Integration of RS, GIS and MIKE 11 Hydrodynamic Modeling for Flood Early Warning: A case study of the Langat river basin Malaysia

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Abstract:

Floods are considered the most significant natural disaster affecting Malaysia from the perspective of their frequency, financial cost and most importantly the impact on the population and the disruption to socio-economic activities. Since it is evidently clear that it is neither possible nor desirable to control floods completely, the state of preparedness and mitigation should be improved with a operational flood early warn system. This paper investigates flood early warning system development for Langat river basin through the coupling of remote sensing for quantitative precipitation forecasting (QPF) and GIS hydrodynamic modeling. Real-time NOAA-AVHRR data is processed for rainfall estimates using cloud indexing and model base techniques. Digital hydrological and cadastral data are used to generate DEM and river geometry in ArcView GIS and MIKE 11 hydrodynamic model for the operational hydraulic modeling of runoff and simulation of flooding scenarios. Expected flood inundation area map are developed.

Keywords: Remote sensing; GIS; QPF; DEM; Runoff simulation; Flood inundation maps; Malaysia

1.Introduction

The basic cause of flooding in Malaysia is the incidence of heavy monsoon rainfall and the resultant large concentration of run-off, which exceeds river systems (Ho, 2002). Rapid urbanization within river catchments in recent years have also served to compound the problem with higher run-off and deteriorated river capacity that have resulted in increased flood frequency and magnitude. Various flood forecasting and warning system based on an advanced hydraulic model has been applied in Malaysia, but they proved inadequate for their inability to predict impending floods thus, they have had limited effect in reducing costs and damage to life and property due to flood.

Over the years various flood forecasting and warning system based on an advanced hydraulic model has been applied in Malaysia. However, the systems have been limited to the forecasting of water levels in the major rivers and thus have proved inadequate for flood early warning due to their inability to predict impending floods. Moreover the practical limitations of rain gauges for measuring mean rainfall over large areas and sometimes-inaccessible areas are becoming apparent. Hydrologist are thus increasingly turning to remote sensing as a possible means for quantifying the expected precipitation as input in to hydrological models, particularly in areas in of few surface gages.

2. Methods and Materials

The Langat river basin catchment area is about 1, 988 km^2 (Fig1). The average annual rainfall depth is approximately 2,400 mm ranging from 1,800 to 3,000 mm. The highest rainfall occurs in the month of April and November with a mean of 280 mm. The lowest rainfall occurs in the month of June with a mean of 115 mm. The wet seasons occur in the transitional periods of the monsoons, from March to April and from October to November.

In this study near real-time NOAA-AVHRR data received at our local ground station are processed for quantitative precipitation estimates using cloud based modeling techniques. Precipitation estimates are then applied rainfall as input to a hydrological oriented GIS based on an integrated MIKE 11 hydrodynamic simulation model and ArcView GIS for pre flood “Nowcast”. The framework of the operational coupling of quantitative precipitation forecasting (QPF) with Mike 11 hydrodynamic oriented GIS in the bid to implement a fully automated simulation and early warning system is illustrated in figure 2.

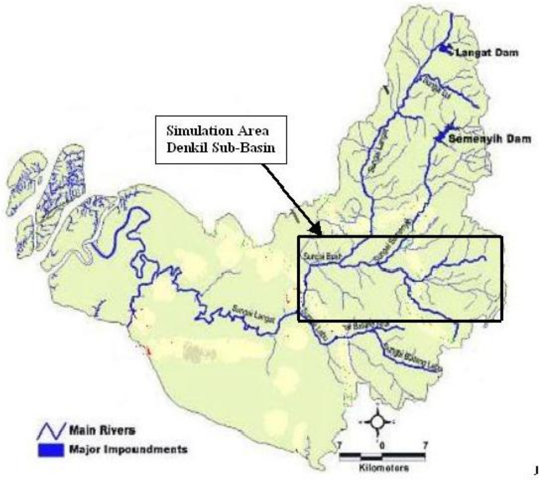


Fig1. Langat river basin and Dekil simulation area

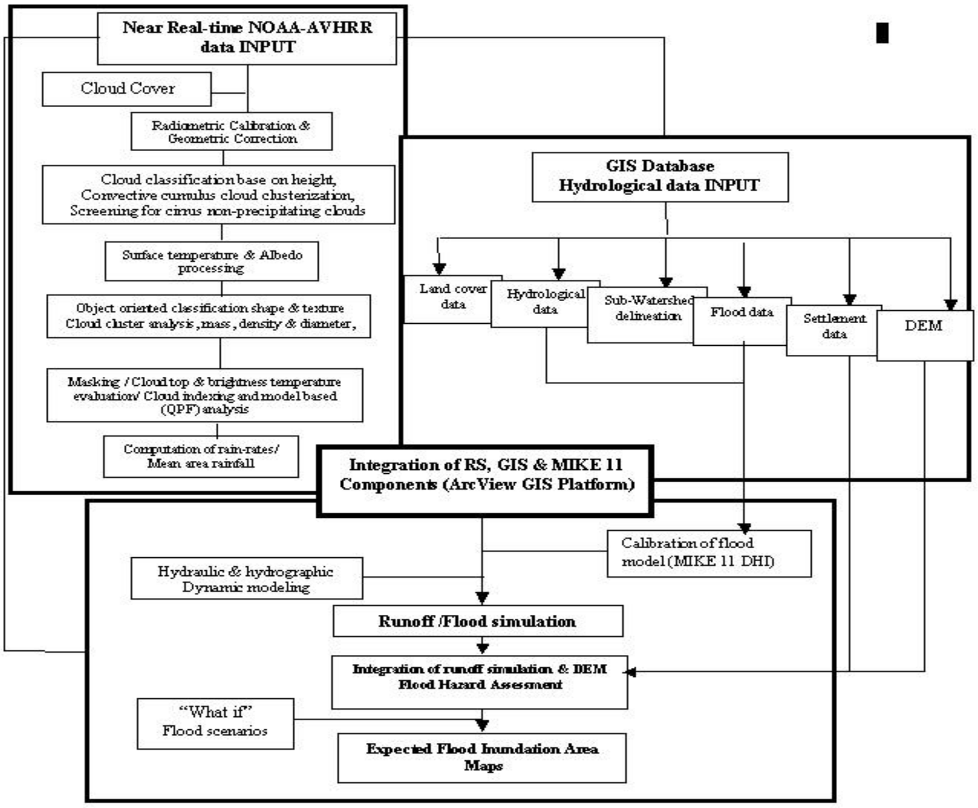


Fig 2. Frame -work of the flood early warning system

In the first part of the study (Fig 2) NOAA-AVHRR data are processed for QPF although it has moderately low spatial resolution of 1.1km but its repeated temporal resolution of about 6 hr daily, provides the near real-time data required for the precipitation estimate. NOAA-12 local area coverage (LAC) data is acquired for November 20, 2003 in monsoon season, as this period provides a better understanding into rain baring clouds. Bi-spectral techniques based on the relationship between cold and brightness temperature of clouds are used to evaluate precipitation probability.

Cloud model-based and cloud-indexing technique are used for the estimate of precipitation. Cloud model-base technique is a one dimensional cloud model that relates cloud temperature to rain-rate and rain area in convective stratiform technique (CST). Details this model can be found in (Gruber, (1973), Anagnostou et al., (1999), Reudenbach et al., (2001), Bendix, (1997, 2002)). The formulate for the model is where Slope S is calculated for each temperature minimum T_{min}. Parameters defined as:

$S = T_{1\text{-}6} - T_{min}$, T_{min} is Ave Temp of six closest pixels.

The rain area (A_r) is assumed to be five times the model up

$A_r = 5\pi r^2$, $R_{mean} = VRR/A_r$,, $R_{mean} = 74.89\text{-}0.266T_c$, $A_r = \exp(15.27\text{-}0.0465T_c)$

The second part of the study involves the compilation of hydrological data to develop a GIS database on ArcVeiw GIS platform. The variously defined hydrological data are as listed in the illustration of figure 2. The GIS provides the essentials for digital elevation model (DEM), river and floodplain surface geometry. It also provides the tools for visual interpretation and evaluation of flood distribution and inundation maps. The MIKE 11 hydrodynamic model combines advance time series simulation and automated water level discharge and rainfall-runoff process. MIKE 11 is calibrated based on expect pre-flood rainfall data compute from the QPF and also historical time series of available hydrological data of rainfall. Rainfall runoff is computed based on the NAM distributed model.

3. Results and Discussion

The NIR and IR channels 3, 4, and 5 of the data were processed for temperature and brightness. In an infrared (IR) image cold clouds are high clouds, so the colors typically highlight the colder regions Mid height clouds with T_B below 235k were identified as cumulonimbus cloud with a high probability to precipitate. Lower probabilities were associated to warm but bright stratus cloud and thin cirrus cloud that were cold but dull. Rainfall is estimated based on the assumption that every cloud pixel has a constant unit rain-rate of $3mm^{h-1}$, which is appropriate for tropical precipitation over 2.5^{o} x 2.5^{o} areas around the equator.

The study area shows warm but bright non-precipitating stratus cloud. Object orient classification technique is use for cloud classification based on cloud type, probability to precipitate and height, figure 3 shows various cloud type identified on the AVHRR data**.** Although the coarse resolution of 1.1km of AVHRR data did not allow for high-level classification, the object orient classification proved effective for the cloud type identification due to the input of shape, texture and spectral information in the classification process through the multi dimensional input object functions. The processing for QPF is still preliminary and thus results are indicative and were not used for this study's hydrodynamic simulation.

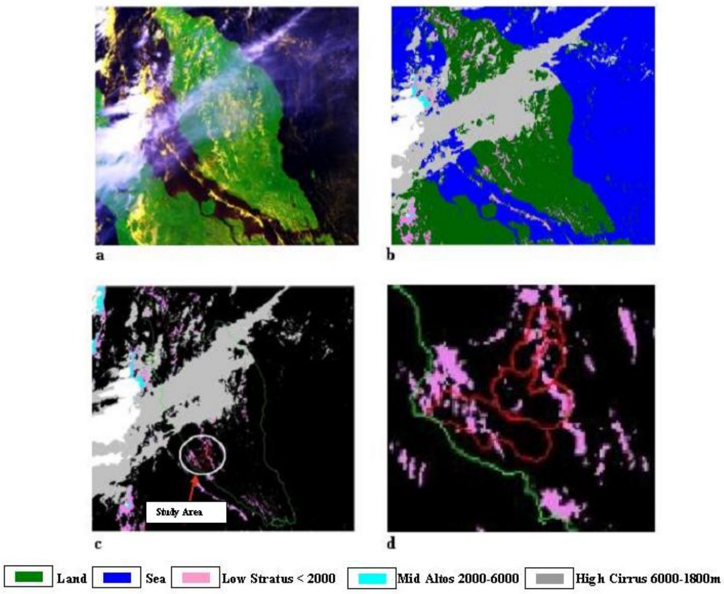


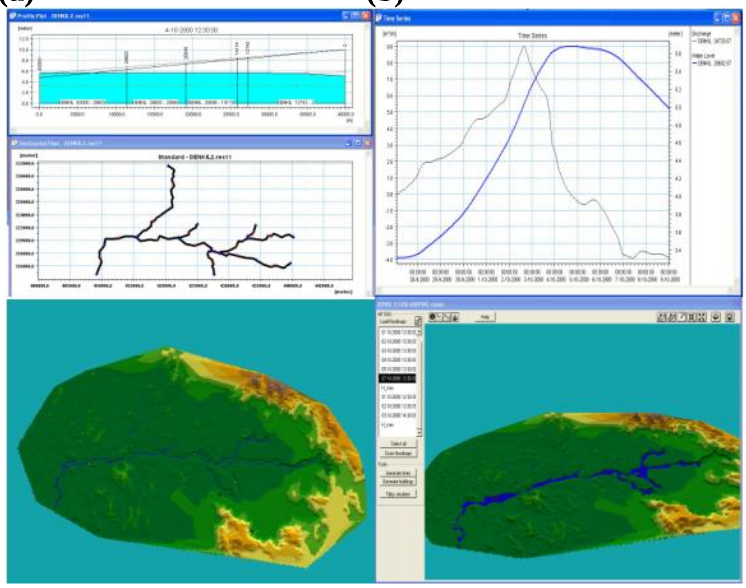
Fig 3 Cloud Type Identification and Classification

The Langat river basin is divided into sub-basins to enable an easy computation of runoff for each watershed. Hydrodynamic simulation is performed for the Denkil sub-basin of Langat for the for the flood record of the monsoon 2000. The simulation period is 12 day from Sept 27 to Oct 8, this period saw high level of water in the Denkil branch of Langat river causing floods. A simulation profile of water level is shown on Fig 4 (a) with water level exceeding river capacity at the left end of the profile. Fig 4 (b) shows the unit time series graph for discharge and water level for this period.

The processing of data for simulation in MIKE 11 hydrodynamic module involves preparation of network, cross section hydrodynamic and boundary parameters. The hourly data rainfall, water level and flow are created into compatible MIKE 11 time series in a separate file as input the for parameter editors. The results of the simulation were called to the integrated ArcView GIS 3.2 for the development and generation flood inundation maps.

In the ArcView GIS digital elevation model (DEM) is developed for Denkil sub-basin of Langat (Fig 4c). The integrated MIKE 11 GIS provides tools thorough channel and surface geometry modeling that includes embankment and floodplain. The DEM module was variously applied to prepare denkil catchment area, after which the MIKE 11 simulation results and network branches were imported and prepared for flood modeling. The Flood Management (FM) module in the MIKE 11 GIS was to process simulation result and generate flood inundation Map (Fig. 4d). An evaluation of the inundation map result showed significant similarity with flood extent of 2000 that was the simulation period.

(a) **(b)**



(c) **(d)**

Fig. 4 Dekil river simulation, DEM & Flood inundation Map

4. Conclusion

The operational coupling of remote sensing techniques with a 'hydrologically oriented' Geographical Information System is done with particular emphasis on the suitability of distributed hydrological modeling for the implementation of reliable and fully automated flood simulations and early warning. In this study the steps for the development of advance flood early warning and forecasting for the Langat basin were discussed. Remote sensing techniques are explored for QPF using near real-time AVHRR data. An integrated MIKE 11 hydrodynamic model and ArcView GIS are used for runoff and water level simulation and hydrological data process to generated flood inundation maps. The processing QPF is preliminary thus results are indicative requiring further investigation. The integrated MIKE11 GIS aimed at early warning and flood mitigation were however very positive as result of the flood map show.

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