AGGREGATION SIMULATION MODEL OF FLOW AND RAINFALL SERIES

NURUL ADZURA ISMAIL

UNIVERSITI TEKNOLOGI MALAYSIA

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NURUL ADZURA ISMAIL

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To my beloved soul mate

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ABSTRACT

Synthetic hydrology series is useful for evaluating the consequences of water supply management decisions and reservoir design. The main objective of this study is to identify and confirm the best model in flow and rainfall simulation. The study covers the application of aggregation and disaggregation methods for flow and rainfall stochastic simulation. In general, the application of various periodic models for the flow simulation was mostly successful. The application of disaggregation models was found to yield sufficient performance and competitive to the periodic models. It has been proven that the transformation does not always guarantee improvement in the candidate models performance. The Periodic Autoregressive of Order One (PAR (1)) model is the best performer for the monthly and annual flow simulation using periodic models for both untransformed and transformed series. The Valencia and Schaake (VLSH) model is the robust model from disaggregation group for the monthly and annual flow simulation. Simulation for monthly and annual rainfall series shows that the VLSH model is the best performer to produce sufficient results for both untransformed and transformed series. The results from this study are based on investigation from graphs and frequency analysis. The outcome of study has potential to assist the water engineers and consultant in making decisions for the operation of the water resources systems. It is suggested that the rainfall simulation should be applied in water resources planning because observed flow series are subjected to disturbance due to development.

ABSTRAK

Siri hidrologi sintetik ialah satu kaedah yang berguna untuk menilai keputusan dalam pengurusan bekalan air dan rekabentuk empangan. Objektif utama kajian ini dibuat adalah untuk mengenalpasti dan menetapkan model yang terbaik dalam simulasi aliran sungai dan hujan. Kajian ini merangkumi aplikasi kaedah agregasi dan disagregasi untuk simulasi aliran sungai dan hujan. Secara amnya, aplikasi pelbagai model berkala untuk simulasi aliran sungai adalah baik. Aplikasi model-model disagregasi didapati menghasilkan pencapaian yang mencukupi dan kompetetif dengan model-model berkala. Ini dapat membuktikan transformasi tidak menjanjikan peningkatan dalam pencapaian model-model yang dipilih. Kalaan purata bergerak tertib satu (PAR (1)) merupakan pencapai yang terbaik untuk simulasi bulanan dan tahunan aliran sungai menggunakan model berkala untuk siri tanpa transformasi dan transformasi. Model Valencia dan Schaake (VLSH) ialah yang paling kuat daripada kumpulan disagregasi untuk simulasi bulanan dan tahunan aliran sungai. Simulasi untuk siri hujan bulanan dan tahunan menunjukkan model VLSH ialah pencapai yang terbaik untuk menghasilkan keputusan yang mencukupi untuk kedua-dua siri tanpa transformasi dan transformasi. Keputusan kajian ini berdasarkan pemerhatian ke atas graf-graf dan analisis frekuensi. Hasil kajian ini berpotensi untuk membantu jurutera-jurutera air dan perunding dalam membuat keputusan untuk operasi sistem sumber air. Kajian ini juga mencadangkan penggunaan simulasi hujan untuk perancangan sumber air adalah pilihan yang terbaik kerana cerapan siri aliran sungai dipengaruhi oleh gangguan akibat pembangunan.

TABLE OF CONTENTS

5 RESULTS AND DISCUSSIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

GENERAL

mm	Millimeter
km	Kilometer
m	Meter
km^2	Kilometer square
km^3	Kilometer cube
%	Percent
^oC	Degree Celsius
N	Sample size
X	Original observed series
a, b	transformation coefficients
τ	season
ν	year
μ	mean
σ	standard deviation
ω	Number of season in the year
Y	monthly flow or rainfall
Y_τ	Column matrix containing the seasonal values
Y_{t-1}	A column matrix of the previous matrix of the previous substation
ε	The current value from a completely random series (stochastic term)
$\varepsilon_{\nu,\tau}$	Matrix of an independent random variable at year ν and season τ
Q_t	Matrix of the annual/seasonal flow or rainfall value of year
χ^2	chi-square test density function

PERIODIC MODELS (AGGREGATION MODELS)

PAR	Periodic autoregressive model
PARMA	Periodic autoregressive and moving average model
A, B	Parameter matrices
Y	Monthly flow
$Y_{\nu,\tau}$	Matrix of monthly flow at year ν and season τ
$r_k(\varepsilon)$	Correlogram of the residuals
L	Maximum lag considered
σ^2	Maximum likelihood estimate of the residual variance
c	Lower bound of three parameter log normal distribution
p	is the term of periodic autoregressive parameter
q	Order of autoregressive parameter of MA model
G	Backward shift operator of PARMA models
$\rho_{k,\tau}$	Autocorrelation function
$\phi_{1,\tau}\ldots\ldots,\phi_{p,\tau}$	Seasonal autoregressive parameters
$\theta_{1,\tau}\ldots\ldots,\theta_{q,\tau}$	Seasonal moving average parameters
$\theta_\tau(G)$	Periodic polynomials

DISAGGREGATION MODELS

A, B and C	Parameter matrices
Q_ν	Annual series vector
$Q_{\nu,\tau}$	Generated annual flow/rainfall vector.
m	Rank of residuals matrix
M_o	Lag-zero correlation matrix or population moment
M^1	Lag-one correlation matrix or population moment
M^{-1}	Inverse matrix of population moment
M^T	Transpose matrix of population moment
Q	Single value and a column vector which contains an annual value
Q_t	Matrix of the annual rainfall/flow value of year
p	Order of autoregressive parameter of AR model
q	Order of autoregressive parameter of MA model

SVD	Singular Value Decomposition
VLSH	Valencia-Schaake disaggregation model
MJRS	Mejia-Rouselle disaggregation model
LANE	Lane disaggregation model
SPIGOT	Stedinger disaggregation model

LIST OF APPENDICES

APPENDIX B

APPENDIX C

APPENDIX D

APPENDIX E

APPENDIX F

CHAPTER 1

INTRODUCTION

1.1 Background

Hydrological data such as flows and rainfall are the basic information used for the design of water resources systems. Hence, the studies are needed regarding the relatively accuracy of the data required for various types of water resources planning and management. Therefore, modeling rainfall and flow series at a useful time and specified scale for different applications has been important problem in hydrology for the last 30 years (Sanso and Guenni, 1999). This situation needs one to select the most appropriate time interval of hydrological data for the design purposes because the characteristics (mostly statistical) behaviors between time interval is different to each other. Based on the literature review done by previous researchers, the overall statistical characteristics (such as standard deviation, skewness coefficient and lag-one correlation coefficient) decrease as the time interval increases. Long sequences of daily rainfall or flows are required increasingly, not only for hydrological purposes but also to provide inputs for models of crop growth, landfills, tailing dams, land disposal of liquid waste and other environmentally-sensitive projects (Buras, 1975). Rainfall and flows are generally measured at the daily time scale and this forms the basis for monthly and annual rainfall and flows series. The need for hourly data for hydrological applications, especially in flood studies, suggests the use of disaggregation model (Koutsoyannis and Onof, 2001). Meanwhile, observations taken in minutes or hours will exhibit temporal dependence will tend decrease and to be very small or non-existent of the annual scale. Beside of that, as the time interval is longer, the underlying time series becomes simpler to analyze and to model; conversely, as the sample time series is smaller, the amount of information contained in the sample is longer but the characteristics of the series become more complex and the corresponding statistical modeling are more difficult.

Lane (1980) suggested simulating the very short time period because at the short time interval weather persistence and season has an effect. Beside, Salas et al. (1980) proposed the aggregation model regarding to the basic form of the original on lower level time series. In fact, the need to preserve annual and seasonal time series properties inspired the development of simulation models (Salas, 1989; Grygier and Stedinger, 1991, Shah et al., 1996). The monthly and annual hydrological data have been used for the short and medium term planning and operation of water resource systems (Maheepala and Perera, 1996).

Despite the resolution of the time interval, the data quality and accuracy should also be taken into account. The data uncertainties and randomness that is one of the factors that stems from difficulties in estimating future demands for water developments. Shah et al. (1996) stated, there may be some situations where rainfall exhibits reasonable spatial uniformity (e.g. frontal storms over basins with gently varying topography), these tend to be the exception rather than the rule, particularly where a rainfall regime is dominated by convective storms or is subjected to pronounce orographic effects. This situation shows that by applying stochastic approach can currently provide the only effective route towards a hydrological description of rainfall in the absence of satisfactory mathematical and physical representatives of the laws governing its complexity (Stedinger and Taylor, 1982). The stochastic models of daily rainfall with annually varying parameters usually do not preserve the variance of monthly and annual precipitation (Buishand, 1977; Zucchini and Guttorp, 1991; Woolhiser et al., 1993; Boughton, 1999). This underestimation may be due to real long-term trends in rainfall, changes in the data collection techniques or in rain gauge exposure, model inadequacies, and/or the existence of large-scale atmospheric circulation patterns that do not exhibit annual periodicities (Woolhiser, 1992). Hydrology and its process must also be affected by human activities and various disruptions in nature.

Many hydrologists use the forecasting technique to design and implementations the water resources systems. The main objective of forecasting is to use the time series model fitted to a data set to obtain the most accurate estimate or prediction of the future unknown series. However, forecasting itself unable to test whether or not a class of time series models statistically preserves important historical statistics of the data sets to which the set of models is fitted (Box and Jenkins, 1976). One would quite naturally, like to employ models, which can account for the key statistical characteristics of hydrological time series. However, when a mathematical model can be employed for determining exactly of a system, the model is said to be deterministic. Deterministic models are designed and used for identifying and evaluating system performance in its uncertain environmental and it is a point of implicit stochastic models (Troch et al., 1993).

Stochastic modelings were preceded by structural analysis of temporal and spatial stochastic process such as the analysis of errors, trend types and composition, intermittency, periodicity and stochasticity (Hipel and McLeod, 1994). By considering stochastic hydrology it becomes the light of its application to simulation and optimization in water resources planning and operation. Furthermore, synthetic hydrology stays in fact the overall science of fitting stochastic models to hydrological series and using these models for simulation purposes. The goal of simulation is to employ the fitted model to generate a set of stochastically equivalent observation series, which could possibly occur in the future. Simulation or generation of samples may be very effective tool for experimentally finding the sampling frequency distributions of testing parameters and various other estimates (Yevjevich, 1989). The synthetic flow or rainfall data generation (or in short synthetic hydrology) was later suggests as the term operational hydrology would be more appropriate. It is because, synthetic hydrology can be useful in both analytical and simulation models.

However, there is nothing about approximate methods that makes better use of the limited data and most such approximate methods have been demonstrated to be highly unreliable. There are many techniques, which can be used to adopt the limited data to simulation. By careful use of simulation models, data of poor quality can be checked, missing records completed and a considerable extension of the record can be made (Hipel et al., 1977b; Koch, 1985; Grygier and Stedinger, 1991). The most critical data for simulation are the flows and rainfall series and without both series it is impossible to carry on a study by any other reasonable adequate hydrologic technique and a simulation study. It will usually take no more time to develop the necessary data for simulation than it will require developing the estimates desired. Meanwhile, one simulation of rainfall or flows runs, it will provide an abundance of data, which can answer many hydrologic problems. As an example, if one wish to explain the effect of changing vegetal cover on the watershed, of increasing the amount of urban land use, or other possible land use changes, this is easily done with simulation (Chatfield, 1979). Using conventional methods, is would be difficult, if not impossible, to estimate the effect of such changes. In any case, if time and cost are measured against the quality and completeness of the results, simulation is far ahead of the conventional technique (Hipel and McLeod, 1994). In such case, Loucks et al. (1981) stated that, the type of condensation and storage of data in the format models and estimated parameters are more useful rather than keeping the original data in master data files as is done at present with data bank storage for final backup and for verification purposes when needed.

Based on the simulation methods, the basic disaggregation and aggregation models can be used to simulate and generate both data sequences. Disaggregation models are generally considered a very variable feature for flows and rainfall simulation (Salas et al., 1980). The earliest model such as Thomas-Fiering model (Thomas and Fiering, 1962), H-C model (Harms and Campbell, 1967) and Box-Jenkins model (Box and Jenkins, 1976) seem to currently unsuitable for a fully simulation or generating use. The first well-accepted model was presented by Valencia and Schaake (1973) by developing the Valencia-Schaake technique (VLSH). Further studies, modification and applications of disaggregation model, have been made in the past year such as Mejia and Rouselle (MJRS) model (Mejia and Rouselle, 1976), Lane (LANE) model (Lane, 1980) and Grygier and Stedinger (SPIGOT) model (Grygier and Stedinger, 1991). Aggregation is a new study technique by which an assumption is made regarding the basic form of the original or lower level time series are calculated. Work also has been performed using Fourier series model (Yevjevich, 1984). In order to model adequately the seasonally varying correlation structure and to preserve the stationary statistical properties within each season, one would have to consider the families of the periodic autoregressive (PAR) model (Salas et al., 1980) or periodic autoregressive and moving average (PARMA) model (Vecchia, 1985a). The application of these models has been attractive in simulation area mainly because, the form has an intuitive type of time dependence and they are simplest models to use.

Recent development of using the alternative simulation models available led to developing many software packages. For instance well-known packages are IMSL, STATGRAPHICS, ITSM, SASS/ETS, SPSS and MATLAB. However, despite of the availability of such general-purpose programs, specialized software for simulation of hydrological time series have been attractive because of several reasons (i.e. HEC-4 (U.S ARMY Corps. of Engineer, 1971), LAST (Lane and Frevert, 1988), SPIGOT (Grygier and Stedinger, 1991) and SAMS (Salas et al., 1996)).

Based on the above-mentioned fact, this study will focus on rainfall and flows simulation based on the disaggregation procedures using VLSH model, MJRS model, LANE model and SPIGOT model. Despite of that, the aggregation models in the class of PAR and PARMA models will be used for simulation the flows sequences. Two software packages namely SAMS and SPIGOT would be used to generate the historical flows and rainfall sequences. The effectiveness of models depends on the estimation of model parameters, fitting stage and diagnostic check. The model estimated stage needs to be checked in order to verify how well it represents the historical flow and rainfall series. The evaluation of the selected models are based on the preservation of statistical characteristics such as mean, standard deviation, skewness coefficient and lag one season to season correlation coefficient. It is therefore necessary to evaluate the validity of a model before it is used for such purposes.

1.2 Statement of Problems

Rainfall and flow series are essential parameters for the water resources planning and management. However, the observed rainfall data have randomness, systematic (or inconsistency) and sampling errors based on the effects of anticipate climate change and historical flow data is due to the non-homogeneity (conceived as changes in nature by humans and natural disruptions). As this problem cannot, in general, be solved analytically, a simulation approach must be adopted in which a stochastic model of rainfall or flow is used to generate a long synthetic input series to the mathematical model; the required magnitude frequency relationship can then be estimated from the derived synthetic output series. One of the major problems in water resources design is the selection of the stochastic process to model the given flow or rainfall record. This involves using the historical rainfall and flow records to estimate the model parameters of an appropriate model, which may then be used to simulate the desired length of data series. Various types of stochastic models are available for use in engineering design, such as, aggregation and disaggregation models. For such a system, if simulation is conducted which used only the historical records as inputs data and is then used as a basis for decision. It is implied that the future history of the system will repeat the same pattern, which is hardly ever likely to be the case. Worse little idea of the risks, which will be encountered in making any decision, will be obtained. To avoid this situation, statistical models have been developed which generate synthetic records of flow or rainfall that are statistically similar to observed flow and rainfall records, that can be used in simulating the behavior of water resource systems. However, the generation of flow series required the totally undisturbed observed data sequences. In fact, this situation is quite impossible due to the above-mentioned problem. Due to this need, the rainfall simulation is carried out to overcome the possibility of the weakness in flow simulation. Despite, the simulated rainfall can be transformed to flow using the simple monthly linear rainfall-flow model and the rainfall simulation itself; will supply the synthetic rainfall data to the rainfall-runoff model. The need for the long-term planning of reservoir planning, management and design required the good model for synthetic data generation. However, to show the widespread applicability, the generated data series were evaluate from the preservation of the historical statistical properties. The study on synthetic simulation will identify the right model to preserve the historical statistical characteristics. In addition, use of the simulation techniques offers the potential benefits to solve natural processes of rainfall and flow pattern based on the statistical characteristics. In reality, the flow and rainfall processes are random and uncertain. Therefore, the stochastic time series modeling is essential to model the random component in the system.

1.3 Objectives

The objectives of this study are:

i. To propose the application of aggregation and disaggregation models in the flow simulation and the application of disaggregation model in the rainfall simulation.
ii. To investigate the performance of aggregation and disaggregation model in the flow simulation and the disaggregation model in the rainfall simulation.
iii. To identify and confirm the best model in flow and rainfall simulation.

1.4 Scope of Study

The study covers the application of aggregation and disaggregation methods for flow simulation and the disaggregation models in the rainfall simulation. The aggregation model usually called as a seasonal series model follows a periodic autoregressive (PAR) and periodic autoregressive and moving average (PARMA) models. For disaggregation model, the well-known model namely, Valencia and Schaake (VLSH), Mejia and Rouselle (MJRS), Lane (LANE) and Grygier and Stedinger (SPIGOT) models are used for flow simulation. Meanwhile, the VLSH, MJRS and LANE models are used for rainfall simulation. The data analysis methods consist of time series plots and Box-Whisker plots. The development stages are designed to decide the families of models to be considered for fitting to a flow and rainfall series. The overall methodology to fitting models consists of identification, estimation and diagnostic checking. At the identification stage the most suitable models to fit to the data can be selected by examining various types of graphs. If a transformation is required but this fact is not discovered at the identification stage, the need for a data transformation will probably detected at the diagnostic check of model development when properties of the residuals are examined. The data will be transformed using either Box-Cox; Logarithmic or Power transformation. Efficient estimates of the model parameters can be obtained at the estimation stage by employing the method of moments. Following this, the fitted models can be checked for possible inadequacies. The diagnostic checks were employed to ensure that the selected model adequately describes the flow and rainfall series under consideration by subjecting the model to a range of statistical tests. The results of generating monthly sequences will be investigated and compared the historical mean, standard deviation, lag one correlation coefficient and skewness coefficient to identify the best model. The best model is identified based on the model ability to preserve the statistical properties. The flow and rainfall gauging stations are based on four state namely; Negeri Sembilan, Melaka, Selangor and Johor. Despite of this, river basin and catchment area under studies are: Sg. Linggi basin, Sg. Triang basin, Sg. Muar basin, Sg. Selangor basin, Sg. Bernam basin, Sg. Melaka catchment and Sg. Johor basin. Four rainfall stations are under studies which two of them in the Sg. Selangor catchment area and the others in Sg. Melaka catchment and Sg. Segamat catchment. The duration of the monthly records range from less than 20 years to more than 40 years for some stations.

1.5 The Importance of Study

The need for monthly and annual data for hydrological applications, especially in flood studies, suggests the use of aggregation and disaggretion model to use the available data information. In this way, the model would provide a continuous simulation tool for use for simulation studies and design. This study will present an improved aggregation and disaggregation method for generation of alternative sequences of monthly and annual hydrologic data sequences. This study also proposed the significant advantage over the current models for such studies. The proposed model is therefore a valuable tool for flow and rainfall simulation studies, which abound Malaysia. Using the synthetic data then provides a broad base for development of proper water resources planning and management. The results of this study also provide a new tool for keeping the data in the form of models and estimated parameters rather than in original data.

1.6 Research Hypothesis

To achieve the goal the following hypothesis have been made;

i. The applications of the VLSH model yield a better performance than the widely used disaggregation models for flow and rainfall simulation.
ii. The modeling of periodic series is more complex than modeling the annual series because the former have the influence of the annual cycle which produces the periodic variations in some or all of the statistical characteristics of the series.
iii. The preservation of historical statistical characteristics of rainfall simulation yields a better performance than flow simulation.
iv. The transformation of rainfall and flow series to normal distribution does guarantee the best results in the rainfall and flow simulation.

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