UNIVERSITI PUTRA MALAYSIA

ANALYZING AND MODELING AN URBANIZING TROPICAL WATERSHED FOR SUSTAINABLE LAND USE PLANNING

HADI MEMARIAN KHALIL ABAD

FP 2012 79

ANALYZING AND MODELING AN URBANIZING TROPICAL WATERSHED FOR SUSTAINABLE LAND USE PLANNING

HADI MEMARIAN KHALIL ABAD

DOCTOR OF PHILOSOPHY
UNIVERSITI PUTRA MALAYSIA

2012

ANALYZING AND MODELING AN URBANIZING TROPICAL WATERSHED FOR SUSTAINABLE LAND USE PLANNING

By

HADI MEMARIAN KHALIL ABAD

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

October 2012

DEDICATION

Dedicated to my kind wife

my dear parents

and

my lovely son "Eilia"

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

ANALYZING AND MODELING AN URBANIZING TROPICAL WATERSHED FOR SUSTAINABLE LAND USE PLANNING

By

HADI MEMARIAN KHALIL ABAD

October 2012

Chairman: Siva Kumar Balasundram, PhD

Faculty: Agriculture

Land use changes in river basins result in flooding events that increase sediment load, which is a global concern and is becoming one of the main land management issues. Urban and agriculture development contributes to increasing trend of environmental damage within the Langat River Basin. Thus, an optimum land use pattern is necessary to meet long-term sustainable development in and around the basin. Recently, the geographic information system-based spatial process modelling have become indispensable tools for understanding natural processes occurring at the watershed scale. This study was concentrated on an applied framework for land use planning within the Langat upper catchments using the most applicable approaches for trend analysis, land use and hydrological modelling, and goal programming. In this study, the proposed framework for land use planning involved four main steps, i.e. hydrological trend analysis, land use modelling, landscape assessment and scenario making, hydrological modelling, and goal programming. Non-parametric tests, i.e. Mann-Kendall and Pettitt were used to detect gradual and abrupt changes in the hydrological data sets. The 'Cellular Automata-Markov' (CA-Markov) approach

was utilised to simulate the land use change for 2020. Landscape analysis was performed using Patch Analyst to calculate six fundamental landscape metrics. Hydrological analysis was done using the 'Kinematic Runoff and Soil Erosion, Version 2' (KINEROS2) as an event-based model and 'Soil and Water Assessment Tool' (SWAT) as a continuous simulation model. Weighted goal programming (WGP) integrated with analytic hierarchy process (AHP) was employed to define optimum land use scenarios. Trend analysis results indicated significant upward trend in water discharge and increasing tendency in sediment load at the Hulu Langat Sub Basin. These increasing trends were mainly caused by rapid changes in land use. Therefore, the Hulu Langat sub basin was introduced as the most critical sub basin, in terms of hydrological changes. Validation results of CA-Markov showed a weak robustness for land use and cover change simulation due to uncertainties in the source data, the model, and future land use and cover change processes in the study area. The future land use map simulated by CA-Markov was not applied in SWAT application. However, due to capability of SWAT in land use updating, the land use map dated 2006 was updated using a transition probability matrix computed by the Markov chain. Calibration results of KINEROS2 showed excellent and very good fittings for runoff and sediment simulations based on the aggregated measure. Validation results demonstrated that KINEROS2 was reliable for runoff modelling while KINEROS2 application for sediment simulation was only valid for the period 1984-1997. Land use and cover change impacts analysis by KINEROS2 revealed that direct runoff and sediment discharge increased with the progress of urban development and unmanaged agricultural activities. The SWAT robustness for water discharge simulation during the period 1997-2008 was good. However, due to uncertainties in the conceptual model, its robustness for sediment load simulation

was only acceptable for the validation period of 2002-2004. SWAT simulation based on the future scenario caused 2.37% and 25.59% increase in monthly direct runoff and monthly sediment load, respectively, as compared to the baseline scenario. Hydrological simulation based on the water conservation scenario resulted in 2.76% and 27.48% relative decrease in monthly direct runoff and monthly sediment load, respectively, as compared to the baseline scenario. In land use optimisation, four planning alternatives were defined, i.e. A1, A2, B1, and B2. The deriving factors in land use optimisation using goal programming were: (1) Water yield, (2) Sediment load, (3) Biomass yield, (4) Surface runoff, and (5) Net income. The alternatives A1 and A2 were formulated to optimise the baseline scenario in order to achieve a possible level of water conservation targets and yield a moderate level of transition cost, with and without limitation in horticulture/cropping activities, respectively. The alternatives B1 and B2 were formulated using the same concept, but with some constraints aimed at transforming the baseline scenario toward the future plan. The analytic hierarchy process integrated with weighted goal programming approach resulted in four optimised land development alternatives that can be applied within the Hulu Langat Sub Basin.

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

MENGANALISIS DAN PERMODELAN PERBANDARAN LEGEH TROPIKA BAGI PERANCANGAN PENGGUNAAN TANAH LESTARI

Oleh

HADI MEMARIAN KHALIL ABAD

Oktober 2012

Pengerusi: Siva Kumar Balasundram, PhD

Faculti: Pertanian

Perubahan penggunaan tanah dalam lembangan sungai mengakibatkan kebanjiran peristiwa-peristiwa yang meningkatkan beban endapan, yang merupakan satu kebimbangan global dan menjadi satu daripada isu-isu pengurusan tanah utama. Yang bandar dan pembangunan pertanian menyumbang kepada aliran meningkat kerosakan persekitaran dalam Langat River Basin. Oleh itu, satu corak guna tanah optimum perlu bertemu pembangunan lestari jangka panjang di dalam dan di sekitar lembangan. Baru-baru ini, peragaan proses ruang berasaskan Geographic Information System (GIS) telah menjadi alat-alat penting untuk proses alamiah bersefahaman berlaku di skala legeh. Kajian ini dipusatkan di satu rangka kerja gunaan untuk perancangan guna tanah dalam Langat kawasan tadahan atas menggunakan pendekatan-pendekatan kebanyakan dapat dikaitkan untuk analisis arah aliran, penggunaan tanah dan peragaan hidrologi,dan pemprograman matlamat. Dalam kajian ini, rangka kerja dicadangkan untuk perancangan guna tanah melibatkan empat langkah utama, iaitu analisis arah aliran hidrologi, peragaan penggunaan tanah, mendatar pembuatan penilaian dan senario, peragaan hidrologi, dan pemprograman matlamat. Ujian-ujian Non-berparameter, iaitu Mann Kendall and Pettitt merupakan digunakan untuk mengesan perubahan-perubahan mendadak

dan beransur-ansur dalam set-set data hidrologi. Pendekatan Cellular Automata-Markov (CA-Markov) digunakan untuk mensimulasi perubahan penggunaan tanah untuk 2020. Analisis landskap dijalankan menggunakan Patch Analyst menghitung enam metrik landskap asas. Analisis hidrologi dibuat menggunakan Kinematic Runoff and Soil Erosion-Version 2 (KINEROS2) kerana satu model berasaskan acara dan Soil and Water Assessment (SWAT) sebagai satu model simulasi selanjar. Pemprograman matlamat berat disepadukan dengan proses hierarki analitik digajikan untuk mentakrifkan senario-senario guna tanah optimum. Keputusan-keputusan analisis arah aliran menunjukkan aliran meningkat penting dalam luahan air dan kecenderungan bertambah dalam beban endapan di Hulu Langat Sub Basin. Tren-tren bertambah ini sebahagian besarnya di sebabkan oleh perubahan pesat dalam penggunaan tanah. Oleh itu, Hulu Langat telah diperkenalkan kerana lembangan bawah yang paling kritikal itu. Pengesahan menyebabkan CA-Markov menunjukkan satu keteguhan lemah untuk simulasi penggunaan tanah dan pertukaran kulit disebabkan ketidakpastian dalam data sumber, model, dan penggunaan tanah masa hadapan dan pertukaran kulit memproses dalam kawasan kajian. Berhubung dengan keputusan-keputusan ini, peta penggunaan tanah masa hadapan dibuat-buat oleh CA-Markov tidak digunakan dalam permohonan SWAT. Bagaimanapun , disebabkan keupayaan SWAT dalam pengemaskinian penggunaan tanah, peta penggunaan tanah bertarikh 2006 dikemas kini menggunakan satu matriks kebarangkalian peralihan dikira oleh rantai Markov. Penentukuran menyebabkan KINEROS2 menunjukkan kelengkapan cemerlang dan sangat baik untuk simulasi larian dan endapan berdasarkan ukuran teragregat. Keputusan-keputusan pengesahan menunjukkan yang KINEROS2 boleh dipercayai untuk peragaan larian manakala permohonan KINEROS2 untuk simulasi endapan hanya sah untuk tempoh 1984-1997. Land

Use/Cover Change (LUCC) memberi kesan kepada analisis oleh KINEROS2 mendedahkan bahawa aliran terus dan pengeluaran keladak menambah dengan kemajuan pembangunan bandar dan tidak diuruskan aktiviti pertanian. Keteguhan SWAT untuk simulasi luahan air sepanjang tempoh itu 1997-2008 baik. Bagaimanapun, disebabkan ketidakpastian dalam model konsep, keteguhannya untuk simulasi beban endapan hanya diterima untuk tempoh pengesahan 2002-2004. Memukul simulasi berdasarkan senario pada masa hadapan menyebabkan 2.37% dan 25.59% peningkatan dalam bulanan aliran terus dan bulanan beban endapan, masing-masing, seperti yang berbanding dengan senario garis dasar. Simulasi hidrologi berdasarkan senario pemuliharaan air menyebabkan dalam 2.76% dan 27.48% saudara dalam bulanan aliran terus dan bulanan beban endapan, masing-masing, seperti yang berbanding dengan senario garis dasar. Dalam pengoptimuman penggunaan tanah, empat alternatif-alternatif perancangan ditakrifkan, iaitu A1, A2, B1, dan B2. A1 alternatif-alternatif dan A2 dirumuskan untuk mengoptimumkan senario garis dasar supaya mencapai satu peringkat mungkin sasaran-sasaran pemuliharaan air dan menghasilkan satu tahap sederhana peralihan menelan belanja, dengan dan tanpa had dalam hortikultur/memotong aktiviti-aktiviti, masing-masing. Alternatif-alternatif B1 and B2 dirumuskan menggunakan konsep serupa, tetapi dengan beberapa kekangan bertujuan untuk berubah senario garis dasar ke arah rancangan masa depan. Pendekatan Analytic Hierarchy Process (AHP) bersepadu dengan Weighted Goal Programming (WGP) menyebabkan dalam empat alternatif-alternatif pembangunan tanah dioptimumkan yang dapat diaplikasikan dalam Hulu Langat Sub Basin.

ACKNOWLEDGEMENTS

First and foremost, I wish to express my utmost thanks and gratitude to Almighty Allah SWT for his blessings and for giving me the ability and capacity to complete this dissertation.

I wish also to express my most sincere gratitude and deepest appreciation to my supervisor, Dr. Siva Kumar Balasundram, for his kindness, continuous support, fruitful advice and invaluable guidance, and for encouraging and inspiring me during the period of this study.

I am also very grateful to the members of my supervisory committee, Dr. Alias Mohd Sood, Dr. Christopher Teh Boon Sung, and Dr. Karim C. Abbaspour for their kindness, support, constructive comments, very helpful suggestions and insights which contributed to the many aspects of this study and improved the quality of this dissertation.

I would like to thank Associate Professor Dr. Jamal Bin Talib who always supported me in all stages of my study, particularly in data collection and proposal writing.

I would like to acknowledge all the lecturers in UPM who taught me a lot of things which improved my knowledge to conduct this study.

I would like to thank the UPM library management and support staff at the Department of Land Management and the Department of Agriculture Technology, Universiti Putra Malaysia for their help throughout my doctoral study.

I would also like to thank my sisters who always encouraged and supported me.

Last but not least, I wish to express my deepest gratitude to my beloved wife, parents and lovely son "Eilia" for their endless encouragement, patience and sacrifices which had helped me to finish this study.

APROVAL

I certify that a Thesis Examination Committee has met on 29/10/2012 to conduct the final examination of Hadi Memarian Khalil Abad on his thesis entitled “Analyzing and Modeling an Urbanizing Tropical Watershed for Sustainable Land Use Planning” in accordance with the Universities and University Colleges Act 1971 and the constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Halimi Mohd Saud, PhD

Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Ahmad Husni Bin Mohd Hanif, PhD

Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Internal Examiner)

Mohd Amin Bin Mohd Soom, PhD

Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

David Mulla, PhD

Professor
Department of Soil, Water and Climate
University of Minnesota
USA
(External Examiner)

SEOW HENG FONG, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree Doctor of Philosophy.
The members of the Supervisory Committee were as follows:

Siva Kumar Balasundram, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Alias Mohd Sood, PhD
Faculty of Forestry
Universiti Putra Malaysia
(Member)

Christopher Teh Boon Sung, PhD
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Karim C. Abbaspour, PhD
Swiss Federal Institute of
Aquatic Science and
Technology
(Member)

BUJANG KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

HADI MEMARIAN KHALIL ABAD

Date: 29 October 2012

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AGLT	Agricultural activities in Langat basin
AGNPS	Agricultural Non-Point Source Pollution
ATtILA	Analytical Tool Interface for Landscape Assessment
AGWA	Automated Geospatial Watershed Assessment
AHP	Analytic Hierarchy Process
AM	Aggregated Measure
AVSWAT	ArcView SWAT
BMP	Best Management Practice
BSVG	Barren or sparsely vegetated lands in Langat basin
CA	Class Area
CA-Markov	Cellular Automata-Markov
CI	Consistency Index
CLUE-S	The Conversion of Land Use and its Effects
CR	Consistency Ratio
CV	Coefficient of Variation
DA	Discriminant Analysis
DEM	Digital Elevation Model
DHR	Digital Hybrid Reflectivity
DID	Department of Irrigation and Drainage
DSS	Decision Support System
ED	Edge Density
EMN_MN	Euclidean Mean Nearest Neighbour Distance
ETM	Enhanced Thematic Mapper
FA	Factor Analysis
FGP	Fuzzy Goal Programming
FRAC_AM	weighted mean patch fractal dimension
FRSE	Evergreen forest in Langat basin
GA	Genetic Algorithm
GIS	Geographic Information System
GLUE	Generalised Likelihood Uncertainty Estimation
GP	Goal Programming
GSSHA	Gridded Surface Subsurface Hydrologic Analysis
HACA	Hierarchical Agglomerative Cluster Analysis
HEC-HMS	Hydraulic Engineering Committee-Hydrologic Modelling System
HRU	Hydrological Response Unit
IJI	Interspersion and Juxtaposition Index
IWM	Integrated Watershed Management
K2	KINEROS2
KINEROS2	Kinematic Runoff and Erosion- Version 2
LISEM	Limburg Soil Erosion Model
LPI	Largest Patch Index
LUCC	Land Use/Cover Change
LULC	Land Use/Land Cover
MB	Model Bias
MCE	Multi Criteria Evaluation

MCMC	Markov Chain Monte Carlo
MEFIDIS	Spatially Distributed Physical Erosion Model
MicroLEIS	Mediterranean Land Evaluation Information System
MK	Mann-Kendall
MLD	Million Litre per Day
MOLA	Multi Objective Land Allocation
MPS	Mean Patch Size
MUSLE	Modified Universal Soil Loss Equation
NAHRIM	National Hydraulic Research Institute of Malaysia
NDVI	Normalised Difference Vegetation Index
NINC	Net Income
NP	Number of Patches
NS	Nash-Sutcliffe
NSE	Nash-Sutcliff Efficiency
NUMP	Number of Patches
OILP	Oil palm in Langat baisn
PBIAS	Percent Bias
PCA	Principal Component Analysis
PD	Patch Density
PLAND	Percentage of Landscape
PSCOV	Patch Size Coefficient of Variation
PWMK	Pre-Whitening Mann-Kendall
RNGE	Rangeland in Langat basin
RUBR	Rubber in Langat basin
RUSLE	Revised Universal Soil Loss Equation
SCEUA	Shuffled Complex Evolution UA
SCS	Soil Conservation Service
SD	System Dynamic
SDI	Shannon's Diversity Index
SEI	Shannon's Evenness Index
SDSS	Spatial Decision Support System
SEDL	Sediment Load
SHEI	Shannon's Evenness Index
SINMAP	Stability Index Mapping
SL	Sediment Load
SPI	Standard Precipitation Index
SUFI-2	Sequential Uncertainty Fitting-Version 2
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Procedures
SWD	Spatiotemporal Watershed Dynamic
SWH	Significant Wave Height
TFPW	Trend Free Pre-Whitening
TM	Thematic Mapper
TRMM	Tropical Rainfall Measuring Mission
TSSR	Total Sum of Squared Residuals
URLT	Urbanised and built up area in Langat basin
USLE	Universal Soil Loss Equation
WATR	Water bodies in Langat basin
WCON_1stL	Water Conservation scenario at the first level of control

WCON_2ndL	Water Conservation scenario at the second level of control
WD	Water Discharge
WEPP	Water Erosion Prediction Project
WETL	Wetland in Langat basin
WGP	Weighted Goal Programming
WLC	Weighted Linear Combination
WTP	Water Treatment Plant
WYLD	Water Yield

CHAPTER 1

INTRODUCTION

1.1 Background

Land use changes in river basins, which result in flooding events can increase sediment load (Garcı´a-Ruiz *et al.*, 2008; Zhang *et al.*, 2008; Zhang *et al.*, 2010). Changes in land cover result in some alterations in watershed condition and hydrological response. Globally, this is becoming one of the main land management issues (Hernandez *et al.*, 2000).

Many studies about the impact of human activities and climate change on the hydrological processes of rivers have been conducted (Nearing *et al.*, 2005; He *et al.*, 2008; Ghaffari *et al.*, 2009; Li *et al.*, 2009; Ouyang *et al.*, 2010). In recent years, application of process models and Decision Support Systems (DSSs) has become an indispensable tool for understanding natural processes occurring at the watershed scale (Sorooshian *et al.*, 1995). GIS (Geographic Information System)-based spatial modelling has become a very important tool in runoff and soil erosion studies and consequently in development of appropriate soil and water conservation strategies, especially at the watershed scale. Currently, using Spatial Decision Support Systems (SDSS) and integration of process models are increasingly being concerned to evaluate the impacts of policy measures under different scenarios in Integrated Watershed Management (IWM) (de Kort and Booij, 2007).

River systems in Malaysia consist of 1800 rivers with a total length of 38,000 km. Rapid development in Malaysia can change the natural hydrology and infiltration properties of the watersheds due to increase in impermeable acreage. Urbanisation and deforestation and uncontrolled agricultural activities are contributing to river pollution via the changes in soil physical and chemical properties and consequently change in erosion/sediment processes. Surface runoff and sediments from these regions can lead to some on-site and off-site impacts (Ayub *et al.*, 2009).

The Langat Basin is located at the south of Klang Basin, which is the most urbanised river basin in Malaysia, and it is believed that this basin is currently experiencing 'spill over' effects due to excessive development within the Klang Valley. In recent decades, the Langat Basin has experienced rapid development toward urbanisation, industrialisation and intense agriculture (Mohamed *et al.* 2009). The Langat Basin is also a main source of drinking water for surrounding areas, a source of hydropower and has an important role in flood mitigation. Over the past four decades, the Langat Basin has served approximately 50 % of the Selangor State population. However, Selangor is currently facing water shortage problems, especially in urban areas (Ayub *et al.*, 2009; Juahir *et al.*, 2010).

1.2 Justification

Urbanization and unmanaged agricultural activities are the most important land use types which are took place within the Langat river basin. These changes of undeveloped to developed area contribute the changes of discharge, direct runoff volume and sediment load into Langat River. The urbanization will increase the pervious and impervious area, which is identified as the main factor in increases of direct runoff volume as well as increases pollution loading into Langat River. The growing population pressure of the past decades, deforestation, lake reclamation, and embankment construction on riverbanks all exacerbated the flood situation. Thus, an optimum land use pattern is necessary to meet long-term sustainable development in and around the basin. Surface runoff and sedimentation are the most impressible hydrological and soil processes to improper land use decisions. Therefore, monitoring, assessing and predicting these processes are essential in the planning of an optimum land use pattern towards sustainable development. This leads to evaluation of suitable models (such as KINEROS2[1], SWAT[2], CA-Markov[3]) or integration of process models under local environmental and climatic conditions.

1.3 Significance of the Study

This study for the first time at the Langat Basin, provides a way for integrating hydrological trend analysis with hydrological and land use/landscape modelling and assessment to determine the critical sub basins, in terms of hydrological changes. Additionally, for the first time in Malaysia, weighted goal programming, integrated with analytic hierarchy process is used to optimise land use scenarios at the watershed scale.

1.4 Objectives

This research was conducted to achieve the following objectives:

[1] Kinematic Runoff and Erosion-Version 2
[2] Soil and Water Assessment Tool
[3] Cellular Automata-Markov

1.4.1 Main Objective

To determine suitable tropical land use scenario with regard to sustainable development concept using a multi-objective programming approach

1.4.2 Specific Objectives

i. To determine the most critical sub basin in terms of hydrological changes through analysis of hydrological trends
ii. To determine Land Use/Cover Change (LUCC) by simulation and analysis using CA-Markov technique and landscape metrics
iii. To estimate surface runoff and sediment load resulted from different tropical land use scenarios by KINEROS2, as an event based model
iv. To estimate surface runoff and sediment load resulted from different tropical land use scenarios by SWAT, as a continuous model

1.5 Study Area

Hydrometeorologically, the Langat Basin is affected by two types of monsoons, i.e. the Northeast (November to March) and the Southwest (May to September). The average annual rainfall is about 2400 mm. The wettest months are April and November with average monthly rainfall exceeding 250 mm, while the driest month is June with an average monthly rainfall not exceeding 100 mm. Topographically, the Langat Basin can be divided into three distinct areas in reference to the Langat River, i.e. mountainous area in the upstream, undulating land in the centre and flat flood plain in the downstream. The Langat Basin consists of a rich diversity of landform, surface feature and land cover (Noorazuan *et al.*, 2003) (Figure 1.1).

Based on the availability of hydrometric stations in the Langat Basin, three sub basins (upstream of the Langat River) were investigated as follows:

1.5.1 Lui Sub Basin

The Lui Sub Basin is located at 3° 07' - 3° 12' N, and 101° 52' - 101° 58' E on the upstream of Langat River with a drainage area of 68.25 km^2 and basin length of 11.5 km (Figure 1.1). Minimum and maximum altitudes of the basin are 61 and 1207 meters, respectively, while the average height is about 354 m above the sea level. The Lui Sub Basin is steep with an average slope of 35 %. Sg. Lui hydrometer station (Ref. No. 3118445) is located at the outlet of Lui Sub Basin with an average annual water discharge of 55.05×10^6 m^3 and an average annual sediment load of 5.88×10^3 tonnes. The average annual precipitation in Kg. Lui rain gauge station (Ref. No. 3118102) is about 2188.3 mm. In terms of land use, the Lui Sub Basin comprises 80.35 % forest, 9.85 % cultivated rubber and 2.6 % orchards (mostly include tropical fruits like Banana, Durian and Mango). The remaining portion of this sub basin consists of mixed horticulture and crops, urbanised area, and mining land.

1.5.2 Hulu Langat Sub Basin

The Hulu Langat Sub Basin is located at 3° 00' - 3° 17' N and 101° 44' - 101° 58' E upstream of the Langat River with a drainage area of 390.26 km^2 and basin length of

34.5 km. Minimum and maximum altitudes of the basin are 20 and 1479 meters, respectively while the average height is about 277.4 m above the sea level. The Hulu Langat Sub Basin is steep also with an average slope of 29.4 %. Sg. Langat hydrology station (Ref. No. 2917401) is located at the outlet of Hulu Langat Sub Basin with an average annual water discharge of 289.64×10^6 m^3 and average annual sediment load of 146.6×10^3 tonnes. The average annual precipitation in UPM Serdang station (Ref. No. 44302) is about 2453 mm. In terms of land use, the Hulu Langat Sub Basin involves 54.6 % forest, 15.6 % cultivated rubber, 15 % urban area and 2 % orchards. The remaining area of this sub basin is covered by horticulture and crops, oil palm, lake, marshland and mining land.

1.5.3 Semenyih Sub Basin

The Semenyih Sub Basin is located at 2° 55' - 3° 08' N and 101° 49' - 101° 58' E with a drainage area of 235.62 km^2 and basin length of 26.5 km. This sub basin is also located upstream of the Langat River with minimum and maximum altitudes of 21 and 1070 meters, respectively. The average altitude is about 243.9 m above sea level with an average slope of 27.4 %. Sg. Semenyih hydrometer station (Ref. No. 2918401) is located at the outlet of Semenyih Sub Basin with an average annual water discharge of 146.11×10^6 m^3 and average annual sediment load of 36.81×10^3 tonnes. Average annual precipitation in the Ldg. Dominion rain gauge station (Ref. No. 3118107) is about 2548.8 mm. With respect to the land use map dated 2006, 53.8% of the catchment area is covered by forest and 17.4% by rubber while the oil palm and urbanised area cover 6.3% and 5.6% respectively. Secondary forest and scrub land uses occupy 3.6% and 2.4% of the sub basin area and the rest is mostly covered by the mining activities, other crops, mixed horticulture, orchard, cleared land, marshland and aquaculture activities.

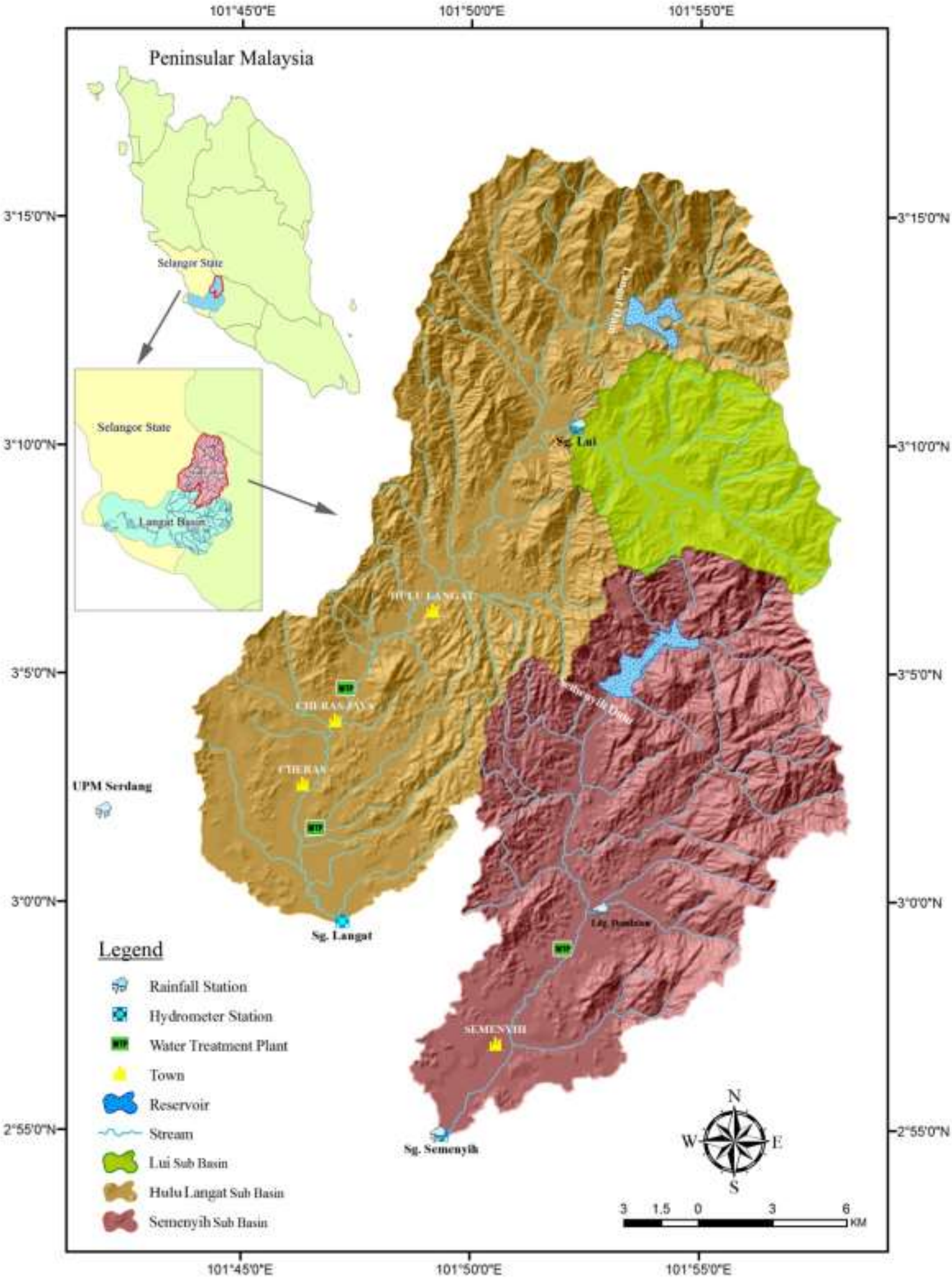

Figure 1.1. Geographic location of the three sub basins in the Langat basin (Source: Topographic Maps, JUPEM)

1.6 General Methodology

In this work, two types of process models, i.e. land use simulation and hydrological simulation with mathematical programming approach were integrated into an analytic framework. The main desired measures were surface runoff and sediment load. Hydrological time series analysis was applied to define the most critical sub basin.

As depicted in Figure 1.2, this study involved four main steps to establish an analytic framework for land use planning at the watershed scale as follows,

1.6.1 Hydrological Trend Analysis

Understanding the trends of water discharge and sediment load time series can be a key solution to determine how hydrological systems are affected by climate change and anthropogenic disturbances (Zhang *et al.* 2008). Hence, Mann-Kendall, Pre-Whitening Mann-Kendall (PWMK), and Pettitt tests were utilised to detect gradual and abrupt changes of hydrological time series. In this work, trend analysis was employed as a key approach for determining the critical sub basins in terms of significant increase in water discharge and sediment load, additionally.

1.6.2 Land Use Modelling, Landscape Analysis, and Scenario Development

The CA-Markov approach was used to project the 2020 land use map. As outlined by Mahatir Bin Mohamad (1991), the year 2020 is the target time, so that by this year

Malaysia is targeted to be a fully developed country. CA-Markov modelling allows simulation of land changes among the multiple categories, and combines the CA and Markov Chain procedure for land cover prediction (Eastman, 2003). This procedure relaxes strict assumptions associated with the Markov approach and considers both spatial and temporal changes (Agarwal *et al.*, 2002).

In order to assess the changes in land use patterns over the period 1984-2020, Patch Analyst 3.0 (Grid) program under ArcView GIS software was applied for calculating the landscape metrics (Elkie *et al.* 1999), which are fundamental indices for detecting the land use change trend (Ouyang *et al.* 2010).

Different Land Use/Land Cover (LULC) scenarios, i.e. past, present, future, and water conservation scenarios were constructed to be evaluated and optimised in Goal Programming (GP).

1.6.3 Hydrological Modelling

With regard to the objectives of this study, two hydrologic models were utilised to assess the impacts of LUCC on the basin hydrological status.

1.6.3.1 KINEROS2

KINEROS2 (K2) is a physically event-based, distributed and dynamic hydrologic model (Smith *et al.*, 1999; Semmens *et al.*, 2008). In this model the catchment is approximated by a cascade of overland flow planes, channels and impoundments.

Overland flow planes can be split into multiple components with different slopes, roughness, soils, etc. In this model contiguous planes can have different width (Semmens *et al.*, 2008). Urban element models runoff based on pervious and impervious fractions (Semmens *et al.*, 2008). In K2, infiltration is dynamic and interacts with both rainfall and runoff. Conceptual model of infiltration incorporates two layers in soil profile and soil moisture will be redistributed during the storm hiatus. Sediment simulation of K2 considers multiple particle class size sediment routing, raindrop impacts and hydraulic shear entrainments. Compound channel routing in K2 differentiates main and overbank infiltration (Semmens *et al.*, 2008).

1.6.3.2 SWAT

SWAT, a continuous model, is capable to simulate the impact of different management practices on water, sediment and chemical yields in large complex watersheds. Simulation of the hydrology of a watershed in SWAT can be separated into two major divisions. The first division is the land phase of the hydrologic cycle. This phase controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub basin. The second division is water or routing phase of the hydrologic cycle which is defined as the movement of water and sediments through the channel network of watershed to the outlet (Neitsch *et al.*, 2011).

1.6.4 Weighted Goal Programming Integrated with Analytic Hierarchy Process

GP is a way to make the treatment of evaluation criteria more comparable (Mau-Crimmins and Liberti, 2002). For a particular problem, GP formulates all of the targets in equivalent terms and they are included in the model as constraints. In GP, the relative importance of each target can be explicitly considered by assigning weights to the deviations in the objective function. In this way, specific directions of deviation for each target can be emphasised. GP is based on the March and Simon's (1958) "satisficing" theory and represents a practical and logical approach for modelling complex, real world problems (Mohseni Saravi *et al.*, 2003; Mau-Crimmins and Liberti, 2002). Weighted Goal Programming (WGP) is a distance metric-based variant of GP to solve multi-objective optimisation problems. WGP forms a single objective function as the weighted sum of various objective functions (Verma *et al.*, 2010).

Analytic Hierarchical Process (AHP) is a measurement theory based on expert judgment to drive priority scales using pair wise comparisons (Saaty, 1980). In cases with both quantitative and qualitative criteria, a combined AHP-WGP approach can be useful for solving optimisation problems (Ho, 2007). In this work, AHP was used to determine the weight or priority of the objectives in a multi-objective optimisation problem.

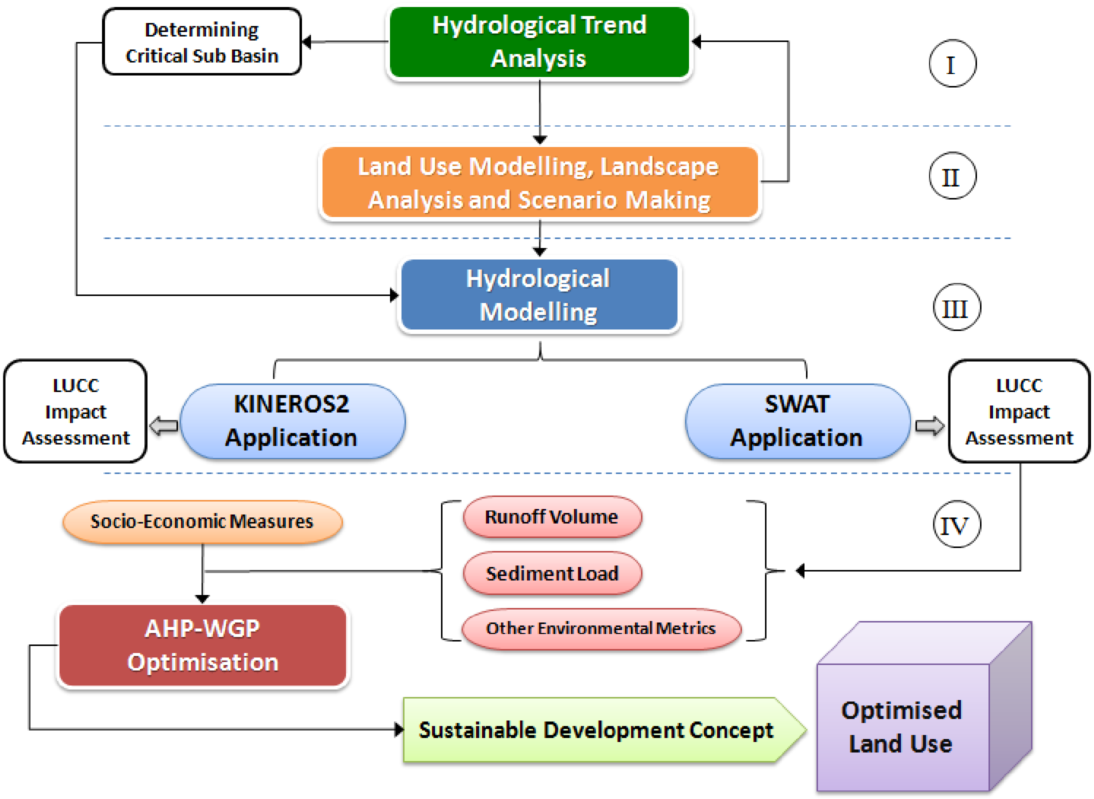

Figure 1.2. General flowchart of the research methodology

REFERENCES

Abbaspour, K.C. 2011. User Manual for SWAT-CUP4, SWAT Calibration and Uncertainty Analysis Programs. *Swiss Federal Institute of Aquatic Science and Technology, Eawag, Dübendorf, Switzerland*. Available at www.eawag.ch.

Abbaspour, K.C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, et al. 2007. Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. *Journal of Hydrology* 333(2-4): 413-430.

Abdul Aziz, O.I. and Burn, D.H. 2006. Trends and variability in the hydrological regime of the Mackenzie River Basin. *Journal of Hydrology* 319: 282-294.

Abdul Ghaffar, A.B., Ghani, A.A., Zakaria, N.A., Abu Hasan, Z. and Kiat, C.C. 2004. Determining Manning's flow resistance coefficient for rivers in Malaysia. *1st International Conference on Managing Rivers in the 21st Century: Issues and Challenges*, Penang, Malaysia.

Abdul Ghani, A.N., Shahwahid, M., Mohd, R., Mohd, S., Hanum, I.F. and Zakaria, M. 1999. Economic valuation of forest goods and services of Ayer Hitam Forest, Puchong, Selangor. *Journal of Tropical Agricultural Sciences* 22(2):147-160.

Arcement Jr, G.J. and Schneider, V.R. 1984. Guide for Selecting Manning's roughness coefficients for natural channels and flood plains, Water Supply Paper # 2339, Metric Version. *United States Geological Survey*, p. 67.

Agarwal, C., Green, G.M., Grove, J.M., Evans, T.P. and Schweik, C.M. 2002. A review and assessment of land-use change models: Dynamics of space, time, and human choice. *Northeastern Research Station, USDA, Forest Service*. Delaware, OH: USDA Forest Service.

Ahmad, S. and Abdul Ghani, A.N. 2004. Forest resource valuation and accounting in Malaysia: Present status and future directions. Available at *http://www.eco-services.ac.cn/DownLoad.asp?id=131&flag=c*.

Aldwaik, S. and Pontius Jr, R.G. 2011. Size, intensity, and stationarity of land changes by interval, category, and transition. *Worcester*. Available at *www.clarku.edu/~rpontius/.*

Al-Qurashi, A., McIntyre, W.H. and Unkrich, C. 2008. Application of the Kineros2 rainfall-runoff model to an arid catchment in Oman. *Journal of Hydrology* 355: 91-105.

Anand, S., Mankin, K.R., McVay, K.A., Janssen, K.A., Barnes, P.L. and Pierzynski, G.M. 2007. Calibration and validation of ADAPT and SWAT for field-scale runoff prediction. *Journal of American Water Resources Association* 43(4): 899-910.

Anuar, S.H., Abdullah, A., Mahamod, L.H. 2000. Using Geographical Information System (GIS) to determine the water catchment area: Malaysia application study. *17th EAROPH World Congress, "Local Development and Planning in the 21st Century"*, Asan, Korea.

Araya, Y.H. and Cabral, P. 2010. Analysis and modelling of urban land cover change in Setúbal and Sesimbra, Portugal. *Remote Sensing* 2: 1549-1563.

Arnold, J.G., Kiniry, J.R., Srinivasan, R., Williams, J.R., Haney, E.B., Neitsch, S.L. 2011. Soil and Water Assessment Tool, Input/Output file documentation, Version 2009. *Texas Water Research Institute*, Tech. Rep. 365.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R. 1998. Large area hydrologic modelling and assessment, part I: model development. *Journal of American Water Resources Association* 34(1): 73-89.

Ayub, K.R., Hin, L.S., Abd Aziz, H. 2009. SWAT application for hydrologic and water quality modeling for suspended sediments: A case study of Sungai Langat's Catchment in Selangor. *International Conference on Water Resources (ICWR 2009)*. Langkawi, Malaysia.

Azhari, N. and Zainal, B. 2007. Operational aspects of water demand management for domestic and industrial use. *Jabatan Bekalan Air*. Available at *http://www.jba.gov.my*.

Barnett, D., Black, B. and McCarl, B.A. 1982. Goal programming via multidimensional scaling applied to Senegalese subsistence farms. *American Agricultural Economics Association* 64(4):720-727.

Bekele, E.G. and Nicklow, J.W. 2007. Multi-objective automatic calibration of SWAT using NSGA-II. *Journal of Hydrology* 341(3-4): 165-176.

Benaman, J., Shoemaker, C.A. and Haith, D.A. 2006. Calibration and validation of soil and water assessment tool on an agricultural watershed in upstate New York. *Journal of Hydrologic Engineering* 10(5): 363-374.

Bisri, M., Othman, F. and Sholichin, M. 2008. Determination of runoff value using Kineros model (Case study in Sumpil catchment, Indonesia), ICCBT 2008 Proceeding, pp. 157-168.

Biswas, A. and Pal, B.B. 2005. Application of fuzzy goal programming technique to land use planning in agricultural system. *Omega 33*: 391-398.

Bouraoui, F., Galbiati, L. and Bidoglio, G. 2002. Climate change impacts on nutrient loads in the Yorkshire Ouse catchment (UK). *Hydrology and Earth System Sciences* 6(2): 197-209.

Bracmort, K.S., Arabi, M., Frankenberger, J.R., Engel, B.A. and Arnold, J.G. 2006. Modelling long-term water quality impact of structural BMPs. *Transactions of the ASABE* 49(2): 367-374.

Cai, T., Li, Q., Yu, M., Lu, G., Cheng, L. and Wei, X. 2011. Investigation into the impacts of land-use change on sediment yield characteristics in the upper Huaihe River basin, China. *Physics and Chemistry of the Earth*. In press.

Canfield, E. 2006. Runoff characteristics of the old west branch of the Santa Cruz River. *Planning and Development Division, Pima County Regional Flood Control District.*

Canfield, H.E. and Lopes, V.L. 2004. Parameter identification in a two-multiplier sediment yield model. *Journal of the American Water Resource Association (JAWRA)* 40(2): 321-332.

Cao, W., Bowden, W.B., Davie, T. and Fenemor, A. 2006. Multi-variable and multi-site calibration and validation of SWAT in a large mountainous catchment with high spatial variability. *Hydrological Processes* 20(5): 1057-1073.

Chang, N.B. and Wang, S.F. 1995. Managerial fuzzy optimal planning for solid waste management systems. *Journal of Environmental Engineering* 122(7): 649-658.

Chang, N.B. and Wang, S.F. 1997. A fuzzy goal programming approach for the optimal planning of metropolitan solid waste management systems. *European Journal of Operational Research* 99(2): 303-321.

Chang, N.B., Wen, C.G., Chen, Y.L. and Yong, Y.C. 1996. A Grey fuzzy multiobjective programming approach for the optimal planning of a reservoir watershed. Part B: Application. *Water Resources* 30(10): 2335-2340.

Chang, H. 2008. Spatial analysis of water quality trends in the Han River basin, South Korea. *Water Research* 42(13): 3285-3304.

Cho, J., Bosch, D., Lowrance, R., Strickland, T. and Vellidis, G. 2009. Effect of spatial distribution of rainfall on temporal and spatial uncertainty of SWAT output. *Transactions of the ASABE* 52(5): 1545-1555.

Chow, V.T., Maidment, D.R. and Mays, L.W. 1988. Applied hydrology. *McGraw-Hill, Inc.*, New York, NY.

Cifaldi, R.L., David Allan, J., Duh, J.D. and Brown, D.G. 2004. Spatial patterns in land cover of exurbanising watersheds in southeastern Michigan. *Landscape and Urban Planning* 66(2): 107-123.

Confessor Jr, R.B. and Whittaker, G.W. 2007. Automatic calibration of hydrologic models with multi-objective evolutionary algorithm and pareto optimization. *Journal of American Water Resources Association* 43(4): 981-989.

Coyle, G. 2004. The Analytic Hierarchy Process (AHP). Retrieved from Practical Strategy: Open Access Material at *http://www.booksites.net/download/coyle/student_files/AHP_Technique.pdf.*

Crews-Meyer, K.A. 2004. Agricultural landscape change and stability in northeast Thailand: Historical patch-level analysis. *Agriculture, Ecosystems and Environment* 101(2-3): 155-169.

Cruise, J.F., Limaye, A.S. and Al-Abed, N. 1999. Assessment of impacts of climate change on water quality in the Southeastern United States. *Journal of American Water Resources Association* 35(6): 1539-1550.

de Kort, I.A.T. and Booij, M.J. 2007. Decision making under uncertainty in a decision support system for the Red River. *Environmental Modelling and Software* 22: 128-136.

de la Rosa, D., Mayol, F., Diaz-Pereira, E., Fernandez, M. and de la Rosa Jr. D. 2004. A land evaluation decision support system (MicroLEIS DSS) for agricultural soil protection with special reference to the Mediterranean region. *Environmental Modelling and Software* 19: 929–942.

de Lara, M. and Doyen, L. 2008. Sustainable management of natural resources, mathematical models and methods. *Springer,* p. 266.

de Lima Paiva, F.M., de Silva, R.M. and Guimaraes Santos, C.A. 2005. Study of vegetal cover influence on experimental erosion plots by a runoff-erosion modelling. *Sociedade and Natureza, Uberlândia*, Special Issue: 235-242.

DiBari, J.N. 2007. Evaluation of five landscape-level metrics for measuring the effects of urbanisation on landscape structure: The case of Tucson, Arizona, USA. *Landscape and Urban Planning* 79(3-4): 308-313.

Duru, J.O. and Allen Hjelmfelt, Jr. 1994. Investigating prediction capability of HEC-1 and KINEROS kinematic wave runoff models. *Journal of Hydrology* 157: 87-103.

Eastman, J.R. 2003. IDRISI Kilimanjaro, guide to GIS and image processing. *Worcester, MA*: *Clark Labs, Clark University*.

Eckhardt, K., Breuer, L. and Frede, H.G. 2003. Parameter uncertainty and the significance of simulated land use change effects. *Journal of Hydrology* 273:164-176.

Eckhardt, K. 2005. How to construct recursive digital filters for baseflow separation. *Hydrological Processes* 19(2): 507-515.

Eckhardt, K. and Arnold, J.G. 2001. Automatic calibration of a distributed catchment model. *Journal of Hydrology* 251(1-2): 103-109.

Eckhardt, K., Breuer, L. and Frede, H.G. 2003. Parameter uncertainty and the significance of simulated land use change effects. *Journal of Hydrology* 273: 164-176.

Eckhardt, K. and Ulbrich, U. 2003. Potential impacts of climate change on groundwater recharge and streamflow in a central European low mountain range. *Journal of Hydrology* 284(1-4): 244-252.

Edmonds, J.A. and Rosenberg, N.J. 2005. Climate change impacts for the conterminous USA: An integrated assessment summary. *Climate Change* 69: 151-162.

Elkie, P., Rempel, R. and Carr, A. 1999. Patch Analyst user's manual. *Ontario Ministry of Natural Resources. Northwest Science and Technology*. Thunder Bay, Ontario. TM–002. 16 p. + Appendices.

Faramarzi, M., Abbaspour, K.C., Schulin, R. and Yang, H. 2009. Modelling blue and green water resources availability in Iran. *Hydrological Processes* 23: 486–501.

Felix, N., Simon, S. and Markus, W. 2002. A process based assessment of the potential to reduce flood runoff by land use change. *Journal of Hydrology* 267: 74-79.

Fohrer, N., Haverkamp, S., Eckhardt, K. and Frede, H.G. 2001. Hydrologic response to land use changes on the catchment scale. *Physics and Chemistry of the Earth* 26 (7-8): 577-582.

Frohn, R.C. and Hao, Y. 2006. Landscape metric performance in analysing two decades of deforestation in the Amazon Basin of Rondonia, Brazil. *Remote Sensing of Environment* 100(2): 237-251.

Garcia-Ruiz, J.M., Regüés, D., Alvera, B., Lana-Renault, N., Serrano-Muela, P. and Nadal-Romero, E. 2008. Flood generation and sediment transport in experimental catchments affected by land use changes in the central Pyrenees. *Journal of Hydrology* 356 (1-2): 245-260.

Geza, M. and McCray, J.E. 2007. Effects of soil data resolution on SWAT model stream flow and water quality predictions. *Journal of Environmental Management* 88 (3): 393-406.

Gezelius, S.S. and Refsgaard, K. 2007. Barriers to rational decision-making in environmental planning. *Land Use Policy* 24(2): 338–348.

Ghaffari, G., Keesstra, S., Ghodousi, J. and Ahmadi, H. 2009. SWAT-simulated hydrological impact of land-use change in the Zanjanrood Basin, Northwest Iran. *Hydrological Processes* 24(7): 892-903.

Goepel, K. 2011. AHP Analytic Hierarchy Process: An excel worksheet, version 27.8.2011. Available at *http://bpmsg.com*.

Gosain, A.K., Rao, S. and Basuray, D. 2006. Climate change impact assessment on hydrology of Indian river basins. *Current Science (India)* 90(3): 346-353.

Green, W.H. and Ampt, G.A. 1911. Studies on soil physics, 1. The flow of air and water through soils. *Journal of Agricultural Sciences* 4: 11-24.

Haan, C.T. 2002. Statistical methods in hydrology (second edition). *Ames, Iowa State Press*, p. 496.

Hamed, K.H. and Ramachandra Rao, A. 1998. A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology* 204(1-4): 182-196.

Hamed, K.H. 2008. Trend detection in hydrologic data: The Mann-Kendall trend test under the scaling hypothesis. *Journal of Hydrology* 349(3-4): 350-363.

Hamed, K.H. 2009. Enhancing the effectiveness of pre-whitening in trend analysis of hydrologic data. *Journal of Hydrology* 368(1-4): 143-155.

Haverkamp, S., Fohrer, N. and Frede, H.G. 2005. Assessment of the effect of land use patterns on hydrologic landscape functions: a comprehensive GIS-based tool to minimise model uncertainty resulting from spatial aggregation. *Hydrological Processes* 19(3): 715-727.

He, C. 2003. Integration of geographic information system and simulation model for watershed management. *Environmental Modelling and software* 18: 809-813.

He, H., Zhou, J. and Zhang, W. 2008. Modelling the impacts of environmental changes on hydrological regimes in the Hei River Watershed, China. *Global and Planetary Change* 61(3-4): 175-193.

Hernandez, M., Miller, N.S., Goodrich, D.C., Goff, B.F., Kepner, W.G., Edmonds, C.M. and Jones, K.B. 2000. Modelling runoff response to land cover and rainfall spatial variability in semi-arid watersheds. *Environmental Monitoring and Assessment* 64: 285-298.

Heuvelmans, G., Garcio-Qujano, J.F., Muys, B., Feyen, J. and Coppin, P. 2005. Modelling the water balance with SWAT as part of the land use impact evaluation in a life cycle study of CO_2 emission reduction scenarios. *Hydrological Processes* 19 (3): 729-748.

Hezri, A.A. and Hasan, M.N. 2004. Management framework for sustainable development indicators in the State of Selangor, Malaysia. *Ecological Indicators* 4(4): 287-304.

Ho, W. 2007. Combining analytic hierarchy process and goal programming for logistics distribution network design. *ISIC. IEEE International Conference on Systems, Man and Cybernetics*, 714-719.

Ismail A. and Mamat, M.N. 2002. The optimal age of oil palm replanting. *Oil Palm Industry Economic Journal* 2(1): 11-18.

Jones, C., Sultan, M., Yan, E., Milewski, A., Hussein, M., Al-Dousari, A., Al-Kaisy, S. and Becker, R. 2008. Hydrologic impacts of engineering projects on the Tigris-Euphrates system and its marshlands. *Journal of Hydrology* 353(1-2): 59-75.

Jones, T. and Tamiz, M. 2010. Practical goal programming. 1st Edition. *Springer*. p. 238.

Juahir, H. 2009. Water quality data analysis and modelling of the Langat River basin. *Ph.D. Thesis*, *Faculty of Science, University of Malaya*, Kuala Lumpur. pp. 68-138.

Juahir, H., Zain, S.M., Yusoff, M.K., Hanidza, T.I.T., Armi, A.S.M., Toriman, M.E. and Mokhtar, M. 2010. Spatial water quality assessment of Langat River Basin (Malaysia) using environmetric techniques. *Environmental Monitoring and Assessment*, Published online at *Springerlink.com*.

Kahya, E. and KalaycI, S. 2004. Trend analysis of streamflow in Turkey. *Journal of Hydrology* 289(1-4): 128-144.

Kalin, L. and Hantush, M.M. 2003. Evaluation of sediment transport models and comparative application of two watershed models. *National Risk Management Research Laboratory*, EPA/600/R-03/139, p. 81.

Kalin, L., Govindaraju, R.S. and Hantush, M.M. 2003. Effect of geomorphologic resolution on modelling of runoff hydrograph and sedimentograph over small watersheds. *Journal of Hydrology* 276: 89-111.

Kamil, N.F., Syed Abdillah, A. and Mukhtiar, S. 1996. Malaysia. Available at *http://www.avrdc.org.*

Kamusoko, C., Aniya, M., Adi, B. and Manjoro, M. 2009. Rural sustainability under threat in Zimbabwe – Simulation of future land use/cover changes in the Bindura district based on the Markov-cellular automata model. *Applied Geography* 29: 435-447.

Kepner, W.G., Hernandez, M., Semmens, D.J. and Goodrich, D.C. 2008. The use of scenario analysis to assess future landscape change on watershed condition in the Pacific Northwest (USA). *Use of Landscape Sciences for the Assessment of Environmental Security*, pp. 237–261.

Khaliq, M.N., Ouarda, T.B.M.J., Gachon, P., Sushama, L. and St-Hilaire, A. 2009. Identification of hydrological trends in the presence of serial and cross correlations: A review of selected methods and their application to annual flow regimes of Canadian rivers. *Journal of Hydrology* 368(1-4): 117-130.

Kok, K., Verburg, P. and Veldkamp, T. 2007. Integrated assessment of the land system: The future of land use. *Landuse Policy* 24: 517-520.

Kuala Lumpur Kepong Berhad. 2010. Annual report. Available at *http://www.klk.com.my/ar/klk_ar2010.pdf.*

Kwak, N.K. and Lee, C.W. 1998. A multicriteria decision-making approach to university resource allocations and information infrastructure planning. *European Journal of Operational Research* 110: 234-242.

Lam, Q.D., Schmalz, B. and Fohrer, N. 2011. The impact of agricultural best management practices on water quality in a North German lowland catchment. *Environmental Monitoring and Assessment* 183(1-4): 351-379.

Lambin, E.F., Rounsevell, M. and Geist, H. 2000. Are current agricultural land use models able to predict changes in land use intensity? *Agriculture, Ecosystem, and Environment* 1653: 1-11.

Latif, J. and Mamat, M.N. 2002. A financial study of cattle integration in oil palm plantations. *Oil Palm Industry Economic Journal* 2(1): 34-44.

Leete, R. 2005. Malaysia, achieving the millennium development goals, successes and challenges. Kuala Lumpur: *The United Nations Country Team, Malaysia*.

Li, Q., Cai, T., Yu, M., Lu, G., Xie, W. and Bai, X. 2011. Investigation into the impacts of land-use change on runoff generation characteristics in the upper Huaihe River basin, China. *Journal of Hydrologic Engineering*. in press.

Li, Z., Liu, W.Z., Zhang, X.C. and Zheng, F.L. 2009. Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China. *Journal of Hydrology* 377(1-2): 35-42.

Lim, K.J., Engel, B.A., Tang, Z., Choi, J., Kim, K.S, Muthukrishnan, S. and Tripathy, D. 2005. Automated web GIS based hydrograph analysis tool, WHAT. *Journal of American Water Resources Association* 41(6): 1407-1416.

Lin, Y.P., Hong, N.M., Wu, P.J., Wu, C.F. and Verburg, P.H. 2007. Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in Northern Taiwan. *Landscape and Urban Planning* 80(1-2): 111-126.

Lonergan, S.C. and Cocklin, C. 1988. The use of lexicographic goal programming in economic/ecological conflict analysis. *Socio-Economic Planning Sciences* 22(2): 83-92.

Luo, G., Yin, C., Chen, X., Xu, W. and Lu, L. 2010. Combining system dynamic model and CLUE-S model to improve land use scenario analyses at regional scale: A case study of Sangong watershed in Xinjiang, China. *Ecological Complexity* 7: 198-207.

Mahathir, B.M. 1991. The Way Forward. *Prime Minister's Office*, Malaysia.

March, J.G. and Simon, H.A. 1958. Organizations. New York: *Wiley*.

Markov, A.A. 1907. Extension of the limit theorems of probability theory to a sum of variables connected in a chain. *The Notes of the Imperial Academy of Sciences of St. Petersburg, VIII Series, Physio-Mathematical College XXII*.

Martínez-Carreras, N., Soler, M., Hernández, E. and Gallart, F. 2007. Simulating badland erosion with KINEROS2 in a small Mediterranean mountain basin (Vallcebre, Eastern Pyrenees). *Catena* 71: 145-154.

Mas, J.F., Paegelow, M., de Jong, B., Masera, O., Guerrero, G., Follador, M., et al. 2008. Modelling tropical deforestation: A comparison of approaches. Available at *www.csr.ufmg.br/dinamica/publications*.

Matthews, K., Sibbald, A. and Craw, S. 1999. Implementation of a spatial decision support system for rural land use planning: integrating GIS and environmental models with search and optimisation algorithms. *Computers and Electronics in Agriculture* 23: 9–26.

Mau-Crimmins, T. and Liberti, L. 2002. Combined integer goal programming and analytic hierarchy process approach for nature reserve design: A Southern Arizona case study. *Symposium on Models and Systems in Forestry,* Chile. Available at *http://www.dii.uchile.cl/~sympfor/CD/files/papers*.

McGarigal, K. and Marks, B.J. 1995. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. General Technical Report. PNW-GTR-351. Portland, OR: *U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station*. p. 122.

McColl, C. and Aggett, G. 2007. Land-use forecasting and hydrologic model integration for improved land-use decision support. *Journal of Environmental Management* 84: 494-512.

Millennium Ecosystem Assessment. 2005. Millennium Ecosystem Assessment,Ecosystems and Human Well-Being: General Synthesis, *Millennium Ecosystem Assessment Series, Island Press*. ISBN: 1-59726-040-1. *http://millenniumassessment.org//en/Products.Synthesis.aspx*.

Miller, S.L. and Childers, D. 2004. Markov processes. In Probability and Random Processes (pp. 323-367). Burlington: *Academic Press*.

Miller, S.N., Semmens, D.J., Goodrich, D.C., Mariano Hernandez and Miller, R.C. 2007. The automated geospatial watershed assessment tool. *Environmental Modelling and Software* 22: 365-377.

Mishra, A., Kar, S. and Singh, V.P. 2007. Prioritising structural management by quantifying the effect of land use and land cover on watershed runoff and sediment yield. *Water Resources Management* 21(11): 1899-1913.

Mohaddes, A.S., Ghazali, M., Rahim, K.A., Nasir, M. and Kamaid, A.V. 2008. Fuzzy environmental-economic model for land use planning. *American-Eurasian Journal of Agriculture and Environmental Sciences* 3(6): 850-854.

Mohamed, A.F., W.Yaacob, W.Z., Taha, M.R. and Samsudin, A.R. 2009. Groundwater and soil vulnerability in the Langat Basin Malaysia. *European Journal of Scientific Research* 27(4): 628-635.

Mohseni Saravi, M., Farzanegan, M., Koopaee, M. and Kholghi, M. 2003. The determination of optimal land use pattern in watershed resources using goal programming. *Iranian Natural Resources Journal* 56(1/2): 3–16 (in Farsi, with English Abstract).

Moriasi, D.N. and Starks, P.J. 2010. Effects of the resolution of soil dataset and precipitation dataset on SWAT 2005 streamflow calibration parameters and simulation accuracy. *Journal of Soil and Water Conservation* 65(2): 163-178.

Muhamat, A.A., Jaafar, M.N. and Rosly, H.E. 2011. A study on the revitalisation of Waqaf (endowment) lands for agribusiness activities. *2nd International conference on business and economic research (2nd ICBER)* proceeding.

Nash, J.E. and Sutcliffe, J.V. 1970. River flow forecasting through conceptual models. Part I. A discussion of principles. *Journal of Hydrology* 10(3): 282-290.

Nearing, M.A., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., et al. 2005. Modelling response of soil erosion and runoff to changes in precipitation and cover. *Catena* 61(2-3): 131-154.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R. 2011. Soil and water assessment tool, theoretical documentation, version 2009. *Texas Water Research Institute,* Tech. Rep. 406.

Nikkami, D., Shabani, M. and Ahmadi, H. 2009. Land use scenarios and optimisation in a watershed. *Journal of Applied Sciences* 9(2): 287-295.

Njiti, C.F. and Sharpe, D.M. 1994. A goal-programming approach to the management of competition and conflict among land uses in the tropics; the Cameroon example. *Ambio* 23(2): 112-119.

Noorazuan, M.H., Rainis, R., Juahir, H., Zain, S.M. and Jaafar, N. 2003. GIS application in evaluating land use-land cover change and its impact on hydrological regime in Langat River basin, Malaysia. *Conference of MapAsia 2003, Malaysia*, Kuala Lumpur. Available at *www.geospatialworld.net*.

Oeurng, C., Sauvage, S. and Sánchez-Pérez, J. 2011. Assessment of hydrology, sediment and particulate organic carbon yield in a large agricultural catchment using the SWAT model. *Journal of Hydrology* 401: 145-153.

Omar, I. 2002. Rules affecting the land development process in Malaysia: A review on regulation of Environmental Impact Assessment (EIA). *8th Pacific Rim Real Estate Society Conference. Christchurch, New Zealand: Lincoln University*.

Ouyang, W., Hao, F., Skidmore, A.K. and Toxopeus, AG. 2010. Soil erosion and sediment yield and their relationships with vegetation cover in upper stream of the Yellow River. *Science of the Total Environment* 409: 396-403.

Ouyang, W., Skidmore, A.K., Hao, F. and Wang, T. 2010. Soil erosion dynamics response to landscape pattern. *Science of the Total Environment* 408(6): 1358-1366.

Pack, R.T., Tarboton, D.G. and Goodwin, C.N. 2001. SINMAP, A stability index approach to terrain stability hazard mapping. *UTAH State University*.

Paegelow, M. and Camacho Olmedo, M.T. 2005. Possibilities and limits of prospective GIS land cover modelling: A compared case study: Garrotxes (France) and Alta Alpujarra Granadina (Spain). *International Journal of Geographical Information Science* 19(6): 697-722.

Palamuleni, L.G., Ndomba, P.M. and Annegarn, H.J. 2011. Evaluating land cover change and its impact on hydrological regime in Upper Shire river catchment, Malawi. *Regional Environmental Change* 11(4): 845-855.

Peel, D. and Lloyd, M.G. 2007. Neo-traditional planning. Towards a new ethos for land use planning? *Land Use Policy* 24(2): 396-403.

Pontius Jr, G.R. and Malanson, J. 2005. Comparison of the structure and accuracy of two land change models. *International Journal of Geographical Information Science* 19(2), 243-265.

Pontius Jr, R.G. and Millones, M. 2011. Death to Kappa: Birth of quantity disagreement and allocation disagreement for accuracy assessment. *International Journal of Remote Sensing* 32(15): 4407-4429.

Pontius Jr, R.G. and Neeti, N. 2010. Uncertainty in the difference between maps of future land change scenarios. *Sustainability Science* 5: 39-50.

Pontius Jr, R.G. and Petrova, S.H. 2010. Assessing a predictive model of land change using uncertain data. *Environmental Modelling and Software* 25: 299-309.

Pontius Jr, R.G., Boersma, W., Castella, J.C., Clarke, K., de Nijs, T., Dietzel, C., et al. 2008. Comparing the input, output, and validation maps for several models of land change. *The Annals of Regional Science* 42: 11-37.

Pontius Jr, R.G., Cornell, J.D. and Hall, C.A. 2001. Modelling the spatial pattern of land-use change with GEOMOD2: Application and validation for Costa Rica. *Agriculture, Ecosystems and Environment* 85: 191-203.

Pontius Jr, R.G., Peethambaram, S. and Castella, J.C. 2011. Comparison of three maps at multiple resolutions: A case study of land change simulation in Cho Don District, Vietnam. *Annals of the Association of American Geographers* 101(1): 45-62.

Pontius Jr, R.G., Walker, R., Yao-Kumah, R., Arima, E., Aldrich, S., Caldas, M., et al. 2007. Accuracy assessment for a simulation model of Amazonian Deforestation. *Annals of the Association of American Geographers* 97(4): 677-695.

Pontius Jr., R.G. and Chen, H. 2006. GEOMOD modelling. *Clark Labs. Worcester: Clark University*.

Pontius Jr, R.G. 2000. Quantification error versus location error in comparison of categorical maps. *Photogrammetric Engineering and Remote Sensing* 66: 1011-1016.

Puncak Niaga Sdn Bhd. 2008. A report on dam operations and management. Selangor, Malaysia. Available at *http://www.puncakniaga.com.my/Portals/0/pdf/Investor-Relations/PUNCAK2008_(english).pdf.*

Qiu, G.Y., Yin, J., Tian, F. and Geng, S. 2011. Effects of the "Conversion of Cropland to Forest and Grassland Program" on the water budget of the Jinghe River catchment in China. *Journal of Environmental Quality* 40(6): 1745-1755.

Radcliffe, L.L. and Schniederjans, M.J. 2003. Trust evaluation: an AHP and multi-objective programming approach. *Management Decision* 41: 587-595.

Ragkos, A. and Psychoudakis, A. 2009. Minimising adverse environmental effects of agriculture: a multi-objective programming approach. *Operational Research, an International Journal* 9: 267-280.

Randhir, T.O. and Tvestkova, O. 2011. Spatiotemporal dynamics of landscape pattern and hydrologic process in watershed systems. *Journal of Hydrology* 404: 1-12.

Recatala, L., Ive, J.R., Baird, I.A., Hamilton, N. and Sanchez, J. 2000. Land-use planning in the Valencian Mediterranean region: using LUPIS to generate issue relevant plans. *Journal of Environmental Management* 59: 169-184.

Richard, C. and Gratton, D.J. 2001. The importance of the air temperature variable for the snowmelt runoff modelling using the SRM model. *58th Eastern Snow Conference, Ottawa, Ontario, Canada*.

Rostamian, R., Jaleh, A., Afyuni, M., Mousavi, S.F., Heidarpour, M., Jalalian, A. and Abbaspour, K.C. 2008. Application of a SWAT model for estimating runoff and sediment in two mountainous basins in central Iran. *Hydrological Sciences Journal* 53(5): 977-988.

Saaty, T.L. 1980. The analytic hierarchy process. *New York, McGraw-Hill.*

Saaty, T.L. 2008. Decision making with the analytic hierarchy process. *International Journal of Services Sciences* 1(1): 83-98.

Sadeghi, S.H.R., Jalili, K. and Nikkami, D. 2009. Land use optimisation in watershed scale. *Land Use Policy* 26: 186-193.

Safari, A., De Smedt, F. and Moreda, F. 2009. WetSpa model application in the Distributed Model Intercomparison Project (DMIP2). *Journal of Hydrology* 418-419: 78-89.

Sahoo, D. and Smith, P.K. 2009. Hydroclimatic trend detection in a rapidly urbanizing semi-arid and coastal river basin. *Journal of Hydrology* 367(3-4): 217-227.

Schniederjans, M.J. and Garvin, T. 1997. Using the analytic hierarchy process and multi-objective programming for the selection of cost drivers in activity-based costing. *European Journal of Operational Research* 100: 72-80.

Schneider, L. and Pontius Jr., R.G. 2001. Modeling land-use change: the case of the Ipswich watershed, Massachusetts, USA. *Agriculture, Ecosystem and Environment* 85: 83–94.

Semmens, D.J., Goodrich, D.C., Unkrich, C.L., Smith, R.E., Woolhiser, D.A. and Miller, S.N. 2008. KINEROS2 and the AGWA modelling framework. In: Hydrological modelling in arid and semi-arid areas, Wheater, H., Sorooshian, S. and Sharma, K.D. (eds.). *Cambridge University Press, New York*, p. 206.

Shaaban, A.J. and Sing, L.K. 2003. Droughts in Malaysia: A look at its characteristics, impacts, related policies and management strategies. *Water and Drainage 2003 Conference, Malaysia*. Available at http://*www.nahrim.academia.edu*.

Shahwahid, M. 2011. Forest policy in Malaysia: challenges and prospects. Available at *http:// www.ikdpm.upm.edu.my*.

Sharma, K.S. and Jana, R.K. 2009. Fuzzy goal programming based genetic algorithm approach to nutrient management for rice crop planning. *International Journal of Production Economics* 121: 224-232.

Shively, G. and Coxhead, I. 2004. Conducting economic policy analysis at a landscape scale: examples from a Philippine watershed. *Agriculture, Ecosystem, and Environment* 104(1):159-170.

Smith, R.E., Goodrich, D.C. and Unkrich, C.L. 1999. Simulation of selected events on the Catsop catchment by KINEROS2: A report for the GCTE conference on catchment scale erosion models. *Catena* 37: 457-475.

Song, I.J., Hong, S.K., Kim, H.O., Byun, B. and Gin, Y. 2005. The pattern of landscape patches and invasion of naturalised plants in developed areas of urban Seoul. *Landscape and Urban Planning* 70(3-4): 205-219.

Sorooshian, S. and Gupta, V.K. 1995. Model calibration. In: Computer models of watershed hydrology, Singh, V.P. (Ed.). *Water Resources Publications*, pp. 23–68.

Stewart, T.J., Janssen, R. and van Herwijnen, M. 2004. A genetic algorithm approach to multiobjective landuse planning. *Computers and Operations Research* 31: 2293-2313.

Sundell-Turner, N.M. and Rodewald, A.D. 2008. A comparison of landscape metrics for conservation planning. *Landscape and Urban Planning* 86(3-4): 219-225.

Tain, J. and Wang, Y. 2010. Project trend on coastal wetland change and prediction Tupu models. *International Conference on Educational and Network Technology (ICENT 2010), IEEE*.

Tolson, B.A. and Shoemaker, C.A. 2004. Watershed modelling of the Cannonsville basin using SWAT2000: model development, calibration and validation for the prediction of flow, sediment and phosphorus transport to the Cannonsville Reservoir. Technical Report, *School of Civil and Environmental Engineering, Cornell University, Ithaca, New York, USA*.

Unkrich, C.L., Schaffner, M., Kahler, C., Goodrich, D.C. and Troch, P. 2010. Real time flash flood forecasting using weather radar and distributed rainfall-runoff model. *Second Joint Federal Inter-agency Conference, Las Vegas, NV*.

USDA Soil Conservation Service. 1972. Section 4: Hydrology. In: *National Engineering Handbook. SCS*.

Veldkamp, A. and Lambin, E.F. 2001. Editorial: predicting land use change. *Agriculture, Ecosystem, and Environment* 85: 1-6.

Verburg, P.H., Schot, P.P., Dijst, M.J. and Veldkamp, A. 2004. Land use change modelling: Current practice and research priorities. *GeoJournal* 61: 309-324.

Verburg, P.H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V. and Mastura, S.S. 2002. Modelling the spatial dynamics of regional land use: The CLUE-S model. *Environmental Management* 30(3): 391-405.

Verma, M.K., Shrivastava, R.K. and Tripathi, R.K. 2010. Evaluation of min–max, weighted and preemptive goal programming techniques with reference to Mahanadi Reservoir Project Complex. *Water Resources Management* 24: 299-319.

Wang, K., Wang, H.J., Shi, X.Z., Weindorf, D.C., Yu, D.S., Liang, Y., et al. 2009. Landscape analysis of dynamic soil erosion in Subtropical China: A case study in Xingguo County, Jiangxi Province. *Soil and Tillage Research* 105(2): 313-321.

Wang, L., Hu, H., Zheng, X., Deng, J. and Ning, G. 2010. Study on LUCC based on vector date source using the CA-Markov model. Available at *www.ieee.org*.

Wang, X.L. and Swail, V.R. 2001. Changes of extreme wave heights in northern hemisphere oceans and related atmospheric circulation regimes. *Journal of Climate* 14: 2204-2221.

Wang, X., Yu, S. and Huang, G.H. 2004. Land allocation based on integrated GIS-optimization modelling at a watershed level. *Landscape and Urban Planning* 66: 61-74.

Weng, Y.C. 2007. Spatiotemporal changes of landscape pattern in response to urbanisation. *Landscape and Urban Planning* 81(4): 341-353.

Wessels, K.J., Prince, S.D., Frost, P.E. and van Zyl, D. 2004. Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series. *Remote Sensing and Environment* 91: 47-67.

Williams, J.R. 1975. Sediment yield prediction with universal equation using runoff energy factor. p. 244-252. In present and prospective technology for predicting sediment yield and sources: *Proceeding of the sediment yield workshop, USDA Sedimentation Lab., Oxford, MS*, November 28-30, 1972. ARS-S-40.

Williams, J.R. 1969. Flood routing with variable travel time or variable storage coefficients. *Transactions of the ASAE* 12(1): 100-103.

Williams, J.R. 1980. SPNM, a model for predicting sediment, phosphorous, and nitrogen yields from agricultural basins. *Water Resources Bulletin* 16(5): 843-848.

Wilson, C.O. and Weng, Q. 2011. Simulating the impacts of future land use and climate changes on surface water quality in the Des Plaines River watershed, Chicago Metropolitan Statistical Area, Illinois. *Science of the Total Environment* 409 (20): 4387-4405.

Wilson, D., Hisdal, H. and Lawrence, D. 2010. Has streamflow changed in the Nordic countries? Recent trends and comparisons to hydrological projections. *Journal of Hydrology* 394(3-4): 334-346.

Wolfe, D. A. and Schechtman, E. 1984. Nonparametric statistical procedures for the changepoint problem. *Journal of Statistical Planning and Inference* 9(3): 389-396.

Wong, I.F.T. 1970. Reconnaissance soil survey of Selangor. *Ministry of Agriculture and Lands, Malaysia*.

Woolhiser, D.A., Smith, R.E. and Goodrich, E.C. 1990. A kinematic runoff and erosion model: Documentation and user manual, *U.S. Department of Agriculture, Agricultural Research Service* 77: p. 130.

Xiang, W.N., Gross, M., Fabos, J.G. and MacDougll, E.B. 1992. A Fuzzy-Group multicriteria decision making model and its application to land use planning. *Environment and Planning B: Planning and Design* 19: 61-84.

Xie, H., Nkonya, E. and Wielgosz, B. 2011. Assessing the risks of soil erosion and small reservoir siltation in a tropical river basin in Mali using the SWAT model under limited data condition. *Applied Engineering in Agriculture* 27(6): 895-904.

Xu, Z.X., Takeuchi, K. and Ishidaira, H. 2003. Monotonic trend and step changes in Japanese precipitation. *Journal of Hydrology* 279(1-4): 144-150.

Yang, J., Abbaspour, K.C., Reichert, P., Yang, H. and Xia, J. 2008. Comparing uncertainty analysis techniques for a SWAT application to the Chaohe basin in China. *Journal of Hydrology* 358: 1-23.

Yang, Y. and Tian, F. 2009. Abrupt change of runoff and its major driving factors in Haihe River Catchment, China. *Journal of Hydrology* 374(3-4): 373-383.

Ye, B. and Bai, Z. 2008. Simulating land use/cover changes of Nenjiang County based on CA-Markov model. In *IFIP International Federation for Information*

Processing, Computer and Computing Technologies in Agriculture, Vol. 1; Daoliang Li; (Boston: Springer), Volume 258; pp. 321–329.

Yenilmez, F., Keskin, F. and Aksoy, A. 2010. Water quality trend analysis in Eymir Lake, Ankara. *Physics and Chemistry of the Earth*, Parts A/B/C 36(5-6): 135-140.

Yevenes, M.A. and Mannaerts, C.M. 2011. Seasonal and land use impacts on the nitrate budget and export of a mesoscale catchment in Southern Portugal. *Agricultural Water Management* 102(1): 54-65.

Yue, S., Pilon, P. and Cavadias, G. 2002. Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology* 259(1-4): 254-271.

Zhang, Q., Xu, C.Y., Becker, S. and Jiang, T. 2006. Sediment and runoff changes in the Yangtze River basin during past 50 years. *Journal of Hydrology* 331(3-4): 511-523.

Zhang, S., Lu, X.X., Higgitt, D.L., Chen, C.T.A., Han, J. and Sun, H. 2008. Recent changes of water discharge and sediment load in the Zhujiang (Pearl River) Basin, China. *Global and Planetary Change* 60(3-4): 365-380.

Zhang, S. and Lu, X.X. 2009. Hydrological responses to precipitation variation and diverse human activities in a mountainous tributary of the lower Xijiang, China. *Catena* 77(2): 130-142.

Zhang, X., Cao, W., Guo, Q. and Wu, S. 2010. Effects of land use change on surface runoff and sediment yield at different watershed scales on the Loess Plateau. *International Journal of Sediment Research* 25(3): 283-293.

Zhang, X., Srinivasan, R. and Hao, F. 2007. Predicting hydrologic response to climate change in the Luohe River basin using the SWAT model. *Transactions of the ASABE* 50(3): 901-910.

Zhou, P., Luukkanen, O., Tokola, T. and Nieminen, J. 2008. Effect of vegetation cover on soil erosion in a mountainous watershed. *Catena* 75: 319-325.

Ziegler, A.D. and Giambelluca, T.W. 1997. Simulation of runoff and erosion on mountainous roads in northern Thailand: A first look at human impact on erosion and sedimentation. *Proceedings of the Rabat Symposium S6. IAHS*, Publication # 245.