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Identification of Rainfall Fluctuations in the Philippines Through Adaptive Kalman Filter

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1. Introduction

This study aims to determine if the four monthly rainfall series typical of the four types of climate in the Philippines show fluctuations of sufficient magnitude to be of help in the evaluation, planning and decision-making processes for water resource development in the country. The search for fluctuations is designed specifically to identify the point in time when the rainfall characteristics within a period was terminated by a rather instantaneous shift to another period with a rainfall characteristics unlike the previous period. The adaptive Kalman filter (AKF) is used to search for this kind of rainfall fluctuations which are associated with the abrupt changes in the system model parameters.

2. Methodology

Since the annual variations of rainfall can be regarded as periodic, the system model is conceived as having two independent components: periodic and stochastic. The periodic-stochastic model considered in this study may be written in the form: $y(k) = M_y + \sum_{i=1}^{q}(A_i \sin 2\pi f_i k + B_i \cos 2\pi f_i k) + w(k)$ ...(1) where y(k) is the transformed monthly rainfall at a time instant k; M_y is the mean of the transformed series; q is the number of significant frequency components; f_i is the frequency component; A_i and B_i are the periodic coefficients of the model; and w(k) is the stochastic component which is assumed to be white Gaussian noise with zero mean and variance W(k). The maximum entropy method is used to find the necessary dominant harmonics to account for the periodicity in equation (1). Transformation of the rainfall data is done to result in a periodic-stochastic model with the stochastic component being uncorrelated and normally distributed.

The AKF detects whether an abrupt change in the system parameters M_y, A_i and B_i does occur or not by evaluating the innovations (step 1 prediction residuals) sequence using generalized likelihood ratio test (GLRT). If such abrupt change is detected, its time of occurrence and magnitude are estimated quantitatively and the state variables are appropriately corrected according to the magnitude of this abrupt change. Details of the adaptive Kalman filter formulation are given in another paper[1].

The average duration of the rainfall fluctuations considered in this study is ten years. This is because rainfall extremes of less than a decade are perceived as isolated events better studied under the direction of natural hazard research[2]. Since the length of the rainfall records at Vigan, Legaspi, Zamboanga and Davao stations is only 33 years, duration of more than ten years limits the detection of the rainfall fluctuations which can be studied. This choice of one decade results into the identification by AKF of two rainfall fluctuations at each station.

3. Results

The time of occurrence of the rainfall fluctuations (or abrupt changes in the system model parameters) divides the time series into three different rainfall periods (or parameter regimes).

Table 1 gives the system parameters as identified by AKF for each rainfall period, by the ordinary Kalman filter (KF) for the whole record and by the least-square method (L-S) for each period and for the whole record (for Vigan station). Notice that the AKF and L-S estimates of the parameters are effectively equal. This table illustrates that the system parameters identified by AKF and L-S methods do differ from one period to another, indicating that the system model obeys three separate parameter regimes.

Table 1 Estimated model parameters by adaptive Kalman filter (AKF), ordinary Kalman filter (KF), and least-square method (L-S).

Station name	Method used	Period No.	Period Interval	M_y	A_1	B_1	A_2	B_2	A_3	B_3	A_4	B_4
					(1/12)		(1/6)		(70/396)		(132/396)	
Vigan	AKF	I	1-118	1.23	-0.85	-0.81	0.08	0.02	-0.03	-0.02	-0.17	-0.00
		II	119-257	1.29	-0.97	-0.95	0.21	0.04	-0.10	-0.18	-0.11	0.15
		III	258-396	1.24	-0.91	-0.88	0.23	0.12	-0.02	-0.01	-0.14	-0.00
	KF		1-396	1.26	-0.93	-0.88	0.18	0.06	-0.06	-0.07	-0.13	0.04
	L-S	I	1-118	1.23	-0.85	-0.81	0.08	0.02	-0.03	-0.02	-0.17	-0.00
		II	119-257	1.29	-0.99	-0.94	0.21	0.03	-0.10	-0.18	-0.09	0.13
		III	258-396	1.25	-0.93	-0.88	0.22	0.11	-0.02	-0.03	-0.13	-0.01
			1-396	1.26	-0.93	-0.88	0.18	0.06	-0.06	-0.07	-0.13	0.04

Note: Figures in the parentheses are the significant harmonics in cycles/month.

Table 2 gives the mean and standard devia-

Table 2 Mean and standard deviation of the residuals (for each climatic period) which resulted from the fit of the adaptive Kalman filter (AKF) and ordinary Kalman filter (KF) identified models to the given observed rainfall time series.

Station name	Period	A K F		K F	
		Mean	Std. dev.	Mean	Std. dev.
Vigan	I	0.000	0.355	0.024	0.375
	II	0.000	0.451	-0.029	0.468
	III	0.000	0.457	0.008	0.462
Legaspi	I	0.000	-0.303	-0.013	0.349
	II	0.000	0.334	0.026	0.339
	III	0.000	0.357	-0.028	0.364
Zamboanga	I	0.000	0.277	0.016	0.310
	II	0.000	0.293	0.006	0.298
	III	0.000	0.388	0.012	0.343
Davao	I	0.000	0.528	-0.013	0.532
	II	0.000	0.597	-0.028	0.627
	III	0.000	0.521	-0.062	0.599

tion of the residuals (for each rainfall period) which resulted from the fit of the model identified by AKF and that by ordinary Kalman filter to the given observed rainfall data. The comparison of the means and standard deviations of the AKF residuals with those of the ordinary Kalman filter residuals suggests that the behaviour of the predictions when using AKF parameter estimates is more satisfactory than when applying those of the ordinary Kalman filter. Hence, improved predictions can be realized after the detection of rainfall fluctuations which are associated with the abrupt changes in the parameters of the periodic-stochastic system model.

Figure 1 depicts the time series plot of the annual rainfall of each station, showing the three rainfall periods. This figure is given in order to show a clearer picture of the inherent fluctuations and to compare relative magnitudes between adjacent periods. In each time series plot, the short solid horizontal lines represent the means of the three rainfall periods. Notable rainfall fluctuations are reflected in the time series plot of Vigan. An increase of 798 mm in annual rainfall occurred during the period 1961-71 compared to the previous 10 years (1951-60). A decrease of over 500 mm in the annual total rainfall occurred from 1961-71 to 1972-83. In Legaspi, the annual rainfall dropped 210 mm during the period 1958-73 from the previous seven years (1951-57) and increased 144 mm in the next 10 years (1974-83). In Zamboanga, a rainfall fluctuation of 209 mm decrease in yearly rainfall occurred during 1957-68 compared to 1952-56. A small increase of 36 mm occurred for the two adjacent periods 1957-68 and 1969-83. The time series plot for Davao shows that rainfall remained constant for the periods 1951-71 and 1972-76. A decrease of over 100 mm occurred from 1972-76 to 1977-83.

4. Conclusions

The AKF successfully identifies the fluctuations inherent in the four monthly rainfall time series representative of the four types of climate in the Philippines. The AKF automatically estimates the time of occurrence of these rainfall fluctuations. Knowledge of the magnitude and extent of the fluctuations over time horizons will be of valuable help in the evaluation, planning and decision-making for water resource development. This study should caution the hydrologist and water resources engineer about inherent changes in a hydrologic time series which are important in solving water resource problems.

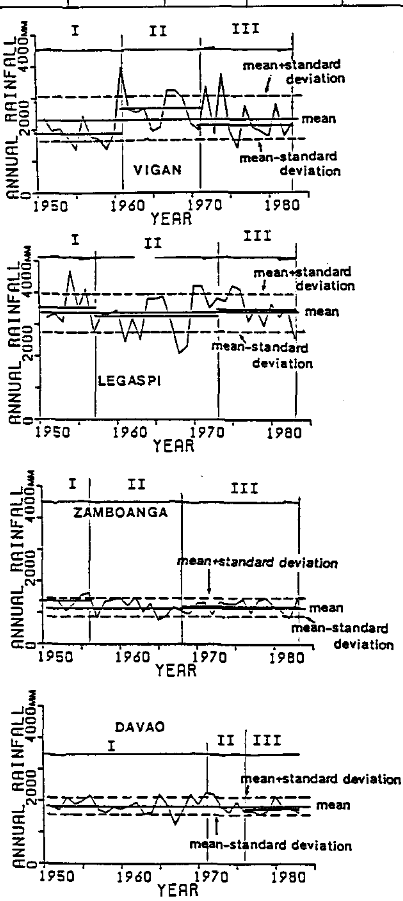

Fig. 1 Climate fluctuations at each station.

References

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