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The identification of recent rainfall fluctuations in the Philippines

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ABSTRACT Our approach to the identification of rainfall fluctuations is to determine whether or not the occurrence of a short-duration rainfall pattern anomaly will cause an abrupt change in rainfall characteristics, i.e., the rainfall characteristics within a period will be terminated by a rather instantaneous shift to another period with different rainfall characteristics. We apply this approach to the recent (1951-1983) monthly rainfall data of four stations representative of the four types of climates in the Philippines. We use the adaptive Kalman filter to identify such kinds of fluctuations in a rainfall sequence by directly linking them with the abrupt changes in the parameters of the periodic-stochastic model of the rainfall time sequence. Fluctuations of 10% or more in the mean between non-overlapping adjacent periods have been detected. However, the Chow test for parameter change has shown that the mean is still not sufficient to describe the rainfall fluctuations.

Identification des fluctuations récentes de pluviosité aux Philippines

RESUME Notre approche pour identifier les fluctuations de pluviosité est de déterminer si oui ou non la survenue d'une courbe de pluviosité anormale de courte durée peut causer un changement brusque dans les caractéristiques de pluviosité, c'est-à-dire que les caractéristiques d'une pluviosité dans une période seraient plutôt terminée par un virement instantané à une autre période avec des caractéristiques différentes. Nous appliquons cette approche aux données récentes de pluviosité mensuelle (1953-1983) aux 4 stations représentatives des 4 types de climat aux Philippines. Nous utilisons le filtre adaptable de Kalman pour identifier de pareilles fluctuations dans une sequence de pluviosite en les liant directement aux changements brusques des paramètres du modèle périodique avec des pointes en crochet de la pluviosité séquentielle dans le temps. Des fluctuatious de 10% ou plus de la moyenne entre 2 periodes adjacentes et ne se chevauchant pas ont été observées. Toutefois, le test de Chow pour changement des paramètres a montrè que la moyenne n'est pas encore suffisante pour décrire les fluctuations de pluviosité.

Introduction

The biggest problem besetting the water resource management planners in the Philippines is the scarcity of hydrologic data. According to the report prepared by the Philippine National Water Resources Council (1976), there are 369 rain gaging stations in the country as of 1976; 66% of this number have less than ten years of record. To complement the rain gaging network, there are 496 stream gaging stations, and some 20% of this number have been abandoned or discontinued. Less than 20% of the 496 stations have more than 20 years of record. Also the density of the existing data collection network is insufficient to meet the needs for long-range development planning.

Potential users of the short records of data must be warned that careless use of these data may lead to wrong assumptions on some parameters, which may cause some undesirable consequences in the future. This is so because of the inherent fluctuations in rainfall characteristics; a reservoir designed using data belonging to a high rainfall period will be vulnerable if that period is terminated abruptly by another period characterized by less rainfall. In order to minimize the risk involved in using short records of data in the design and operation of water resource systems, the rainfall fluctuations in the country must be identified and their characteristics fully understood.

Our approach to the identification of recent rainfall fluctuations is to determine whether or not the occurrence of a short-duration rainfall pattern anomaly will appear as an abrupt change in rainfall characteristics, i.e., the rainfall characteristics within a period will be terminated by a rather instantaneous shift to another period with different rainfall characteristics. We design the identification of fluctuations in this way because it is believed that it is often important not only to detect when a rainfall fluctuation has occurred, but also to know when rainfall is about to change or is in the process of changing its characteristics. In this way, we explore the possibility of early detection of moderate climate change (Nemec, 1985). We apply this approach to the recent (1951-1983) monthly rainfall data of four stations representative of the four types of climates in the Philippines.

In this approach, we use the methodology explained by Kawamura, et al. (1985) to identify and characterize the rainfall fluctuations. This methodology utilizes the ordinary Kalman filter (OKF) to detect short intervals with abnormal rainfall patterns. It also applies the adaptive Kalman filter (AKF) to identify abrupt changes in the parameters of the periodic-stochastic model of the rainfall time sequence. These abrupt changes in the model parameters, which occur in the short intervals with abnormal rainfall patterns, divide the time sequence into several rainfall periods.

Since rainfall fluctuations have always been associated with changes in the mean (Karl & Riebsame 1984, & Nemec 1985), we identify fluctuations of 10% or more in the mean between two adjacent rainfall periods. This value (namely changes in precipitation of 10%) has been considered in defining moderate climate variations (Nemec, 1985). To give prominence to the differences in characteristics between two rainfall periods, statistically significant changes in parameter structures are detected using the Chow test. Results of this test have indicated the inability of the mean by itself to define how severe and how frequent intervals of abnormally low rainfall may occur; the occurrence of such adverse rainfall has been directly linked with the behaviour of the model parameters.

Identification of rainfall fluctuations by the adaptive Kalman filter

Each monthly rainfall time series is transformed and modeled as a periodic-stochastic process in the form:

$$y(k) = M_y + \sum_{i=1}^{q} (A_i \sin 2\pi f_i k + B_i \cos 2\pi f_i k) + w(k) \qquad (1)$$

where $y(k)$ is the transformed monthly mean rainfall at time step 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; and $w(k)$ is the stochastic component which is assumed to be white Gaussian noise with zero mean and variance $W(k)$. The dominant harmonics f_i (in cycles/month) in each series are obtained using MEM spectral analysis. The identification of rainfall fluctuations is associated with the abrupt changes in the model parameters M_y, A_i and B_i.

The ordinary Kalman filter is used to detect the intervals with abnormal rainfall patterns in the four rainfall records. It estimates recursively the abnormality detection index $\phi_*(k,l)$ (Ueda et al., 1984) at each time step k from a finite innovations (step-one prediction residuals) sequence. The occurrence of a peak ϕ_* identifies an interval with an abnormal rainfall pattern, and its value measures the size of the abnormality.

The adaptive Kalman filter detects whether an abrupt change in the system state variables M_y, A_i and B_i occurs by evaluating the finite innovations sequence using the generalized likelihood ratio test (GLRT). This test compares the value of $\phi_*(\theta,l)$ with a threshold value η, where θ is the unknown time step when the abnormality occurred and l is the length of the innovations sequence. If $\phi_*(\ ,l)$ is greater than η, the hypothesis (H_1) that an abrupt change occurred at time $k=\theta$ is accepted; otherwise, the hypothesis (H_o) that no abrupt change has occurred is accepted. Once an 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 to allow the filter to adjust to the new rainfall characteristics. The abrupt changes in model parameters divide the time sequence into parameter regimes, where each parameter regime corresponds to one rainfall period. Moreover, the estimates of the parameters in a period describe the rainfall characteristics of that period and the occurrences of abnormal rainfall patterns. The occurrences of the abnormal patterns in a period characterize the rainfall of that period.

In the absence of prior information on parameter change, it is only possible to make valid inferences, if great care is taken in the interpretation of any parameter change (Bennett,1979). Chosen for reason of its simplicity, the Chow test (Chow,1960) is used for testing each pair of nonoverlapping adjacent rainfall periods for the presence of two parameter regimes.

Short-duration rainfall pattern abnormalities do not happen at regular intervals and, like droughts and floods, can be expressed in terms of return periods. We feel that the most appropriate return period for such abnormalities would be one related to the design and operation of water resource systems. We consider the period in years on the average of about a decade during which rainfall fluctuations can be expected to recur. In designing reservoir capacity, Japan's Ministry of Construction recommends the use of the same drought return period (Hori, 1978). Also, this return period is considered in choosing η.

Rainfall in the Philippines

The Philippine archipelago is comprised of approximately 7000 islands having an aggregate area of 300,000 sq km. It is located in the tropics and the climate prevailing in any particular place in the country is influenced by its geographical position and wind system prevalent at certain times of the year. The prevailing wind systems over the country are as follows: the northeastern monsoon (December to January), trade wind (April), and southwestern monsoon (July, August and September). The driest of these is the trade wind season, while the wettest is the southwestern monsoon season. The classification of Philippine climatic conditions is based on the characteristics of the distribution of rainfall received in a locality during the different months of the year. On the basis of this classification, four types of climate are adopted. Figure 1 shows the climatologic map of the country. It should be noted in this figure that the dividing lines between different climatic types occur along mountain ranges which are high enough to cause variations in rainfall distribution. Figure 1 also shows the locations of the four stations selected for analysis: Vigan, Legaspi, Zamboanga and Davao. Figure 2 presents the mean monthly rainfall at each station (see also Medina _et al._, 1985).

Results and discussion

Figure 3 illustrates the time series plots of $\phi_*(k,1)$ calculated by OKF (broken line), assuming no abrupt change in system parameters, and by AKF (full line), implementing GLRT. The numbered peaks identify the time and magnitudes of the abnormal rainfall patterns. These abnormal rainfall patterns are classified into three types: Type A which is characterized by a dominance of monthly rainfall depths of below the mean values and presence of abnormally dry months, Type B which is typified by a dominance of rainfall depths of above the monthly mean values and existence of abnormally wet months, and Type C which is characterized by both abnormally dry and wet months

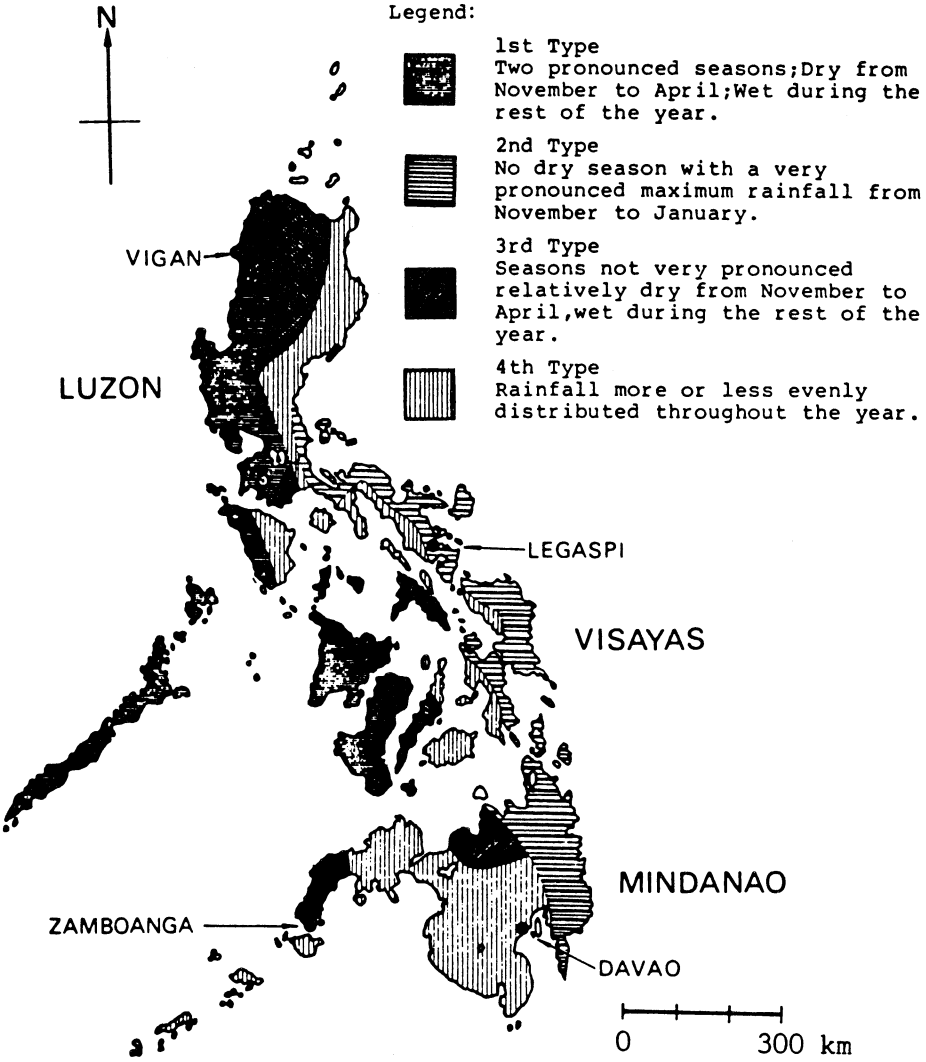

Figure 1 Climatological map (after "Philippines Water Resources", 1976). Vigan, Legaspi, Zamboanga and Davao are the stations selected for analysis.

occurring more or less alternately. These abnormal rainfall patterns may last for one or two years.

In the same figure, the arrowed peaks above the threshold identify the time of occurrences of abrupt changes in model parameters. As can be observed in this figure, these changes coincide with occurrences of abnormal rainfall patterns, indicating that the occurrence of an abnormal rainfall pattern may induce significant rainfall fluctuation. For each sequence, the abrupt changes in model parameters identify three rainfall periods with average duration of 11 years. The estimates of the parameters by AKF are shown to be

Table 1 Parameters slected by AKF

			Period		
Station	f_i	Parameters	I	II	III
Vigan		M_y	1.23	1.29	1.24
	1/12	A_1	-0.85	-0.97	-0.91
		B_1	-0.81	-0.95	-0.88
	1/6	A_2	0.08	0.21	0.23
		B_2	0.02	0.04	0.12
	70/396	A_3	-0.03	-0.10	-0.02
		B_3	-0.02	-0.18	-0.01
	132/396	A_4	-0.17	-0.11	-0.14
		B_4	0.00	0.15	0.00
Legaspi		M_y	2.05	1.99	2.04
	7/396	A_1	-0.02	0.14	0.05
		B_1	0.07	0.00	-0.02
	1/12	A_2	-0.10	-0.22	-0.26
		B_2	0.35	0.20	0.21
	1/6	A_3	-0.09	0.02	0.01
		B_3	0.18	0.12	0.17
	99/396	A_4	-0.12	-0.07	-0.06
		B_4	0.15	0.03	0.05
	160/396	A_5	-0.11	-0.02	0.00
		B_5	0.03	0.08	0.00
Zamboanga		M_y	1.40	1.38	1.36
	21/384	A_1	-0.01	0.05	0.09
		B_1	-0.04	0.03	0.03
	1/12	A_2	-0.36	-0.29	-0.36
		B_2	-0.12	-0.11	-0.14
	1/6	A_3	-0.11	-0.05	-0.08
		B_3	0.09	0.02	0.09
	96/384	A_4	-0.01	0.01	-0.01
		B_4	0.08	-0.11	-0.14
	178/384	A_5	-0.05	-0.09	-0.11
		B_5	0.01	0.00	0.00
Davao		M_y	2.16	2.16	2.10
	7/396	A_1	0.08	0.07	0.20
		B_1	0.10	-0.10	-0.06
	1/12	A_2	-0.22	-0.29	-0.39
		B_2	-0.23	-0.24	-0.31
	1/6	A_3	-0.14	-0.13	-0.07
		B_3	0.10	-0.09	0.26
	99/396	A_4	0.14	0.14	0.16
		B_4	-0.03	0.06	-0.22

effectively equal to those (not shown in this paper) by least squares method, which verifies the validity of the estimates in Table 1.

Table 2 shows that only the I vs II pair at Vigan and Legaspi can be interpreted as obeying two different parameter structures at the 5% level of significance, which suggests that serious changes in rainfall characteristics took place between these periods. Figure 4 presents in a convenient form the three rainfall periods and the distribution of the abnormal patterns identified by OKF.

We propose the following discussion and conclusions regarding rainfall fluctuations on the basis of the behaviour of M_y and A_i and B_i which correspond to the periodicities (longer than one year, one year, and six months) accepted as real (Medina et al.,1985). For these, we refer the reader to Figure 4 and Tables 1 and 2.

The occurrence of Type B abnormal pattern in Vigan initiates a period (II) with an abundance of abnormally high rainfalls as indicated by the presence of Type B and Type C abnormal patterns. This shift from period I to period II is accompanied by an increase in the estimated value of M_y, as well as in coefficients A_1, B_1 and A_2 of the one-year and six-month harmonics. The abrupt change in M_y

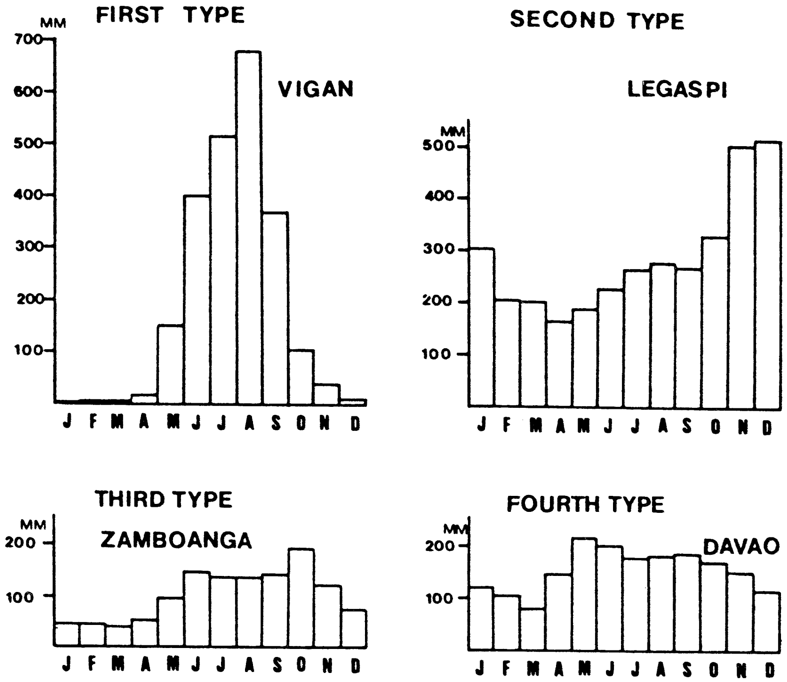

Figure 2 Mean monthly rainfall. First type, second type, third type and fourth type are the types of climates in the Philippines.

Table 2 Results of the Chow test for parameter change. (p is number of parameters, n and m are the numbers of observations in the two periods.)

Station	Pair of periods	F-statistic (critical value)	Degrees of freedom p, n + m - 2p
Vigan	I vs II	2.202 (1.92)	9, 239
	II vs III	1.110 (1.92)	9, 260
Legaspi	I vs II	2.218 (1.83)	11, 251
	II vs III	0.605 (1.82)	11, 293
Zamboanga	I vs II	1.487 (1.83)	11, 195
	II vs III	0.456 (1.83)	11, 283
Davao	I vs II	0.823 (1.91)	9, 296
	II vs III	1.266 (1.95)	9, 125

amounts to an increase of 32.7% in mean rainfall corresponding to an increase of 854 mm (45.6%) in the annual rainfall during 1961-72 over that of the previous ten years (1951-60). In contrast, the shift from period II to period III, which is also initiated by a Type B abnormal pattern, is characterized by a decrease in M_y, A_1 and B_1 and an increase in A_2 and B_2. Although the F-statistic finds these

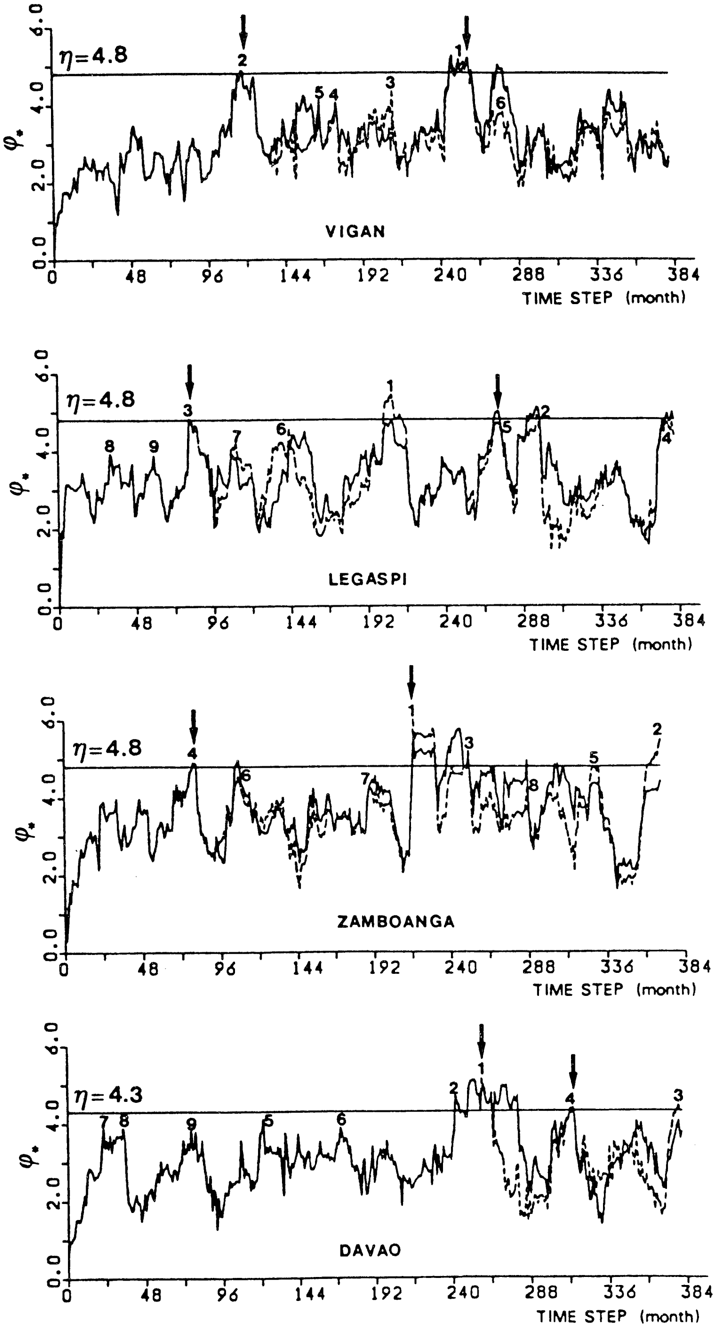

Figure 3 Time series plots of the abnormality detection index ϕ_* as calculated by OKF (broken line) and by AKF (full line). Numbers indicate periods with abnormal rainfall patterns. Downward arrows indicate rainfall fluctuations.

changes to be not significant, it corresponds to a decrease of almost 700 mm in the annual total rainfall that occurred from 1961-72 to 1973-83.

At Legaspi station, the fluctuation from period I to period II is initiated by a Type C abnormal pattern. The decrease in both M_y and

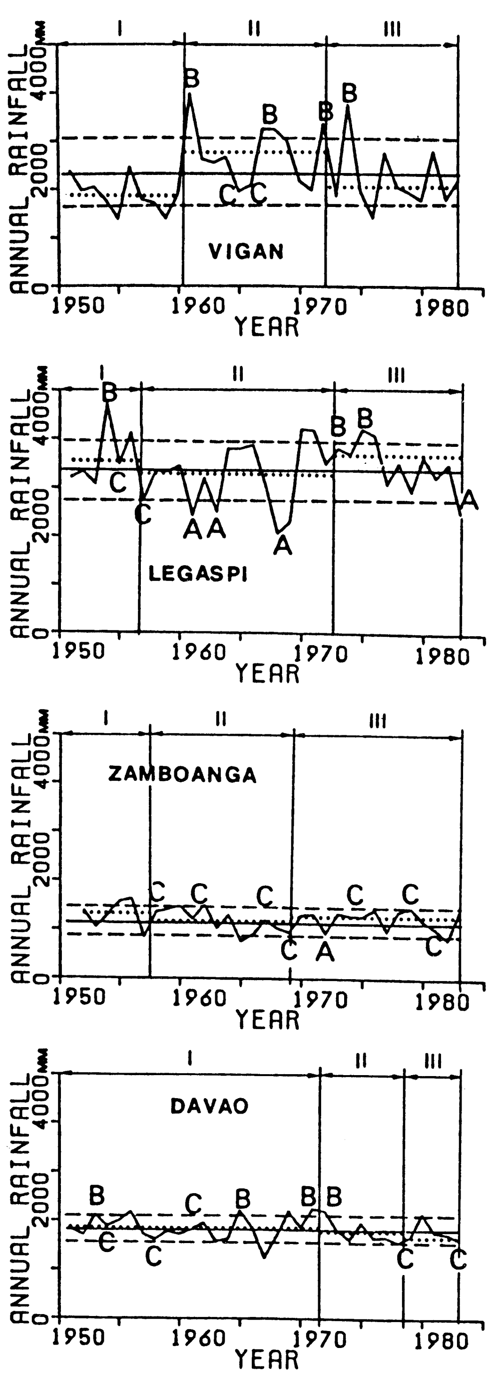

Figure 4 Time series plot of the annual rainfall of each station, depicting two rainfall fluctuations and distribution of abnormal rainfall patterns (A, B and C).

amplitudes of one-year and six-month periodic components plus a remarkable increase in A_1 of the 4.7-year oscillation accompany this fluctuation. The decrease in M_y reflects a drop of only 8.2% in actual monthly mean rainfall during period II from period I. In this shift, the presence of Type B and Type C abnormal patterns typifies period I and accounts for the above-average rainfall in this period, whereas Type A, abnormally dry pattern, prevails in period II. On the other hand, the change from period II to period III is initiated and characterized by Type B occurrences. This shift is described by an increase in M_y of 11.2%, a decrease in the amplitude of the 4.7-year harmonic, and increases in the amplitudes of the one-year and six-month components. Period III experiences Type A and Type B abnormal patterns.

Using drought duration curve analysis, Kawamura et al. (1987) have demonstrated that droughts could be very severe in periods when the rainfall characteristics are similar to those displayed in period II at Legaspi station. This period is characterized by frequent occurrences of Type A abnormal patterns, presence of intervals of above-average rainfall, and particularly, a remarkable 4.7-year oscillation. One of the three Type A abnormal patterns in this period is the 1969-drought episode (Medina et al., 1985) which caused crop failure in the region where Legaspi is situated. It is also the most abnormal rainfall pattern at this station in the sense that the value of its peak θ_* is the highest. Also, similar characteristics emerged in period III of Davao, where the two significant droughts in the country in 1982 and 1983 appear as the occurrence of Type C abnormal pattern.

In the Zamboanga and Davao rainfall sequences, the occurrences of abnormal rainfall patterns, which resulted in the detection of abrupt changes in model parameters, cause neither fluctuation of 10% in the mean nor statistically significant changes in parameter structures. This is understandable, since rainfalls in both Zamboanga and Davao have much lower variances (therefore have much less fluctuations) than those in Vigan and Legaspi. Also, with this result, it appears that rainfall fluctuations would take place more readily at places with climates similar to those in Vigan and Legaspi than at localities with climates like those in Zamboanga and Davao.

Although the shift in the mean is useful for the identification of significant rainfall fluctuations, it is clear from this study that it is not a sufficient parameter. This observation is illustrated by the fluctuations from period I to period II in Legaspi, where the shift in M_y exhibits less than a 10% drop in actual monthly mean rainfall while the F-statistic shows significant changes in the parameter structures between these periods. In particular, the mean describes the average level. This parameter provides a vague description of just how poorly a water resource system might behave in the infrequent situation when flood or drought does occur. Although rainfall may be satisfactory in a decade, our concern must extend to the short intervals of several months when water resources systems might be seriously 'depleted' (at least temporarily). For example, our attention should not be focused exclusively on the ten-year low rainfall as things can be worse in critical parts of the system during several intervals of adverse rainfall. Period II of Legaspi, as shown in Figure 4, illustrates the inability of the mean by itself to define how severe and how frequent intervals of abnormally low rainfall may occur.

However, in cases where rainfall is highly variable, or if the consequences of intervals of abnormal rainfall are severe, then it is appropriate and desirable to consider also the changes in the parameter structures which (unlike the shifts in the mean) describe in a clear and meaningful way what the character of fluctuations might be.

Conclusions

The AKF has proved to be a useful procedure for the identification of the time of occurrence and magnitude of rainfall fluctuations. The AKF approach applied to periodic-stochastic rainfall time series model has not only provided information on shifts in the mean but also automatically exposed hidden periodicities in a particular period, which have been found indispensable in probing for occurrences of adverse rainfall and rainfall fluctuations.

The rainfall fluctuations have been described not only in terms of rainfall amounts but also in terms of the occurrences of adverse rainfall. The magnitude of changes in the mean exhibited in the Vigan record, and the high incidence of adverse rainfall in period II of both Vigan and Legaspi, have demonstrated that the occurrence of a short interval with rainfall pattern anomaly may induce serious changes in rainfall characteristics. These kinds of severities of rainfall fluctuations may serve as a basis for evaluation as to whether or not the existing and proposed water resources systems are robust, vulnerable or resilient. Nevertheless, the occurrence of an abnormal rainfall pattern, which led to the detection of an abrupt change in model parameters, does not always mean that significant rainfall fluctuation is happening or is going to happen as shown by the Zamboanga and Davao rainfall sequences.

While the existence of rainfall fluctuations has been ascertained, it is obvious that the four stations involved are not sufficient to derive general conclusions applicable to other stations of similar or different climatic conditions. With this number of stations, it is also difficult to examine the interrelationships among the four types of climates in the country regarding the spatial occurrence of rainfall fluctuations. Moreover, the shortness of records limits the interpretation of the results reported above. Also, three periods are not enough to draw complete characterization of the temporal occurrence of rainfall fluctuations.

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