Evaluation of Urbanization Impact by Using Distributed Runoff Model in Dense Building Area

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論文内容要旨

This study was aimed to develop distributed runoff model for flood simulation in order to evaluate the effect of urbanization in area with dense building density. Considering physical processes, the developed model covered upstream and downstream condition of a river basin by combining both hydrology and hydraulic aspects. Ciliwung River basin, located in West Java, Indonesia, was selected as study area for this study. This basin was chosen because it flows into central of Jakarta, capital city of Indonesia, which is the important part of the city where the area of government, business and commercial is located. Ciliwung River basin is also known as the biggest among the other rivers that flow through the Jakarta city. Furthermore, the occurrence of flood in Jakarta is always related to this river, especially in the upper part due to uncontrolled changes of land cover to urban area. Nevertheless, the lack of datasets which is the problem that often arises in developing countries, including in this study area, was also found. The developed model should consider this circumstance so that it would be applicable to the case study. Thus, in this study, several new methods and approaches were proposed mainly to deal with availability of datasets in case study.

The developed model used governing equation based on Saint Venant equations to simulate either surface runoff for overland flow or river flow in the channel while hydrologic parameters are simulated based on nearly calibration free (NCF) tank model which has been widely used in many countries for flood modeling. The NCF tank model governed hydrology processes which covered precipitation, interception, and infiltration including sub surface flow. Infiltration in urban area which is often neglected is accommodated by introducing infiltration coefficient in corresponding equation in NCF tank model to define ratio of permeable area in urban land cover. This coefficient determines the loss of water in urban area. Overall,

NCF tank model provided the amount of surface water which will be used as the outsource term in the run off model. Channel model and overland flow model were coupled for urban flood necessity by using flow exchange which enables movement of overflow water either from surface to river or river to surface. The method required that for each cell of overland flow, there is only one river node. The flow exchange direction is managed by the water level in the node and at the corresponding overland flow cell. The hydrology process will contribute to the overland flow model. The calculated hydrology balance will provide the amount of water flowing as overland flow. This amount is treated as the outsource term in the continuity equation.

Spatial distribution data is important for flood modeling, particularly in distributed model which requires adequate temporal and spatial variability of input parameters to represent the real condition of flood event and to achieve good accuracy in simulation result because distributed model is developed to seize each small grid-scale of every related-parameter. Nevertheless, as it has been explained earlier, data availability does not always comply with this requirements, especially in the case where the study area is situated in developing countries. Satellite images may provide information that is useful in assessing spatial distribution of the parameters. In this study, SRTM data was used to assess topography condition of the upstream catchment. Although its resolution (DEM 90) are not very high, nevertheless, it is adequate and appropriate for discharge production modeling where there is no necessities to accurately predict urban area (up to building scale in details). On the other hand, the downstream catchment inundations map reproduction for dense building area which requires higher resolution data used the map obtained from government agency.

In the case of Ciliwung River basin, as in other developing country, it also has important issue related to lack of rainfall datasets which may become a problem when simulating distributed flood model. Rainfall datasets are available from 11 observation stations. Hourly resolution is only available in 3 stations. It is possible to produce good rainfall distribution for daily resolution, based on the data availability. However, distributed flood model usually requires spatial distribution of rainfall in hourly resolution. For this reason, a method is developed in order to assess spatial hourly rainfall distribution by maintaining the daily rainfall distribution. Basically, this method is based on simple linear interpolation where the value of hourly rainfall data in a grid is estimated by using the 2 nearest hourly rainfall station of the grid considering hourly rainfall deviation from daily average. In order to maintain the daily rainfall distribution, the daily distribution from the estimated hourly rainfall must be equal to daily distribution obtained from measurement data. This comparison might not prove the correctness of the estimation of hourly rainfall; however, it gives us the best way to estimate the hourly rainfall distribution from the existing data.

Landcover data which is necessary for evaluation of urbanization impact was obtained from Center for Regional System Analysis, Planning, and Development Indonesia for the year of 1972, 1996 and 2002. The data was derived from satellite images, and was further processed by the issuance agency. The obtained data was clustered and classified further in this study in to 4 classes. They are water, urban, forest and cultivated area. Each category will be treated and given the appropriate parameter values accordingly, depending on the approach. Urban area analysis for upstream catchment used this data since there was not more detail data regarding the building information. Spatial distributed urban density factor is applied to accommodate the physical based process for infiltration in urban area. This factor is defined as the ratio of urban land cover area in a district, to the district area itself. The value will give a spatial physical interpretation of the infiltration process in a district scale, based on the possible permeable area in the corresponding urban class landcover. District scale was chosen based on urbanization centralized pattern in the study area and the resolution of the landcover class. The urban density factor, furthermore, is used to adjust the value of infiltration coefficient in urban area. However, for downstream catchment, a higher resolution map with building lay out information was available. Therefore urban area analysis can be adjusted directly by adjusting amount of building in urban area landcover which will determine the infiltration coefficient in the NCF tank model.

The flood discharge from the upper catchment was simulated by based on investigation of spatial distributed parameter. Since the building was not assessed in detail in this part of the modeling, thus, their effect on hydraulic process is given by high roughness value which gives interpretation of the dense populated area as obstacle when compare to the grid size. The simulations were conducted in two conditions, using spatial distributed parameter and fixed value. The model was calibrated using daily rainfall event in 2002. Calibrated parameters were used in advance for validation processes, using flood event in 1996 and 2002. The model performance is rated with NSI index. The spatial distributed parameters have increased the model accuracy. The use of spatial distributed parameter increases the NSI value in both flood events, NSI for 2002 flood event increases to 0.91 from 0.86. NSI for 1996 flood event increases to 0.93 from 0.8. The landcover change effect was further investigated by re-simulating the events with different landcover condition. The model was applied in two flood events, 1996 and 2002. Each event was simulated under two conditions, the 1996 land cover and 2002 land cover. Simulation results showed that the flood discharge is reduced when simulated with older landcover. Water balance analysis showed that in the study area, the flood discharge reduction mainly came from the interception rate from tree canopies. Furthermore, urbanization causes lower infiltration rate which contributes to the discharge intensification. This was confirmed by the amount of water in the soil storage at the end of simulation, with the higher amount was given by older landcover. As a resume, urbanization in the study area reduces the amount of interception and soil storage, moreover, higher surface water volume is observed in simulation with more recent land cover.

The model was further applied to inundation analysis in the downstream catchment. The model was further applied to inundation analysis in the downstream catchment. As it has been mentioned in the previous paragraph, more detail map with building information is available obtained from government agency for the year of 2002. This made more detail processing possible particularly to include the buildings effect. Nevertheless, a high resolution model will consume the computation time. There are several common methods to add the effect of building in urban flood, such as using a high Manning value to represent blocking effect of building. However, the method does not accurately represent the physical interpretation of the building. Inundation flow will receive drag force from the wall of the building instead of higher bed roughness value. Thus, this study provides an approach to accommodate the physical representation of buildings without having to use a high resolution model. The concept was based on similar manner to the urban density. Building share rate was proposed, which is defines as the ratio of building area to the grid area. Building share rate will have effect on the momentum equation by introducing drag force. Therefore, physical representation of each building in a grid is accommodated. Inundation maps were reproduced for the flood of 2002. The results showed good comparison to water level and the outlet discharge with NSI value of 0.75. It also succeeded to provide reasonable match to the inundation area from measurements. The effect of flood intensification was investigated by simulating the flood event with different upstream discharge. The inundation map was recreated for the case of 2002 flood but with 1996 and 1972 landcover upstream discharge. The simulation results show that levees breaches still occurs even in the 1972 discharge although the inundation area has significantly decrease. Overall, the flood in the study area is attributed to the upstream discharge increment. The tropical forest area contributes to the flood reduction quiet significantly. Furthermore, there were several areas in the city that suffer from flood due to local rainfall. This indicates the lack of drainage system management within the area itself. It is suggested in the future study to analyze this local area separately in details to found the core problems for each area accordingly.

論文審査結果の要旨

近年，上流域の森林伐採や，市街地の家屋密集により，洪水の浸水被害が増してきている．特に発展途上国においては，降雨や河川流量の観測が少なく実態解明が遅れており，都市化の規制等の対策が後手に回ることが多い．本研究は，森林伐採や家屋密集などの土地利用の変化が洪水流出におよぼす影響を定量的に反映できる流出モデルの技術開発を行い，都市化の影響評価を行なったものである．

第１章は，序論であり，研究の背景と目的を述べている．

第２章は，文献調査であり，既往の研究を調査して問題点を総括している．土地利用変化の影響を調べるためには，分布型の流出モデルが不可欠なこと，都市域では家屋と水路の効率的なモデル化が不可欠なことなど，技術開発の方向性を明確にした．

第３章は，研究対象としたインドネシアの首都ジャカルタを流れる Chiliwung 川流域の特徴と，そこで入手可能なデータについて述べている．

第４章は，降雨の空間分布について述べている．この流域では，日雨量の観測点は多いが、流出解析に必要な時間雨量の観測点が少ない．このため，流域の全ての降雨観測データを満足する簡潔な時間雨量の空間補間を開発した．これは，観測データが限られた流域での流出解析に道を拓くものである．

第５章は，流出モデルと浸水モデルの詳細を述べている．降雨の樹冠遮断，地表での浸透，地下の貯留を的確にモデル化し，分布量として扱うことにより，森林伐採の影響を簡単に定量化できるモデルを構築している．また都市域では，水路の影響を空間１次元モデルと２次元モデルの結合により表現し，家屋の流水抵抗を計算格子内で均一化する定式化を行っている．これにより格子寸法が計算精度に与える影響を小さくしている．これらの技術は，同定すべきパラメータの数を最小化し，計算負荷を軽減する画期的な技術である．

第６章は，上記モデルを適用し同定と検定を行なった．降雨や土地利用データを空間分布量として扱うことにより，誤差が大幅に減少すること、都市域での浸水予測モデルでは，水理実験の結果と比較して精度が高く，また現地調査結果とも整合することを示した．これらの成果は，簡易，汎用，高精度の特性を有し，高い実用性を示したものである．

第７章では，土地利用変化の影響評価を行ない，近年の高い洪水流出ピークが森林伐採により増幅されたものであることを明らかにした．これは洪水対策を進める上で極めて有用な知見である．

第８章は結論である．

以上本研究は，簡易で，高精度，汎用性の高い洪水予測技術を開発し，災害軽減の方向性を示したもので，土木工学の発展に多大な貢献している．

よって，本論文は博士(工学)の学位論文として合格と認める．