JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.nn, mon yyyy, pp.

Statistical Modelling of Rainfall and River Flow in Thailand

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Abstract: Thailand experiences severe floods and droughts that affect agriculture. New techniques, such as Data-Based-Mechanistic modelling are being developed to study rainfall and river flow to improve flood and drought alleviation policies and practices. Dynamic Harmonic Regression models are used to analyze rainfall and discharge time series across Thailand to define seasonality, trends and to forecast rainfall and discharge and their spatial distribution. Statistical patterns in the frequency of extreme rainfall and flow periods are identified with a view to improving predictions of medium and longer-term rainfall and river flow patterns. The results show temporal and spatial variation within the annual rainfall pattern in the study catchments. For example, the seasonality of the rainfall in the south is less pronounced (more equatorial). The discharge seasonal pattern shows stronger semi-annual cycles, with the weakest pattern in the south of country, whereas the strongest discharge seasonality is observed in the far north. The overall areal rainfall trend has not changed significantly over the last 20 years. Dry years can be associated with ENSO events. The discharge trend also tended to dip in ENSO years. The DHR forecasts of rainfall and river flow data for 1998-1999 using data up to 1997 have low prediction errors.

Keywords: Statistical modeling, Rainfall, Runoff, ENSO, Thailand.

INTRODUCTION

During the last 10 to 15 years there has been a worldwide perception that drought and flooding have intensified. Many scientists have paid the attention to these natural phenomena and relate the changes to global warming in general and to ENSO events in particular. In Thailand there are incomplete records of floods and droughts from the establishment of Sukhothai Ratcha Thani – the first Capital City – in the 13th Century AD. Using a qualitative classification scheme Tangtham et al. (1999) identified about 21 years of fair drought, 35 years of severe drought and 4 years of very severe drought within the period 1831 to 1999. The most severe droughts of the last 20 years occurred in 1978, 1986, 1987, 1990, 1993 and 1999, (Tangtham et al. 1999). The drought of 1993 spread over every region and caused water shortage for agriculture, industrial and domestic consumption. A more severe drought occurred in 1999 throughout the country especially in the control plain of Chao Phraya Basin. Besides the drought, more frequent floods have also been faced by those people living and farming in Thailand especially in the lower part of the Chao Phraya Basin.

New technologies and methods are developed to study and forecast these events to protect against extreme events and to decrease the risk of their occurrence. Statistical modelling has been developed rapidly. In presenting an abstraction of reality, a model should remain simple enough to understand and use, yet complex enough to be representative of the system being studied. This paper reports the use of Dynamic Harmonic Regression (DHR) models to analyze the rainfall and the discharge time series across Thailand to identify the evolution of annual and supra-annual cycles (which reflect the character of seasonality), trends and to forecast rainfall and discharge. The aims of the study are first, to identify changes in rainfall regime and in river flow and their spatial distribution. Secondly, to identify statistical patterns in the frequency of extreme rainfall and flow periods with a view to improving predictions of medium and longer-term rainfall and river flow patterns.

METHODS

Data-based Mechanistic (DBM) Models

Data-based Mechanistic (DBM) modelling is an alternative methodology to traditional statistical time-series analysis that gives simpler, stochastic descriptions which are more appropriate to the often limited data and information base. DBM modelling can be useful not only for the modelling of environmental and other systems directly from time series data, but also as an approach to the evaluation and simplification of large deterministic simulation models. To achieve these objectives, the DBM approach uses various methodological tools, including advanced methods of statistical identification and estimation; a particular form of Generalised Sensitivity Analysis based on Monte Carlo Simulation; and Dominant Mode Analysis, the latter involving a new statistical approach to combined model linearization and order reduction (Young, 1999). A data-based approach utilizing objective statistical analysis of output and/or input-output time series behaviour leads to improved understanding of the response dynamics of systems, contributes to hypothesis formulation for improved model structure, as well as good predictive capacity. Data-based Mechanistic models are obtained initially from the analysis of observational time-series but are only considered credible if they can be interpreted in physically meaningful terms (Young, 1999).

The methodological tools that have been developed to underpin the DBM modelling philosophy can be unified in terms of an Unobserved Components (UC) model, which can be formulated in full multivariable (multi-input, multi-output) terms (Young, 1998). In the Unobserved Components (UC) model, the observed time series y_t is assumed to be composed of an additive or multiplicative combination of different components, all of which have a physical interpretation and defined statistical characteristics but which cannot be observed directly. A typical, and fairly general, UC model for a scalar time series is the following:

$$y_t = T_t + C_t + S_t + f(u_t) + N_t + e_t \qquad e_t \sim N\{0, s^2\}$$

where y_t = the observed time series, T_t = a trend or low frequency component, C_t = a damped cyclical or AutoRegressive-Moving Average (ARMA) component, S_t = a seasonal component, $f(u_t)$ = captures the influence of a exogenous variables vector u_t, if necessary including nonlinear dynamic relationships, N_t = a stochastic perturbation model (coloured noise), and e_t = a normally distributed Gaussian sequence with zero mean value and variance s^2.

Dynamic Harmonic Regression (DHR)

The DHR model is a special example of a UC model and is a recursive interpolation, extrapolation and smoothing algorithm for non-stationary time-series (Young, 1998; Young et al. 1999). The DHR model identifies three components in the time-series, i.e.,

$$y(k) = t(k) + s(k) + e(k)$$

as they are described by Harvey (1989) or Young et al. (1999), where, *y(k)* = the observation at sample k (as in $y(k) = y(kDt)$, $K = 1, \ldots, T$), *t (k)* = the smooth trend (usually of the integrated random walk - IRW type), *s(k)* = a seasonal component of Dynamic Harmonic Regression type

$$s(k) = \sum_{j=1}^{Ns} \{a_j(k)\cos(\omega_j k) + b_j(k)\sin(\omega_j k)\}$$

where, a_j and b_j = the Time-Variable-Parameters (TVP's) of the model, *Ns* = the number of seasonal components, w_j = the set of frequencies chosen by reference to the spectral properties of the time-series.

This component is a linear combination of harmonics, similar to the harmonic regression used to interpret the spectrum. The main difference is in the fact that the coefficients may now vary in time, and *e(k)* = a zero mean, serially uncorrelated white noise component

The DHR may be described in a sense as a straightforward extension of the classical Fourier analysis into the area of time varying parameters. The Discrete Fourier Transform is based upon the same model of the signal, but with constant harmonic coefficients *a* and *b* and with the number of frequencies w limited by the number of samples. The number of frequencies used in the DHR models is limited by the requirement of spectral separation of the model components, which in the case of time varying parameters are no longer single spectral lines, but have well defined shapes depending on the way the parametric variation is modelled.

In a paper especially relevant to the Thai time-series, Young et al. (1999) utilised the data-based approach to demonstrate the analysis of a univariate output temperature series. The monthly average temperature time series for the Coweeta long-term ecological research site in North Carolina was analysed by Dynamic Harmonic Regression (DHR). The DHR model was selected with an (Autoregressive) AR(1) trend, together with sines and cosines at periods of 12, 6, 4, 3, 2.4 months periods all with time variable parameters defined as AR(1) processes. The results revealed that most of the power is contained in the fundamental 12-month period component and both the 6- and 4-month period components are very small. The DHR model was able to interpolate the temperature series over a 5-year period of missing data between 1966 and 1970 effectively. The estimate of the long-term trend, assuming that it is modelled as an Integrated Random Walk (IRW) process rather than an AR(1), with all the harmonic component coefficients modelled as IRW processes, yields a very similar, although smoother estimated of the trend. Young et al (1999) noted that the approach is objective, with most stages in the analysis being fully automatic. The only subjective element is the choice of stochastic models for the time variable trend and harmonic component coefficients. Young et al. (1999) concluded that data-based approaches to hydrological modelling are a powerful complement or alternative to using traditional models. As well as utilising objective identification and estimation tools and being explicit in their assumptions, they allow the incorporation of prior knowledge and quantify the uncertainty associated with model characterizations and predictions.

STUDY AREA

Climatic conditions in Thailand are related to its geographic position, the topography and to the air streams that cross Thailand during the year. Thailand is located between 5°40' and 20°30' N and between 97° 70' and 105° 45' E. In the west and north, the country is bordered by Myanmar, in the east by Laos and Cambodia. A southward extension, peninsular Thailand stretches to the Malaysian border, the Andaman Sea in the west and the Gulf of Thailand in the east. The estimated land area is 513,000 km^2, 20% of which are under rice paddies (Suwanwong et al. 1983). The land area is divided into several regions (Ogawa et al. 1961; Ohman, 1965) based on their physiographic characteristics. Around 30% of the total land area can be classified as mountainous, while 8% has a rolling topography (TDIC, 1986).

Thailand experiences a tropical climate and depends on wind field characteristics, particularly on the location and intensity of the Inter Tropical Confluence. The Inter Tropical Convergence Zone (ITCZ) refers to the zone where trade winds of the two hemispheres converge. Seasonal shifts in the ITCZ appear to be related to seasonal shifts in the location of the thermal equator and alternating activity in the subtropical high-pressure cells of the two hemispheres. Seasonal movement of the ITCZ induces large-scale reversals of the wind regime (FAO, 1982). The two major air streams affecting Thailand are the northeast monsoon, with winds from northerly and easterly directions, and the southwest monsoon, with wind from southern and western directions (TDIC, 1986).

The northeast monsoon (FAO, 1982) occurs from November to February when the ITCZ moves southward. Northeast trade winds bring cool and dry air from the Siberian anticyclone to the entire country. In the later half of the period, strong sea winds bring humid air from the South China Sea to the east coast of peninsular Thailand, where heavy rainfall occurs until early January. The temporary fronts formed between sea winds and northeast trades, carrying rain to the plains, are critical to plant growth in the dry season. The pre-monsoon season (FAO, 1982) prevails from March to April. As the dry Chao Phraya Plains warm during the day, humid sea breezes flow northward over the plains during the afternoon and night, causing a spell of very humid days. The northward movement of the ITCZ and the weakening of flow from the Siberian anticyclone result in increasing rainfall as the season progresses.

In May, the ITCZ moves rapidly to the north, which results in the prevalence of the southwest monsoon. Southwest trade winds bring very humid air, originating from the Indian Ocean, first along the west coast, and eventually penetrate to the interior, causing heavy rainfall over the whole country from May to September. However the intensity of the southwest monsoon varies from year to year, bringing extensive flooding during intense monsoon activity. The ITCZ starts its movement southward over Thailand in September giving rise to the post-monsoon season, which is dry in the northeast, but still wet in the Chao Phraya Plains and the peninsula.

During the wet season (May through October), monthly rainfall varies greatly from place to place depending on exposure and elevation. The dry season (mid-November to mid-April) is long and severe with monthly rainfall averages less than 30 mm. Southern Thailand, and areas bordering the Gulf of Thailand receive the most rain, averaging as much as 450 mm in Songkla. The least rainfall occurs in central Thailand where annual average precipitation ranges from 110 to 160 mm (FAO, 1982; Bachelet et al. 1992). From the monthly climatology it is evident that Thailand receives most of the rainfall during the summer monsoon period of June to September (Kripalani et al. 1995)

The surface temperature in Thailand is related to latitude, altitude and the rainfall patterns. The annual range in temperature in Thailand is small, especially in the peninsula and eastern region which are under strong influences of the sea. Mean monthly temperature of January, the coolest month, ranges from 22 to 26 ^oC and mean monthly temperature for April, the hottest month, ranges from 28 to 32°C. Daily temperature range is smaller during the southwest monsoon, from May to October. The total radiation in Thailand is relatively low in December-January (400-450 $cal.cm^{-2}d^{-1}$), particularly in the northern part of

Thailand, and reaches maximum values of more than 550 cal.cm^{-2}d^{-1} around April-May. As cloudiness increases and the rainy season commences, radiation drops sharply to values between 400 and 425 cal.cm^{-2}d^{-1} in July-August in the northern part and to values below 400 cal.cm^{-2}d^{-1} in the southern part of the country. In the northern provinces the total radiation remains at the same level until December but increases after September in the southern part of the country (TDIC, 1986).

The relative humidity in central Thailand at night is around 80-85% (19.2 mbar vapour pressure) during the dry season and over 90% (29 mbar) during the wet season. In the peninsula the relative humidity is over 90% (29 mbar) at night throughout the year. During the dry season the relative humidity during the day time drops to values between 40-50% in the central plain and northeast Thailand (or around 20-30 mbar). In the peninsula, the values of relative humidity seldom drop below 50%. During wet season the relative humidity during the daytime is about 65% (29 mbar) in the northern part of the central plain and northeast Thailand and 75% (31 mbar) in southeast Thailand and the peninsula.

Evaporation is low in January, particularly for the northern region (3.3 mmd^{-1}). In spite of clear sky, temperature is low during this month. After January evaporation increases rapidly, both in northern Thailand and in the central part of the country, mainly because both radiation and temperature increase. Evaporation can be 6-7 mmd^{-1}. In the southern part of the country temperature increase is less pronounced and vapor pressure is relatively high. Therefore the increase in evaporation is much less significant (from 4 mmd^{-1} in January to 5 mmd^{-1} in April). After April vapour pressure remains high, while radiation drops, because of the onset of the rainy season. As a result, evaporation is reduced to values between 3.1 and 4.6 mmd^{-1} in September (TDIC, 1986).

DATA

Hydrological data are published by the Royal Irrigation Department in the respective volumes of the Thailand Hydrologic Yearbook. The rainfall and discharge data used in this paper represent 20 years (1st January 1980 – 31st December 1999) and include data on all measured extreme events occurring in Thailand. The unit of rainfall and flow is the millimeter. The data were selected to be representative of a variety of catchments all over Thailand (Fig.1) and to study the relation between the rainfall and discharge. All the catchments scattered in four regions are not more than 5,000 km^2 in area (Table 1).

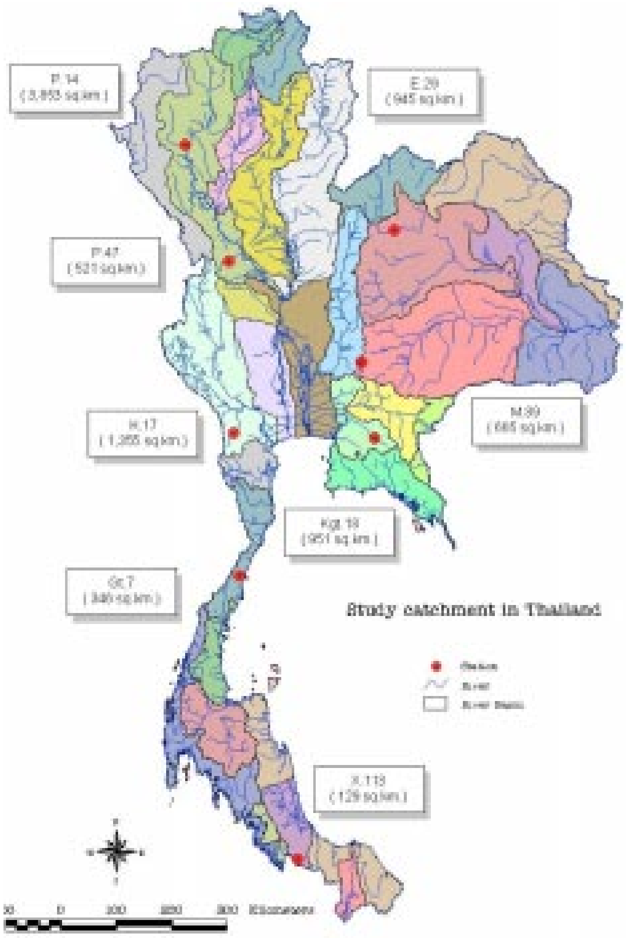

Fig.1. Study catchments in Thailand.

RESULTS

Rainfall and Discharge Time Series

From the rainfall time series analysis, it was found that the rainfall of P.14, P.47 (north), M.89 (lower northeast), Kgt.18 (east), K.17 (west), Gt7 (upper south) of Thailand is more seasonal than the E.29 (upper northeast) and X.113 (south) catchments of Thailand. The rainfall time series (log scale on ordinate) show this seasonality very clearly (Fig. 2) with the monsoon from June to September and the dry season within the period of November to April. However, the degree of seasonality is variable when comparing catchments. For example, the inter-monsoon dry periods are distinctive at the northerly station P14, which contrasts to less seasonality in the northeast (for example, E29) and weak seasonality in the southern catchment of X113. Further, at all stations the distribution of rainfall within the monsoon is highly variable year by year. Rainfall in the north (P.14) and in the west (K.17) is less than the other area, as – (i) in the north the southwest

Table 1. Catchment, location, drainage area and rainfall station

Code	River	Location	Latitude	Longitude	Drainage area	Period	Rainfall Station
P.14	Mae Chaem	A.hot, Chiang Mai	18-13-49	98-33-35	3,853	1954-1999	Aerial rainfall 6 station
P.47	Khlong Suan Mak	A.Khlong Lan, Kamphaeng Phet	16-20-03	99-16-29	521	1983-1998	P.47, P.35, A.Um Phang
E.29	Lam Nam Phong	A.Phu Khadung, Loei	16-50-45	101-56-54	945	1978-1999	E.29, A.Phu Khadung
M.89	Lam Ta Khong	A.Pak Chong, Nakhon Ratchasima	14-41-46	101-25-07	665	1970-1999	A.Pak Chong
Kgt.18	Khlong Sai Yai	A.Tha Ta Kiap, Chachoengsao	13-28-29	101-37-44	951	1969-1999	Kgt.18
K.17	Lam Phachi	A.Suan Phung, Ratchaburi	13-32-41	99-21-22	1,355	1966-1999	K.17
Gt.7	Khlong Bang Saphan Yai	A.Bang Saphan, Prachuap Khirikhan	11-14-02	99-26-35	346	1980-1999	A.Bang Saphan
X.113	Khlong U Tapho	A.Sadao, Songkhla	06-37-59	100-23-46	129	1979-1999	X,113, X.172

monsoon from the Indian Ocean has weaken in travelling across inland Thailand, and (ii) this northerly area is bordered by mountain ranges both in the west and east sides. In the west (K.17), even though the southwest monsoon is strong and may include tropical cyclones from the Bay of Bengal the catchment is in the rainshadow of Tanaosee Mountain Range, so it is relatively drier than others parts. The lower northeast is an area, that receives reduced rainfall for largely the same reason as in the north of Thailand. The humid air from the southwest monsoon does not reach much of this area and it is situated on the Korat Plateau where it is shadowed by the Dong Phaya Yen Mountain Range. In the upper northeast (E.29), the monsoon trough passes over this area during August-September affecting heavy rainfall and thus this area has more rainfall than the lower northeast. The areas of Thailand that have more rainfall are in the east (Kgt.18) and in the south (X.113). As the east of Thailand is adjacent to the Gulf of Thailand therefore the southwest monsoon brings humid air onto land and causes high rainfall. In the south (X.113), catchments receive heavy rain both from the southwest monsoon crossing the Indian Ocean and the northeast monsoon bringing humid air from the South China Sea, hence, this area is quite wet all year round. The discharge time series in log scale are shown in Fig.3. The results exhibit that the north (P.14) and west (K.17) of Thailand have less discharge as the result of less rainfall, while the lower north (P.47) has more flow than the upper north. In the upper northeast (E.29), this area receives temporally scattered rain and further the geology consists of sandstone, so the infiltration is high but storage is shot-lived and runoff is very flashy. In contrast, in the lower northeast (M.89), there is some groundwater storage, which is released as discharge throughout the year. At K17 runoff is short-lived and variable for reasons, which are not clear given the fairly steady rainfall regime (Fig.2). In the upper south (Gt.7), discharges are relatively high, reflecting the high rainfall and there is little flood attenuation as the streams are within small steep catchments. In the south (X.113), discharge is also high as the result of heavy rainfall throughout the year.

DHR Analysis

The daily areal rainfall and discharge data of the representative catchments all over Thailand are analyzed by Dynamic Harmonic Regression (DHR).

Spectral Analysis

The DHR model is selected with sines and cosines at periods of 26, 13, 9, 6.5 and 5 (12, 6, 4, 3 and 2.4 months) and all of the parameters are modelled with an Integrated Random Walk (IRW). The order of the AR spectrum is specified by 28 and the logarithmic AR(28) spectrum is characterised by peaks at the fundamental (12 month) and

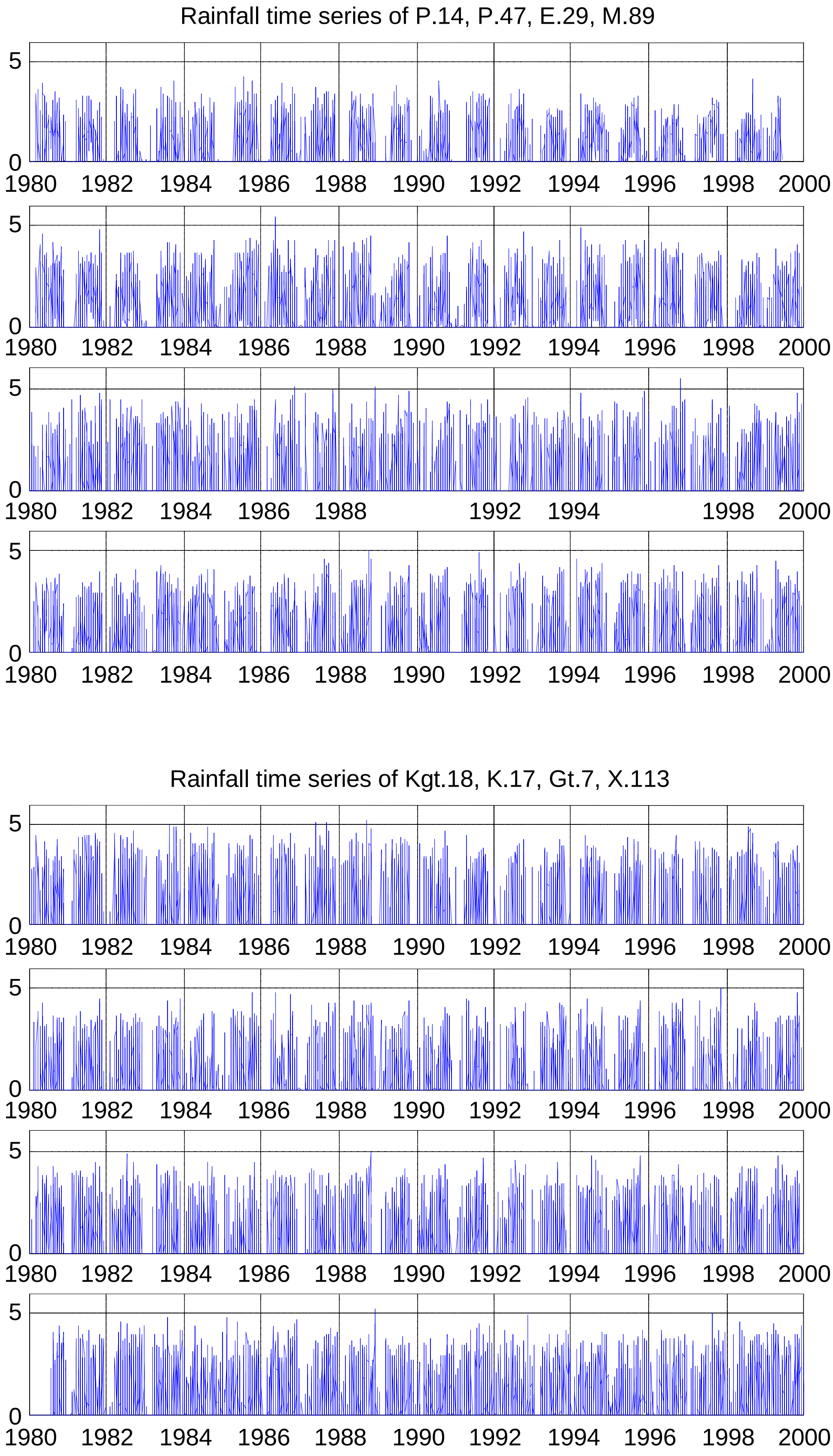

Fig.2. Rainfall (mm on log-scale) time series for each catchment during 1980-1999.

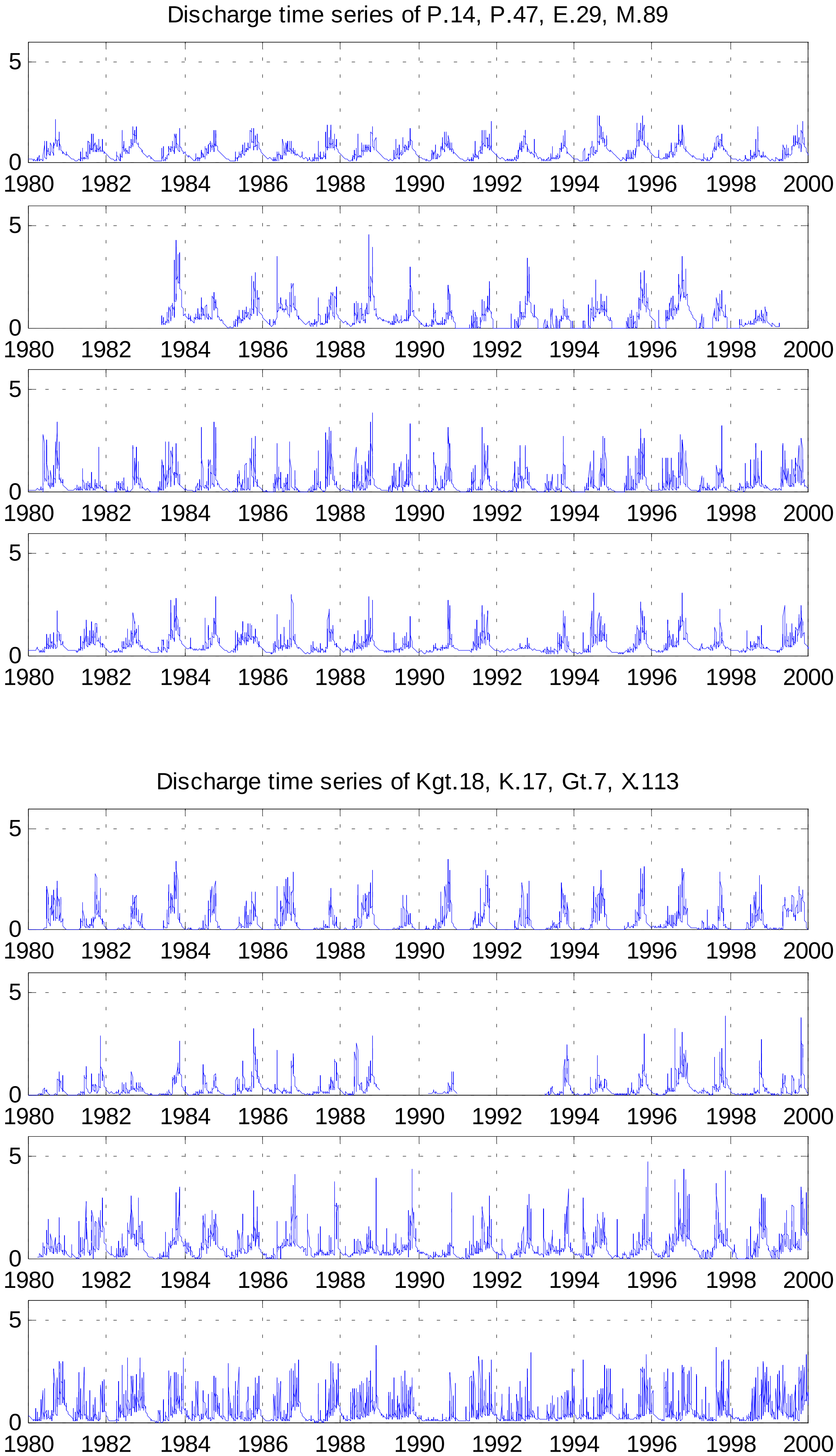

Fig.3. Discharge (mm in log scale) time series of each catchments during 1980 – 1999.

all harmonics (6, 4, 3 and 2.4 months) for both rainfall and flow data (Fig.4). The rainfall and discharge spectral amplitude at the obvious 12, 6 and 4 month periods are shown in Table 2. For rainfall, the best determination is at the fundamental (12 months) in all catchments. The second most significant spectral peak for the north and northeast appears at the 4-month period while for the east, west and south; it appears at the 6-month period. Remarkably in the south X.113, the peak at the fundamental period is not markedly larger than the 6-month harmonic peak, which is a good indicator of weak seasonality. In all cases the shorter period components (3, 2.4 and 2 month periods) are quite small and not well-defined. From the rainfall spectral amplitude, the various peaks indicate that the least rainfall seasonality is in the south (X.113) followed by the upper northeast (E.29), east (Kgt.18), lower north-east (M.89), west (K.17), upper south (Gt.7) whereas the highest rainfall seasonality is in the north of Thailand (P.14 and P.47).

Table 2. Spectral amplitude of each catchment in Thailand

Catch-ment	Rainfall spectral amplitude			Discharge spectral amplitude		
	12 month	6 month	4 month	12 month	6 month	4 month
P.14	3.23	0.95	1.22	3.28	1.80	1.47
P.47	3.18	0.99	1.67	2.76	1.97	1.72
E.29	2.23	0.97	1.21	2.42	1.64	1.73
M.89	2.77	1.29	1.47	2.70	1.77	1.56
Kgt.18	2.70	1.58	1.34	3.20	2.10	1.64
K.17	2.81	2.01	1.40	2.43	2.14	1.50
Gt.7	2.81	1.43	1.29	2.60	1.50	1.15
X.113	2.01	2.03	0.67	2.12	1.90	0.74

For rainfall, the best determination is at the fundamental (12 months) in all catchments. The second most significant spectral peak for the north and northeast appears at the 4-month period while for the east, west and south; it appears at the 6-month period. Remarkably in the south X.113, the peak at the fundamental period is not markedly larger than the 6-month harmonic peak. The shorter period components (3, 2.4 and 2 month periods) are quite small and not well-defined. From the rainfall spectral amplitude, they indicate that the least rainfall seasonality is in the south (X.113) followed by the upper northeast (E.29), east (Kgt.18), lower northeast (M.89), west (K.17), upper south (Gt.7) whereas the most rainfall seasonality is in the north of Thailand (P.14 and P.47). These differences in the rainfall seasonality are the effect of the local topography in addition to the important role of typical monsoon rainfall and the dominant influence of the ITCZ. In wintertime, when the ITCZ moves southward, strong sea winds bring humid air from the South China Sea to the east coast of peninsular Thailand and heavy rainfall will last until early January. Then in May, the ITCZ moves rapidly to the north and southwest trade winds bring very humid air, originating from the Indian Ocean, first along the west coast, and eventually penetrate to the interior, causing heavy rainfall over the whole country from May to September. The ITCZ starts its movement southward over Thailand in September giving rise to the post-monsoon season, which is dry in the north, but still wet in the Peninsula (TDIC, 1986).

There is simultaneous variability of rainfall over the entire country and the orographic structure greatly influences this spatial variability of rainfall. The seasonality in the north and northeast of Thailand has stronger seasonality than in the east and south. Because the inland region is less humid than the area near the sea, there is less chance for rainfall to occur.

For discharge, the best determination is at the fundamental (12 months) and the second most significant spectral peak appears at the 6-month period in all catchments. The shorter period components (3, 2.4 and 2 month periods) are quite small and not well-defined. From the discharge spectral amplitude, they indicate that the least discharge seasonality is in the south (X.113) followed by the upper northeast (E.29), west (K.17), upper south (Gt.7), lower northeast (M.89), lower north (P.47) whereas the highest discharge seasonality is in east (Kgt.18) and upper north (P.14). The stronger seasonality of discharge implies that there is more chance of high flow in the catchments such as P.14 and Kgt.18. When the spectrum at the fundamental and 6 month period doesn't show the obvious amplitude difference, the catchments such as K.17 and X.113 tend to have the regular flow. The actual and fitted AR(28) spectrum are compared in Fig.5. The rainfall spectral analysis shows good fits especially for the north (P.14), west (K.17) and south (X.113) catchments and the discharge spectral analysis shows good fits for all catchments.

The rainfall annual cycle is quite strong in 1985, 1994-1995 and 1997 for P.14, in 1982, 1988, 1992 and 1995 for P.47, in 1982-1983, 1986, 1991 and 1996 for E.29, in 1983, 1992, 1995 and 1998 for M.89, in 1984 and 1991 for Kgt.18, in 1983 and 1996 for K.17, in 1983, 1986 and 1995 for Gt.7 and in 1982-1983 and 1987 for X.113. It is obvious

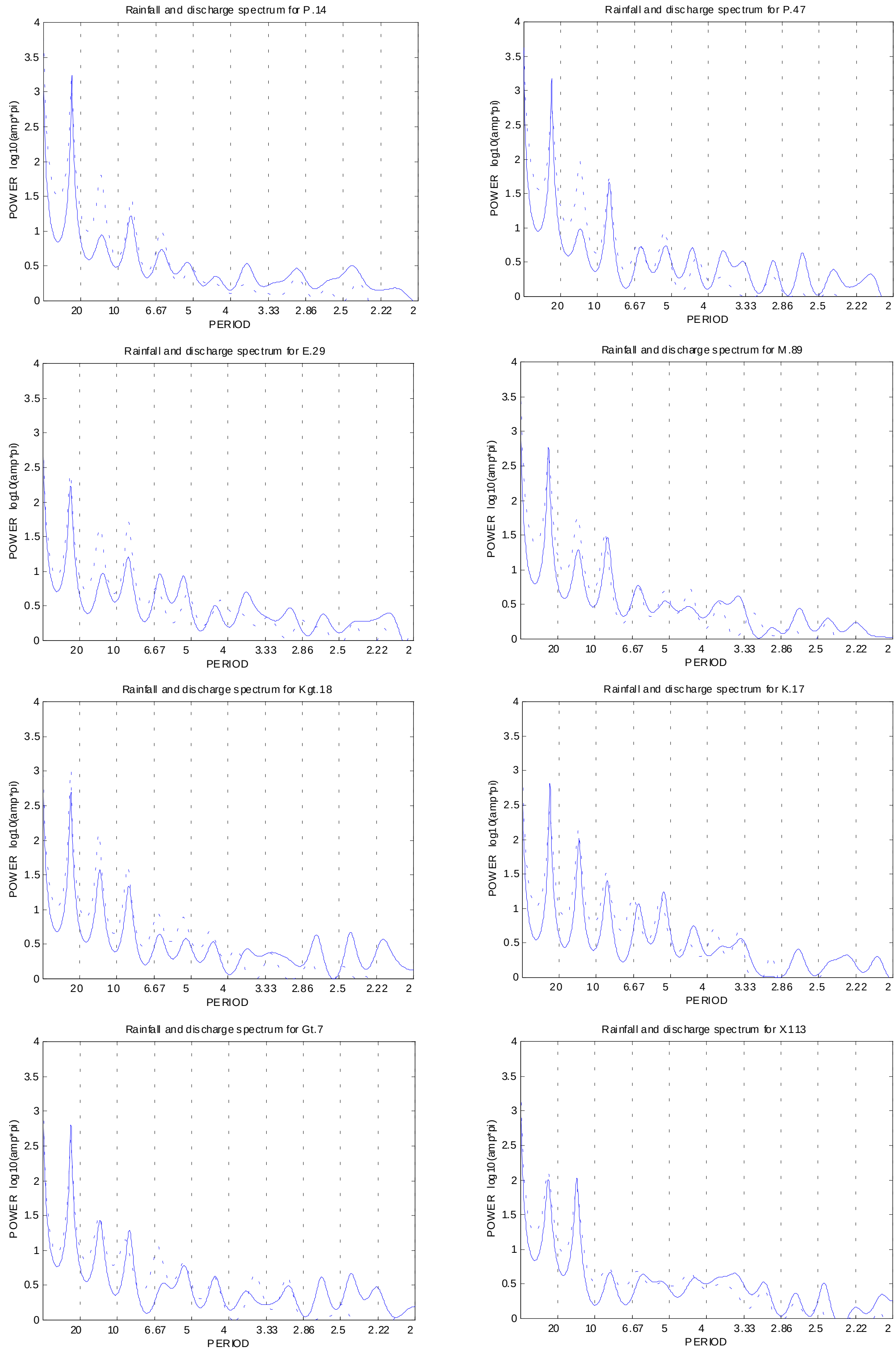

Fig.4. Comparison between rainfall and discharge spectrum by DHR model.

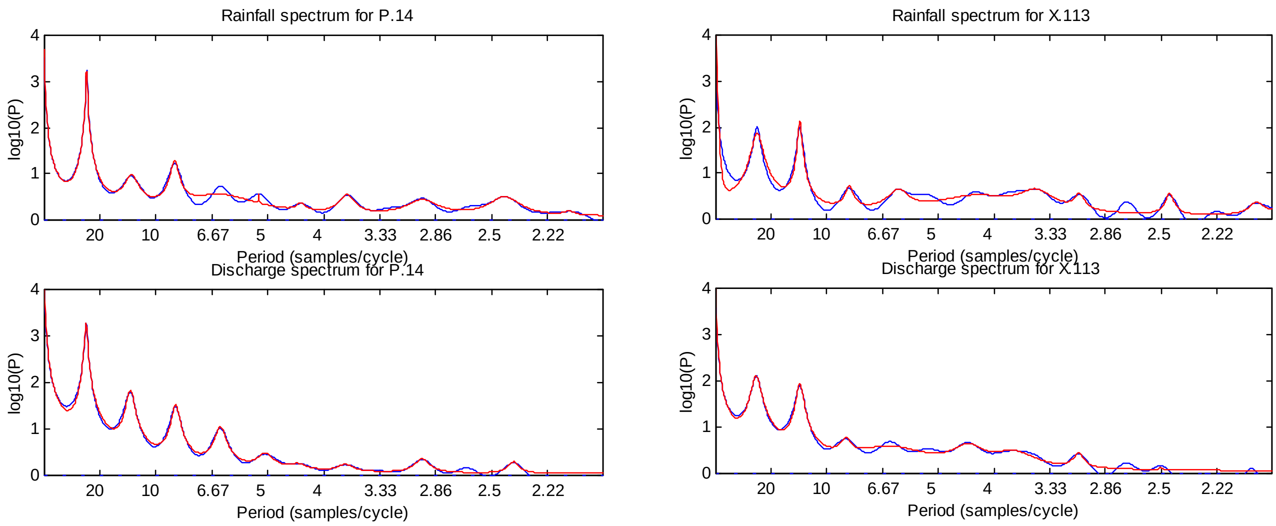

Fig.5. Rainfall and discharge time varying amplitudes of the harmonics of P.14 and X.113.

that these years are associated with the ENSO events indicating the possibility of ENSO effect on the rainfall variation.

For the discharge annual cycle, it is quite strong in 1982, 1987, 1991 and 1995 for P.14, in 1988, 1992 and 1996 for P.47, in 1983, 1987, 1991 and 1995 for E.29, in 1983, 1991 and 1994-1995 for M.89, in 1983, 1986, 1988, 1991-1992, 1994 and 1999 for Kgt.18, in 1981, 1983, 1985, 1988 and 1996 for K.17, in 1982 and 1996 for Gt.7, in 1982-1983 and 1987 for X.113. These extreme discharges match with the years of rainfall extreme event or occasionally lag in the following year.

Trend

The decimated rainfall data and trends of all catchments are shown in Fig.6 and the rainfall, discharge cycles of each catchment are displayed in Table 3. The trend of daily rainfall of P.14 has tended to drop in 1984, 1986, 1993 and 1998. The obvious peak is in 1985, 1988, 1994 and 1999. The rainfall trend of P.47 does not seem to change much over the last 20 years. The apparent drops are in 1982-1983, 1991 and 1997-1998 associated with the ENSO events. For E.29, the trend of rainfall does not change much from 1980-1999. The trend of M.89 rainfall tends to fall in 1981 then gradually rise until 1984 and drop again until 1986. It

Table 3. The rainfall and discharge inter-annual cycles of each catchment

Catchment	Rainfall		Discharge	
	Wet periods	Dry periods	Wet periods	Dry periods
P.14	1985, 1988, 1994, 1999	1984, 1986, 1993, 1998	1982, 1985, 1987, 1991, 1994-95, 1999	1986, 1993, 1998
P.47	1985-86, 1988, 1995-96	1982-83, 1991, 1997-98	1986, 1988, 1992, 1996	1984, 1987, 1990, 1993, 1998
E.29	1982, 1999	-	1983, 1987-88, 1995-96	1981, 1986, 1993, 1997
M.89	1983-84, 1997, 1999	1981, 1997	1983, 1985, 1991, 1994, 1996	1989, 1992, 1998
Kgt.18	1984, 1999	1992	1983, 1986, 1988, 1990-91, 1995-96, 1999	1982, 1987, 1989, 1992
K.17	1985, 1988, 1996	1989-90, 1986, 1998	1981, 1983, 1985, 1988, 1996-97	1983, 1985, 1987, 1999
Gt.7	1981, 1986, 1988, 1999	1985, 1989, 1998	1981-82, 1996, 1999	1990
X.113	1999	-	1982, 1988, 1996, 1999	1985, 1990, 1992-94

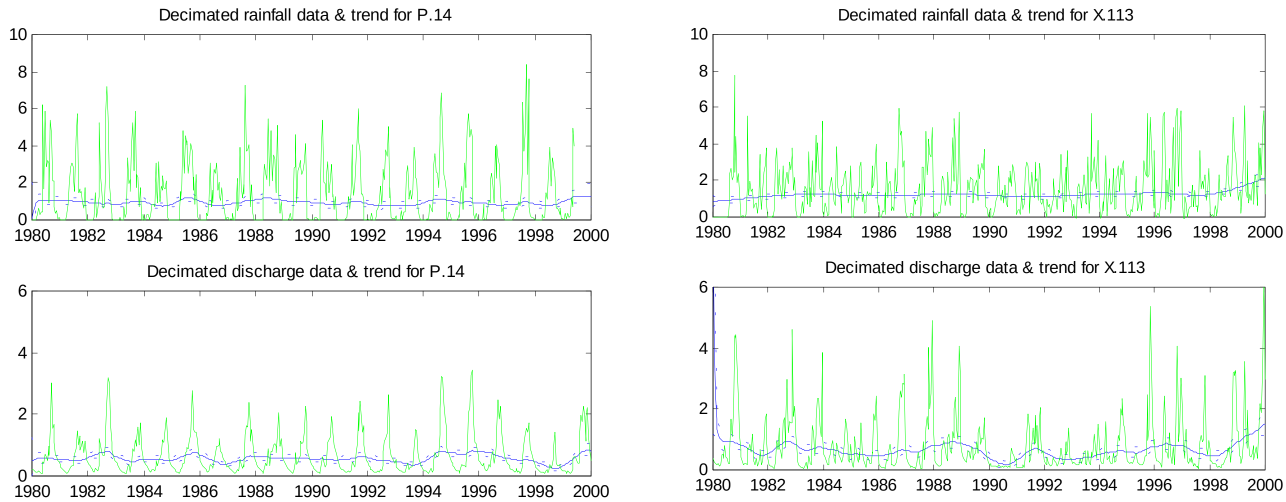

Fig.6. Decimated rainfall and discharge data and trends of P.14 and X.113 catchments.

increases a little from 1988 and then decreases in 1997 only to rise again afterward. The trend of rainfall for Kgt.18 has a higher trend in the first ten years. Then it seems to decrease after 1990. For, K.17, the trend of rainfall does not seem to change much from 1980-1999. There are obvious peaks in 1985, 1988 and 1996 and dry years in 1990-1992, 1995 and 1998. The trend of Gt.7 rainfall does not change much from 1980-1999. There are obvious peaks in 1988, 1999 and dry years in 1985 and 1989. The mean areal rainfall trend of X.113 slightly increases markedly in the last year (1999).

For discharge trend, P.14 has tended to drop 1986, 1993 and 1998 while P.47 has tended to drop in 1984, 1987, 1990, 1993 and 1998. E.29 tends to vary up and down during the last 20 years. There are obvious peaks in 1983-1984, 1988 and 1995 and drops in 1981-1982, 1986, 1993 and 1997. The trend of discharge does not change much for M.89 from 1980-1999. There are obvious peaks in 1983, 1988, 1991, 1994, 1996-1997 and 1999 and dry years in 1989, 1992 and 1998. For Kgt.18, the trend of discharge tends to increase during the last 20 years. There are obvious peaks in 1983, 1986, 1988, 1991-1992, 1995-1996 and 1999 and drops in 1982, 1987, 1989, 1992 and 1997. The trend of K.17 discharge tends to increase during the last 20 years. There are obvious peaks in 1981, 1984, 1986, 1988 and 1996-1997. The trend of discharge for Gt.7 tends to increase during the last 20 years particularly from 1996. For X.113, the trend does not change much only

Table 4. Variance components of DHR model of rainfall and flow

Catchment	Rainfall			Discharge		
	Model fit (R_t^2)	Variance contribution		Model fit (R_t^2)	Variance contribution	
		Seasonal adjusted data	Seasonal component		Seasonal adjusted data	Seasonal component
P.14	0.9383	0.0766	0.8190	0.9685	0.0959	0.8167
P.47	0.9363	0.0754	0.8106	0.9586	0.2080	0.6683
E.29	0.8548	0.1691	0.5552	0.9142	0.1491	0.7147
M.89	0.9026	0.1140	0.7207	0.9454	0.1663	0.6839
Kgt.18	0.8926	0.1413	0.6805	0.9506	0.1046	0.7596
K.17	0.8974	0.1236	0.7162	0.9456	0.1460	0.6653
Gt.7	0.9005	0.1188	0.7198	0.9252	0.2595	0.7304
X.113	0.8736	0.1498	0.6197	0.9193	0.2612	0.6688

Table 5. Rainfall and discharge forecasting error

	Rainfall				Discharge			
Catchment	MAE	MAPE	RMSE	RMSPE	MAE	MAPE	RMSE	RMSPE
P.14	0.5676	0.51	0.00	2.44	0.3147	0.66	0.47	0.81
P.47	1.0622	97.65	1.45	411.57	0.2068	0.29	0.00	1.11
E.29	1.0437	16.46	1.45	86.64	0.4302	0.57	0.61	0.63
M.89	1.9079	13.44	2.33	33.27	0.3964	0.30	0.69	0.31
Kgt.18	0.7472	43.06	1.04	232.61	0.7287	20.22	1.05	105.93
K.17	0.6814	9.80	1.25	35.29	0.5360	3.17	1.15	3.54
Gt.7	0.6942	15.20	0.95	53.87	1.1256	43.50	1.73	158.03
X.113	1.1796	2.61	1.42	10.84	0.7274	0.88	1.16	1.22

rising in the last years. The dry periods are in 1985, 1990 and 1992-1993.

From these results, it is evident that DHR results in good fits between models and the rainfall and discharge data. It is useful in indicating the annual cycle, seasonality, trend and forecasting of the rainfall and discharge (see below). The model fit and the variance components of DHR model of each catchment are shown in Table 4. The Rt2 of the model fit for rainfall and discharge are in the range of 0.85 - 0.94 and 0.91 - 0.97 respectively.

Predicted Rainfall and Flow

DHR was used to predict the daily rainfall and discharge in the last 2 years (1998-1999) from the run of earlier years data, to see how well DHR model can forecast the rainfall and flow data all over Thailand. The examples given were selected to highlight continuing modelling successes and problems. It can be seen that, considering the overall model fit, the model gives generally good results in prediction for rainfall and discharge when comparing to the actual data (Fig. 7) as the rainfall and discharge forecasting errors are quite small (Table 5). The timing of the peak in the monsoon and the troughs in the dry periods is well-predicted. The rising and falling limb of the model fit well the data but the peak of the model although usually in good with data occasionally under predicts the actual data. In general the prediction is better in the first year than in the later year.

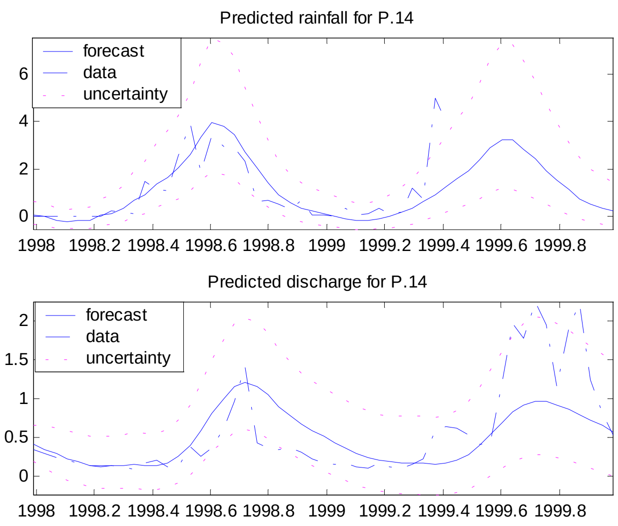

Fig.7. Comparison between predicted and row data of rainfall and discharge for P.14. Note: there is no rainfall data for the latter part of this period.

CONCLUSIONS

A data-based method is presented for understanding the response dynamics of systems and future hypothesis formulation for improved model structure, as well as good predictive capacity. Data-based Mechanistic models obtained initially from the analysis of observational time-series are only considered credible if they can be interpreted in physically meaningful terms, as is the case here.

The DHR model is a special example of an UC model and is a recursive interpolation, extrapolation and smoothing algorithm for non-stationary time-series. It can identify the trend, seasonality and annual cycle so the DHR model is particularly useful for rainfall and discharge time series analysis. The results indicate, as expected, that there is an annual rainfall cycle in all study catchments assumed as the representatives of the whole country of Thailand. However, the model allows the identification of regional differences in seasonality in particular. The rainfall spectral amplitude analysis demonstrates that the rainfall in the south is the least seasonal whereas in the north it is strongly seasonal. Similarly, there is an annual discharge cycle including an increased discharge for every 6 month in all catchments. The discharge spectral amplitude indicates that the least discharge seasonality is in the south (X.113) followed by the upper northeast (E.29), west (K.17), upper south (Gt.7), lower northeast (M.89), lower north (P.47) whereas the most discharge seasonality is in east (Kgt.18), upper north (P.14). The rainfall trend of all catchments does not seem to change much over the last 20 years. The apparent dry years are in 1982-1983, 1991; 1997-1998 associated with the ENSO events. Discharge trend has also tended to drop in 1982 and 1987 ENSO years. The forecasted rainfall and flow data by DHR model in the last 2 years (1998-1999) for all over Thailand give the good with little forecasting errors. So DHR model can give the good results in fitting the rainfall and discharge data. It is useful in indicating the annually cycle, seasonality, trend and forecasting of the rainfall and discharge.

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