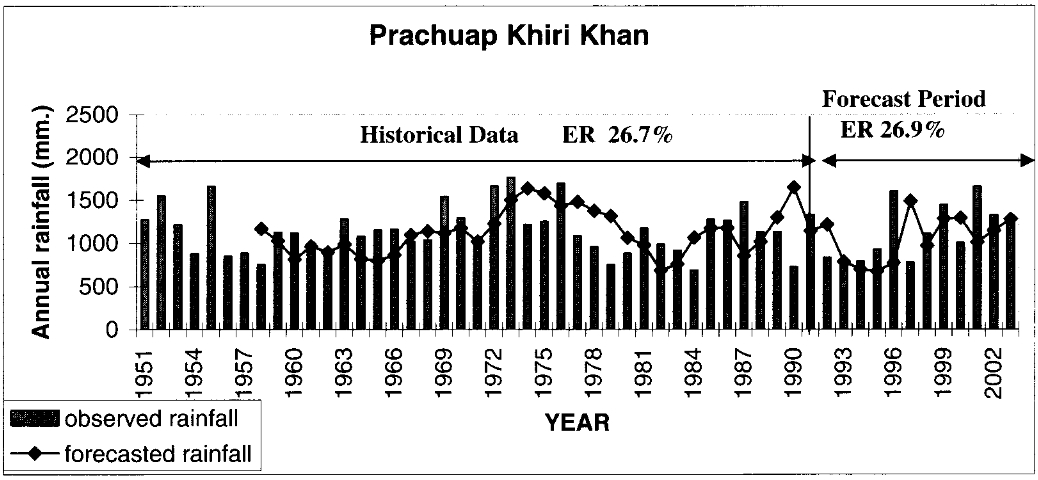

Figure 7. Forecast of annual rainfall by ARIMA(2,1,2) model at Prachuap Khiri Khan station.

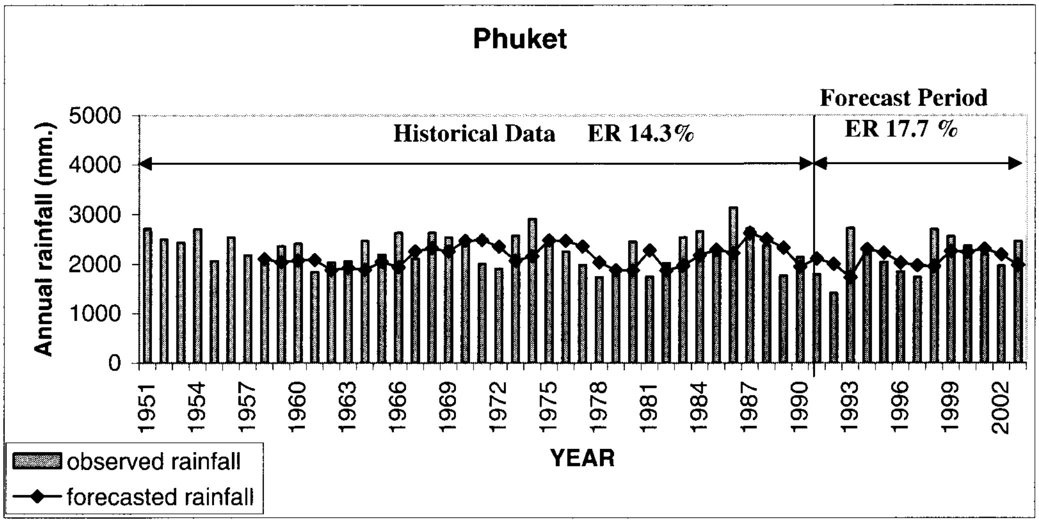

Figure 8. Forecast of annual rainfall by ARIMA(1,1,1) model at Phuket station.