論文の内容の要旨

Thesis summary

論文題目 Title of Dissertation	Study on Early Forecasting of Flood through Historical Hydrologic Data Analysis and Numerical Simulation in Kelantan Watershed, Malaysia.（歴年水文データ解析と数値シミュレーションによるマレーシア・ケランタン川流域の早期洪水予測に関する研究）

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In Malaysia, flood is the most serious natural disaster in terms of frequency, areal extent and the number of population affected. The east coast of Peninsular Malaysia, northern part of Sabah and southern part of Sarawak experience heavy floods/inundations almost every year during the north east monsoon season from November to January.

The Kelantan river watershed, located in the north east of Peninsular Malaysia, is one of the biggest watershed with over 12,000 km^2, and has been damaged seriously by monsoon floods/inundations in many places along the river and its tributaries in midstream to downstream areas. Thus, constructing a reliable system for early warning and evacuation, as well as making countermeasures for reducing the magnitude of damages, is a crucial requirement here.

To address this problem, the author took three main steps; 1) historical data collection and consistency/trend check, 2) development of observation-based statistical models to predict the water level at downstream point from the data of upstream multiple gauge points, 3) construction of physically based, distributed numerical model and determination method of rainfall distribution. Followings are the contents and major results covered in this thesis.

1) <u>Collection of Historical observation data, consistency check and trend analysis</u>

   - The historical rainfall data at distributed gauge stations from 1948 through 2013 were collected. They were arranged and stored with continuous time stamps in the data base together with water level observations and other hydrologic data. To provide a reliable database for further hydrologic analyses, the quality of long-term records were checked by using four statistical homogeneity tests.

- It was found that among fifty rainfall stations within the river basin, nine were flagged as suspect or doubtful by the absolute homogeneity tests. Of these, time-series data from four stations were finally determined as inhomogeneous, then omitted from further analysis.
- For finding out the trends of rainfall in long and short periods, three types of Mann-Kendall Test (MK) were devised. The Mann-Kendall (MK) test using 30-year sampling period showed decreasing rainfall trend in the first half 30 years (1957-1987) and increasing trend in the latter (1981-2011). The MK test using 10-year sampling period successfully extracted very definite trend from the fluctuating observation data. It showed clearly the turning points of the amount of rainfall which corresponded to the historical cycles of El Nino and La Nina. The effect of both cycles was different for upstream inland area and downstream area near coast of South China Sea.
- By extending the MK test of 10-year sampling plot, it was predicted that a slow decrease in La Niña until 2015 in inland areas might occur, whereas rainfall might remain high in downstream areas until 2015, and decrease toward low rainfall years and next strong El Niño event might come around 2020.

2) <u>Observation-based statistical model for early flood prediction.</u>

- To realize quick and reliable early flood prediction, two statistical models that estimate the water level at downstream forecasting point was developed based on the information of upstream gauge stations. Unlike ARMA or any other statistical linear runoff models that use time-series data of forecasting point itself, the first model developed here depends on mainly the information coming to the forecasting point from various upstream gauge stations in hourly scale, while in the second model, most recent observed data at forecasting point was considered to improve predictability.
- The basic form of model consists of a linear combination of the time-series data of multiple upstream stations considering the time lags and its ranges for respective stations. Cross-correlation analyses were conducted to find suitable time lags and lag ranges for respective pairs of gauge stations through monsoon season of the year. In determining coefficients of the linear system, the least square method was used for the summated data sampled over the period from the beginning of monsoon season in November to the end in next January.
- The method was applied for the prediction of water level at Kuala Krai (C) using the observed data at two upstream stations, Galas (A) and Lebir (B), while for the prediction of water level at Guillemard Bridge (D), upstream data at A, B and C were used. It was found that a combination of station A with

average delay time of 5 hours and station B of 4 hours gave more reliable results than using a single station. Similarly, at station D, the case by utilizing all upstream point A (14 hours), B (10 hours) and C (6 hours) provided higher predictability. In most of the cases, the water level predicted from the model has the Absolute Mean Error (MAE) within 1 m from the starting time of flood up to the peak of flood event. However, the predictability of the model deteriorates when the downstream area received rainfall earlier than the upstream area.

- To improve the predictability, the second model included the most recent observation data at forecasting station. It successfully attained good prediction up to 3 hours and 5 hours for station C and D, respectively, with MAE of 0.3 meter for all events in year 2011, 2013 and 2014. This improved method could produce a continuous reliable prediction by updating the A coefficient hourly assuming the upstream telemetry data is updated in monitoring system.

3) <u>Numerical-based approach for early flood prediction.</u>

- A basic 3-D numerical model for the Kelantan watershed was constructed using topographic data (SRTM 90m resolution), river network and land-use information. Two-stage initialization was done to make initial distribution of pressure and surface/subsurface water saturation by setting the sensitive parameters such as permeability, porosity, surface manning's roughness factor, etc. Basic performance of the model was checked by comparing with observed flow rate at Guillemard Bridge.
- Detailed investigation on grid-wise rainfall distribution on daily basis was conducted by using the Inverse Distance Weight (IDW) family methods. It was found that the simplest IDW method was appropriate for the vast Kelantan watershed since the differences among the family methods were insignificant in terms of cumulative amounts and the performances of hydrographs obtained by the numerical simulator under the same simple condition neglecting unclear canopy interception and evapotranspiration effects.
- Considering the necessity of quick timely estimation of rainfall distribution for the numerical prediction, reliability of the estimated distribution by using only telemetry stations sparsely distributed in the watershed was discussed. It was found that the same IDW parameter used for the case of all available stations could be applied to telemetry-based estimation, and difference between two distributions was not significant in terms of cumulative amount over watershed. The simulated hydrographs using two

distributions for year 2010 to 2013 gave relatively small difference and it was concluded that telemetry-based estimation might work for the early prediction purpose by the numerical model.

– The numerical model was run for checking data adaptability using basic parameters and estimated rainfall distributions for years 2007-2013 on daily scale. Simulation results showed that calculated hydrographs were generally in good agreement with the observed flow rate during high peak in monsoon, while they showed significant difference from the observed during low-flood season. Results of trial runs considering evapotranspiration effect gave the difference much smaller. It suggested that in tuning model parameters to attain good matching in the future, the hydrologic treatment of canopy interception, evapotranspiration, as well as basic hydraulic parameters should be properly assembled.

The author expects the discussions and the developed models in this thesis could contribute to practical prediction of flooding. The trend analysis might provide information about regional meteorological background to be considered in administrative policy. The proposed observation-based model might be introduced easily into practical use, and the numerical model, if satisfactory calibration is done, will provide us information what flow is occurring in the surface and subsurface of the whole watershed and help us planning countermeasures to minimize flood/inundation damages in this watershed.