UNIVERSITI PUTRA MALAYSIA

A METHODOLOGY FOR ASSESSING THE IMPACT OF LANDUSE CHANGES ON WATERSHED RUNOFF

MUSTAFA YOUSIF MOHAMED.

A METHODOLOGY FOR ASSESSING THE IMPACT OF LANDUSE CHANGES ON WATERSHED RUNOFF

By

MUSTAFA YOUSIF MOHAMED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

January 2006

DEDICATION

This work is dedicated to my family members who are always giving me encouragement and support

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

A METHODOLOGY FOR ASSESSING THE IMPACT OF LANDUSE CHANGES ON WATERSHED RUNOFF

By

MUSTAFA YOUSIF MOHAMED

January 2006

Chairman: **Professor Ir. Mohd Amin Mohd Soom, PhD**

Faculty: **Engineering**

With rapid land development and limited water resources, good quality water becomes an important commodity that every economic sector is competing for. Landuse changes in a watershed can affect the watershed hydrology in various ways. Some types of land development can be associated with increased impervious area causing increase in surface runoff and decrease in ground water recharge. Both of these processes can have large-scale ramifications through time. Increased runoff results in higher flows during rainfall events, which in turn increases the number of times that a river floods the adjacent land areas. Likewise, this increase in runoff and channel flows can drastically increase the erosion of river channel beds and banks, potentially destabilizing bridges or local structures. On the other hand the groundwater recharge decreased due to the increase in the impervious surfaces and decrease in the soil infiltration rate. This may leads to rescission in the river base flow especially during the dry season. Since rainfed agriculture in Malaysia may not have reservoirs for irrigation water supply, it is very important to maintain high base flows so that enough water is available for irrigation during the dry season. Understanding how the landuse change influences the river basin hydrology may

enable planners to formulate policies to minimize the undesirable effects of land development. The main objective of this study was to develop a methodology to assess the impacts of landuse changes on the watershed runoff. The need for spatial and temporal land-cover change detection over a larger scale makes satellite imagery the most cost effective, efficient and reliable source of data. The applicability of GIS makes it an important and efficient tool for spatial hydrologic modeling. In this study Satellite images and GIS were integrated with a developed spatial hydrological model to evaluate the impacts of land development in the Upper Bernam River Basin of Malaysia. The Bernam River is the main source of irrigation water for a rice granary area. A methodology to assess the hydrological impacts due to landuse modifications was developed using a physically based hydrological model and a mathematical model. While conceptual or physically based models are important in understanding hydrological processes, there are many practical situations where the main concern is with making accurate predictions at specific locations. The well-established HEC-1 model was calibrated and used to simulate the runoff process. Runoff hydrographs were generated for wet and dry seasons using lumped and distributed modeling concepts. In the distributed modeling approach, hydrographs from each sub basin was routed to the outlet point using the Muskingum routing method. Artificial Neural Network (ANN) model was developed because it has the ability to extract the non-linear relation between the inputs and outputs of a process, without the physics being explicitly provided to them, this makes the simulation process more applicable. The models were tested and validated using data collected from the study area. The models performances were checked using both graphical and statistical analysis. Mean absolute errors (MAE), mean square error (MSE), root mean square error (RMSE), Theil's coefficient, coefficient of determination (R^2),

coefficient of efficiency (E), T-test and regression analysis were used as evaluation criteria for model performance. The models show good performance in simulating the runoff process. Results from the hydrological model gave 0.79, 1.35, 0.22, 0.91 and 0.67 for MAE, MSE, U, R^2 and E, respectively. The weighted curve number (CN) was found to have increased by 2% in year 2001 compared to 1989, and had caused an increase in peak flow by 7%. The effect of change in CN is more on the rising limb of the hydrograph and peak runoff than on the falling limb. As CN increases the rising limb shifted backwards. For the ANN model, it was found that correlation coefficients between simulated and observed flow are 0.94 and 0.89 for the training and testing phases, respectively. The model outputs were within the confidence level of 95 %, and most of the scatter output values were within 15 % deviation bands. The statistical evaluation during the training phase gave the values of 0.001, 4.77, 0.06 and 0.87 for MAE, MSE, U and E, respectively, and these values were found to be 17.6, 5.6, 0.11, and 0.58 for the testing phase, respectively. For both models applications, it was found that the percentage change in runoff due to landuse change is constant for different landuse, irrespective of the rainfall pattern and time of occurrence. The models were then applied to simulate the runoff from future land development for the year 2020 and from different landuse scenarios. Predictions from the hydrological model show that an increase in weighted CN by 7 % and 13 % for the wet and dry seasons, respectively, will cause an increase in flow volume by 53 % and 62 % and increase in peak flow by 80 % and 76 % for the wet and dry seasons, respectively. This methodology can be applied for any future development plans to predict the hydrological impacts to mitigate the risk of floods occurrence and avoid the shortage of irrigation water. The methodology can be used as a decision making tool when formulating landuse policies. It can be a practical

tool for hydrologists, engineers and town and country planners. The irrigation engineers can use this tool during the planning for irrigation water supply and determination of future cultivable areas based on the availability of the irrigation water due to the land development.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SATU KAEDAH UNTUK MENTAKSIR IMPAK PERUBAHAN GUNATANAH KE ATAS AIR LARIAN LEMBANGAN

Oleh

MUSTAFA YOUSIF MOHAMED

Januari 2006

Pengerusi: **Profesor Ir. Mohd Amin Mohd Soom, PhD**

Fakulti: **Kejuruteraan**

Dengan pembangunan tanah yang pesat dan sumber air yang terhad, air yang berkualiti baik menjadi komoditi penting bagi setiap sektor ekonomi. Perubahan kegunaan tanah di kawasan tadahan memberi kesan ke atas hidrologi kawasan tadahan dalam pelbagai cara. Beberapa jenis pembangunan tanah boleh dikaitkan dengan peningkatan kawasan lapisan penahan yang menyebabkan peningkatan air larian permukaan dan mengurangkan pengisian semula air bumi. Kedua-dua proses ini boleh mengakibatkan kemusnahan besar akhirnya. Hasil peningkatan air larian bagi aliran yang lebih besar semasa kejadian hujan sebaliknya meningkat kekerapan sungai akan membanjiri kawasan berhampiran. Sama dengan peningkatan air larian, aliran laju yang menghakis tebing mengakibatkan rutuhan tebing sungai yang berpotensi merosakkan jambatan atau binaan setempat. Dalam kata lain, pengisian semula air bumi merosot kerana peningkatan lapisan penahan permukaan dan mengurangkan kadar susupan tanah. Ini mungkin membawa kepada rosotan aliran asas sungai terutama semasa musim kering. Di kawasan jelapang padi yang tidak disediakan dengan empangan bagi membekal air pengairan, adalah amat penting bagi menjaga aliran asas tapak yang tinggi supaya bekalan air yang cukup dapat

disediakan bagi pengairan di musim kering. Kefahaman kesan perubahan kegunaan tanah ke atas hidrologi lembangan sungai adalah penting bagi para perancang dasar supaya mereka dapat mengurangkan kesan negatif pembangunan tanah. Tujuan utama kajian ini adalah untuk membangunkan kaedah anggaran kesan perubahan kegunaan tanah ke atas air larian kawasan tadahan. Keperluan mengetahui kesan perubahan liputan tanah secara ruang dan temporal bagi skala yang lebih besar membuat gambar satelit lebih memberangsangkan sebagai sumber data yang efisien dan benar. Keupayaan menggunakan GIS pula adalah sebagai alat penting dan berkesan bagi pemodelan hidrologi ruang. Dalam kajian ini, gambar satelit dan GIS telah digabungkan dengan model hidrologi ruang yang telah dibangunkan untuk menilai kesan pembangunan di kawasan tadahan hulu Sungai Bernam, Malaysia. Sungai Bernam adalah sumber utama bagi air pengairan di kawasan tanaman padi Tanjung Karang. Satu kaedah bagi menganggarkan kesan hidrologi yang disebabkan oleh perubahan kegunaan tanah telah dibangunkan dengan menggunakan model hidrologi berasaskan fisikal dan model matematik. Model koseptual atau model berasas fisikal adalah penting bagi memahami proses hidrologi, tetapi terdapat banyak suasana praktik yang mana penglibatan utama adalah kejituan anggaran bagi lokasi-lokasi tertentu. Model HEC-1 yang sedia ada telah dikalibrasikan dan digunakan bagi simulasi proses air larian. Hidrograf air larian telah diadakan bagi musim basah dan kering dengan menggunakan konsep longgokan dan pemodelan taburan. Dalam kaedah pemodelan taburan, hidrograf setiap tadahan kecil telah disalur ke titik alurkeluar menggunakan kaedah saluran Muskingum. Model rangkaian neural artificial (ANN) telah dibangunkan oleh kerana ia berupaya mengasingkan hubungkait yang bukan lelurus di antara input dan output bagi satu proses, dengan tidak perlu memberi fizik yang jelas, ini menjadikan proses simulasi

lebih berupaya digunakan. Semua model telah disahkan dengan ujian menggunakan data dari kawasan kajian. Pelakuan model telah diperiksa menggunakan kedua-dua cara analisis grafik dan statistik. Mean Absolute Error (MAE), Root Mean Square Error (RMSE), U-Thiel's coefficient, coefficient of determination (R^2), coefficient of efficiency (E), T-test dan analisis regresi telah diguna sebagai syarat penilaian pelakuan model. Semua model menunjuk pelakuan yang baik dalam simulasi proses air larian. Hasil dari model hidrologi memberi 0.79, 1.35, 0.22, 0.91 dan 0.67 bagi MAE, RMSE, U, R^2 dan E, tersebut. Beratan nombor lengkung (CN) telah meningkat 2% bagi tahun 2001 berbanding 1989, dan menyebabkan peningkatan 7% aliran paling tinggi. Kesan perubahan CN adalah lebih banyak ke atas hidrograf cabang meningkat dan air larian yang paling tinggi berbanding ke atas cabang menurun. CN meningkat, cabang atas menurun. Bagi model ANN, koefisien korilasi di antara aliran simulasi dan yang benar adalah 0.94 dan 0.89 bagi fasa latihan dan ujian tersebut. Hasil output model adalah dalam lingkungan tahap kepercayaan 95% dan kebanyakan nilai output yang bertabur adalah dalam lingkungan jalur selisih 15%. Penilaian statistik semasa fasa latihan memberi nilai 0.001, 4.74, 0.06 dan 0.87 bagi MAE, RMSE, U dan E, dan nilai-nilai ini terdapat 17.6, 5.6, 0.11 dan 0.58 bagi fasa ujian. Bagi kegunaan kedua-dua model, peratus perubahan air larian yang disebabkan perubahan kegunaan tanah adalah sama bagi kegunaan tanah yang berbeza,. Cubaan simulasi air larian untuk pembangunan tanah di tahun 2020 bagi pelbagi sinario kegunaan tanah telah dibuat. Anggaran dari model hidrologi menunjukkan 7% dan 13% peningkatan beratan CN bagi musim basah dan kering akan menyebabkan peningkatan kadar aliran 53% dan 62%, dan meningkatkan aliran paling tinggi sebanyak 80% dan 76% masing-masing bagi musim basah dan kering. Kaedah ini boleh digunakan bagi mana-mana perancangan pembangunan di masa

depan untuk menganggar kesan hidrologi bagi mengurangkan risiko banjir dan mengelak kekurangan air bagi pengairan. Kaedah ini boleh diguna sebagai alat membuat keputusan ketika merancang pembangunan gunatanah. Ia boleh menjadi alat praktik bagi ahli hidrologi, jurutera dan perancang bandar dan desa. Jurutera pengairan boleh menggunakan teknik ini semasa penentuan kawasan pertanian dan merancang penjadualan air pengairan.

ACKNOWLEDGEMENTS

First of all I should thank the Almighty, for without His blessings it would not have been possible for me to do this study. I wish to extend my gratitude to my employer; the Alzaiem Alazhary University and the Sudan government through the Ministry of Higher Education, for granting me the financial support to enable me to pursue this study. Special thanks to Professor Ir Dr Mohd Amin Mohd Soom, who besides being my supervisor, tirelessly worked hard to ensure that I managed to complete study. His commitment all through my studies was overwhelming. I would also like to thank my other supervisory committee members, Assoc. Prof Ir Dr Lee Teang Shui and Assoc. Prof Dr Abdul Rashid Mohamed Shariff for their guidance and advice whenever I encountered problems in the course of my research. I would like to thank the Director of the Institute of Advanced Technology (ITMA) Universiti Putra Malaysia for providing me the use of the laboratory facilities of ITMA, also thanks to all staff of the SMART Farming Laboratory, ITMA for their cooperation. I would like to extend my thanks to the following organizations in Malaysia

- Malaysian Center for Remote Sensing (MACRES)
- Department of Irrigation and Drainage (DID)
- Department of Surveying and Mapping Malaysia (JUPEM)
- Department of Agriculture (DOA), Malaysia
- Department of country and town planning, Selangor
- Department of Biological and Agricultural Engineering, UPM

Last but not least I will never forget to thank my immediate family members especially my father who understood the need for me to be away for studies, my wife Amel Awad for her patience and encouragements and all friends and colleagues.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General

Water is a prime natural resource, a basic human need and a precious national asset. The extent to which water is abundant or scarce, clean or polluted, beneficial or destructive has a major influence on our planet in its rapidly changing face brought about by rapid development on all fronts, ever increasing population and fast rate of scientific and technological advancements.

Deforestations, urbanization, and other land-use activities can significantly alter the seasonal and annual distribution of stream flow within a watershed (Dunne and Leopold, 1978). It is likely that such changes can also affect the seasonal and annual distribution of base flow. Understanding how these activities have influenced stream flow pattern may enable planners to formulate policies to minimize the undesirable effects of future landuse changes.

Due to the land development, land covers are subjected to changes. Many watersheds and river basins soils are converted to impervious surfaces which lead to decrease in the soil infiltration rate and consequently increase the amount and rate of runoff. A lot of water makes its way to the sea during the rainy season due to the higher runoff. Since rainfed agriculture in Malaysia may not have reservoir for irrigation water