UNIVERSITI PUTRA MALAYSIA

MODELING HYDROLOGIC RESPONSE DUE TO THE IMPACT OF LAND USE CHANGES IN THE UPPER BERNAM RIVER BASIN USING MACHINE LEARNING

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By

NAJEEB MOHAMMED NAGEE AL-HEATTAR

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

April 2019

DEDICATIONS

This work is dedicated to:

My precious Father and Mother for their prayers and support.
My lovely Wife and Children, for the hardships they endured
My dear Brothers, Sisters, and Family, for all their support

My previous supervisors Prof. Dr. Amin, Prof. Dr. Thamer, Dr. Halim and Dr. Rowshon.

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Land use 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 an increase in surface runoff and a decrease in groundwater 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. On the other hand, the groundwater recharge decreased due to the increase in the impervious surfaces and decrease in the soil infiltration rate.

The main objectives of this study was to analyze and assess the impacts of land use changes on the watershed runoff in Upper Bernam River Basin by using Soil and Water Assessment Tool (SWAT) model, and to develop a Watershed Best Management Practice model using Machine Learning (WBMP-ML) to determine the best optimal locations, numbers and operations of ponds to control flood during high flow season, maintain river base flow and supply irrigation water demand during low dry season.

The Bernam River is the main source of irrigation water for 20,000 ha rice granary area. Land use changes in the study area have experienced tremendous changes from 1984 to date. Eight land use of years 1984, 1990, 1998, 2000, 2002, 2004, 2006 and 2010 were used for investigation study and assessment analysis. Projected land use of the year 2020 with other scenarios of 40% and 50% of urban were used for flow prediction to assess the future impact of land use change. For forest as a form of land use, there was a percentage decrease from 56.3% in 1984 to 48.02% in 2010 and a further projected decrease to 45.81% in 2020. This decreasing trend is applicable to

other forms of land use like orchard and rubber plantation, except urban area and oil palm which showed an increasing trend.

The study was conducted using a 36 years flow record (1980-2016). Calibration was performed for the period of 1980 to 2004 with three land use of years 1984, 1990 and 1998 while the period of 2005 to 2016 was used for validation with the land use of years 2006 and 2010. The coefficient of determination (R^2) and Nash-Sutcliffe coefficient (E) were used as evaluation criteria for model performance. The model showed a very good performance in simulating the runoff process. During calibration annual, monthly and daily results were 0.83, 0.83 and 0.77 for R^2 and 0.80, 0.81 and 0.76 for E respectively, while during validation, the results were 0.88, 0.89 and 0.79 for R^2 and 0.82, 0.86 and 0.76 for E respectively.

Thus, in this study, watershed modeling was used to simulate and analyze the impact of land use changes on hydrology and stream stability. SWAT model was used to simulate and analyze the impact of land use change on hydrology runoff quantity.

From SWAT application, it was found that the percentage change in runoff due to land use change in period 1998 to 2000 was small because the land use change in that period was not noticeable. However, the runoff increased significantly from 4.18% in 1984 to 22% in 2010 comparing with the scenario of 100% forest land. The model was then applied to simulate the runoff from future land development for the year 2020 (20% urban), scenarios of 40% and 50% urban, the predictions showed an increment of 32%, 45% and 59% due to land use change respectively.

Analyses of three different annual rainfall amounts were carried out to identify the effects of land use change under different rainfall patterns. The results showed that the percentage of flow has increased as a result of rainfall amount change, where the watershed response is noticeably higher due to rainfall change than individual changes in land use.

This study comes to address the challenges of tropical hydrology system. It deals with the application of modeling that is new and an important aspect of understanding the global hydrological system; Machine Learning was used for the purpose of flood and drought control. The number of ponds was reduced by machine learning from 12 ponds that suggested by WARM model to 7 ponds with total area 1942 ha to store maximum water of 98.5×10^6 m^3.

This methodology can be applied for any future development plan to predict the hydrological impacts and mitigate the risk of flood occurrence and avoid the shortage of irrigation water. The developed methodology, therefore, would be useful in assisting policy and decision making tool when formulating land use policies. It can be a practical tool for hydrologists, engineers, and town and country planners.

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

PEMODELAN RESPON HIDROLOGI AKIBAT PERUBAHAN PENGGUNAAN TANAH DI LEMBANGAN ATAS SUNGAI BERNAM, MALAYSIA MENGGUNAKAN PEMBELAJARAN MESIN

Oleh

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Perubahan penggunaan tanah di kawasan tadahan air boleh menjejaskan hidrologi aliran air dengan pelbagai cara. Cara pembangunan tanah tertentu boleh dikaitkan dengan peningkatan kawasan yang mampat menyebabkan peningkatan larian air permukaan dan pengurangan dalam pengaliran bawah tanah. Oleh itu, kedua-dua proses boleh memberi impak yang besar. Peningkatan arus aliran air semasa hujan menyebabkan bilangan arus meningkat secara mendadak serta membanjiri sungai di kawasan tanah bersebelahan. Sebaliknya, pengaliran dibawah tanah kurang resapan disebabkan liang pori tanah tepu dan kadar penyusupan tanah juga menurun.

Objektif utama kajian ini adalah untuk menganalisis dan menilai impak perubahan penggunaan tanah di larian aliran air di Lembangan Sungai Bernam dengan menggunakan model Alat Pengujian Tanah dan Air (SWAT) dan untuk membangunkan model Amalan Pengurusan Terbaik Watershed menggunakan Pembelajaran Mesin (WBMP-ML) untuk menentukan lokasi optimum, kuantiti dan operasi kawasan tadahan yang terbaik untuk mengawal banjir semasa musim aliran air yang tinggi, mengekalkan aliran asas sungai dan bekalan air pengairan semasa musim kering.

Sungai Bernam merupakan sumber utama air pengairan untuk kawasan sawah padi 20.000 ha. Perubahan penggunaan tanah di kawasan kajian telah mengalami perubahan besar dari tahun 1984 hingga kini. Lapan penggunaan tanah pada tahun 1984, 1990, 1998, 2000, 2002, 2004, 2006 dan 2010 digunakan untuk kajian penyiasatan dan analisis penilaian. Penggunaan tanah yang diunjurkan pada tahun 2020 dengan senario lain sebanyak 40% dan 50% daripada bandar digunakan untuk ramalan aliran untuk menilai kesan masa hadapan berdasarkan perubahan penggunaan

tanah. Bagi hutan sebagai satu bentuk penggunaan tanah, terdapat penurunan peratus daripada 56.3% pada tahun 1984 kepada 48.02% pada tahun 2010 dan seterusnya berkurangan kepada 45.81% pada tahun 2020. Kecenderungan ini berkurangan kepada bentuk penggunaan tanah lain seperti kebun dan getah perladangan kecuali kawasan perkotaan dan kelapa sawit yang menunjukkan peningkatan trend.

Kajian ini dijalankan menggunakan 36 tahun (1980-2016) rekod aliran air selama. Penentukuran dilakukan untuk tempoh 1980 hingga 2004 dengan tiga penggunaan tanah tahun 1984, 1990 dan 1998 manakala tempoh 2005 hingga 2016 digunakan untuk pengesahan dengan penggunaan tanah tahun 2006 dan 2010. Koefisien penentuan (R^2) dan Nash-Sutcliffe koefisien (E) digunakan sebagai kriteria penilaian untuk prestasi model. Model menunjukkan prestasi yang sangat baik dalam mensimulasikan proses larian. Semasa keputusan penentukuran tahunan, bulanan dan harian adalah 0.83, 0.83 dan 0.77 untuk R^2 dan 0.80, 0.81 dan 0.76 untuk E masing-masing, manakala semasa pengesahan, keputusannya adalah 0.88, 0.89 dan 0.79 untuk R^2 dan 0.82, 0.86 dan 0.76 untuk E masing-masing.

Oleh itu, dalam kajian ini, pemodelan aliran sungai telah digunakan untuk mensimulasikan dan menganalisis kesan perubahan penggunaan tanah terhadap hidrologi dan kestabilan sungai. Model SWAT digunakan untuk mensimulasikan dan menganalisis kesan perubahan penggunaan tanah terhadap kuantiti aliran air hidrologi. Dari aplikasi SWAT, didapati peratusan perubahan dalam larian disebabkan perubahan penggunaan tanah dalam tempoh 1984 hingga 1998 adalah kecil kerana perubahan penggunaan tanah dalam tempoh itu tidak ketara. Bagaimanapun bacaan aliran air meningkat dengan ketara dari 4.18% pada tahun 1984 kepada 21.89% pada tahun 2010 berbanding dengan senario 100% tanah hutan. Model ini kemudiannya digunakan untuk mensimulasikan bacaan aliran air dari pembangunan tanah masa depan untuk tahun 2020 (20% bandar), senario 40% dan 50% bandar, ramalan menunjukkan kenaikan 32%, 45% dan 59% disebabkan oleh penggunaan perubahan tanah masing-masing.

Analisis tiga jumlah hujan tahunan yang berbeza telah dijalankan untuk mengenal pasti kesan perubahan penggunaan tanah di bawah corak hujan yang berlainan. Hasil kajian menunjukkan bahawa peratusan aliran air telah meningkat berikutan perubahan jumlah hujan, di mana tindak balas tadahannya lebih tinggi disebabkan perubahan hujan daripada perubahan individu dalam penggunaan tanah.

Kajian ini bertujuan untuk menangani cabaran sistem hidrologi tropika. Ia berkaitan dengan pemodelan yang baru dan merupakan aspek penting dalam memahami sistem hidrologi global, Pembelajaran Mesin digunakan untuk mengawal banjir dan kemarau. Bilangan kolam dikurangkan dengan mesin learining dari 12 kolam yang dicadangkan oleh model WARM kepada 7 tadahan dengan luas 1942 ha untuk menyimpan simpanan air maksimum 98.5 x 106 m3.

Metodologi ini boleh digunakan untuk sebarang pelan pembangunan masa hadapan untuk meramalkan kesan hidrologi dan mengurangkan risiko terjadinya banjir dan mengelakkan kekurangan air pengairan. Oleh kerana itu, metodologi ini akan bermanfaat dalam membantu untuk menganalisa penggunaan tanah. Ia boleh menjadi alat praktikal untuk ahli hidrologi, jurutera dan perancang bandar dan negara.

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

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LIST OF ABBREVIATIONS

ALPHA_BF	Base Flow Factor
AnnAGNPS	The Annualized Agricultural NonPoint Source Model
BMP	Best Management Practices
BRH	Bernam River Headwork.
C factors	LandUse/Land Cover Factor
CN2	Curve Number 2
CNs	Curve Numbers
DEM	Digital Elevation Models
DHSVM	Distributed Soil-Hydrology-Vegetation Model
DID	The Department of Irrigation & Drainage Malaysia
DLG	Digital line Graphs
DOA	The Department of Agriculture Malaysia
DSS	Decision Support Systems
DTCM	The Department of Town and Country Planning Malaysia
DTM	Digital Terrain Models
DWSM	The Dynamic Watershed Simulation Model
E	Nash-Suttcliffe Simulation Efficiency
EPCO	Plant Uptake Compensation Factor
ESCO	Soil Evaporation Compensation Coefficient
ET	Evapotranspiration
GA	Genetic Algorithm
GIS	Geographical Information System
HEW	Hydrologic Equivalent Wetland
HSPF	Hydrologic Simulation Program Fortran Model

ICT	Information & Communication Technologies
IFLOD1	Beginning month of the flood season
IFLOD2	Ending month of the flood season
JICA	Japan International Cooperation Agency
MAE	Mean Absolute Error
MASMA	Malaysian Stormwater Management Manual
MMD	The Methodological Department Malaysia
NASA	National Aeronautics and Space Administration
NPS	Nonpoint Source pollution
NSBMP	Non-Structural Best Management Practices
NWP	Numerical Weather Prediction
OCN	Optimal Channel Networks
P	The probability
PND_ESA	Pond's Surface Area when filled to the emergency spillway
PND_EVOL	Pond's Volume Area when filled to the emergency spillway
PND_FR	Fraction of the Sub-basin Area that Drains into Pond
PND_PSA	Pond's Surface Area when filled to the Principle spillway
PND_PVOL	Pond's Volume Area when filled to the Principle spillway
QPF	Quantitative Precipitation Forecasts
R^2	Coefficient of Determination
REMM	Riparian Ecosystem Management Model
RM	Ringgit Malaysian
RMSE	Root Mean Square Error
RS	Remote Seing
SBMPs	Structural Best Management Practices
SCS	Soil Conservation Service

SIS	Spatial Information Systems
SOL_AWC	Soil-Available Water Content
SOL_K	Soil-Hydraulic Conductivity
SPSS	Statistical Package for the Social Sciences
SRTM	The Shuttle Radar Topographic Mission
SWAT	The Soil and Water Assessment Tool
T	The Return Period
Tg K	Tanjong Karang
TSS	Total Suspended Solids
U	Theil's Inequality Coefficient
UBRB	The upper Bernam River basin
USEPA	United State Environmental Protection Agency
USGS	United States Geological Survey
VB	Visual Basic language
WARM	Watershed Runoff Management
WARM-DSS	Watershed Runoff Management- Decision Support System
WBMP-ML	Watershed Best Management Practice Using Machine Learning
WQMPs	Water Quality Management Plans

CHAPTER 1

INTRODUCTION

1.1 Background

Water is a main natural source, an elementary human necessity and a valuable national benefit.SING Quran mentioned in several verses how the extent to which water is beneficial or destructive, abundant or scarce and how it sometimes changes from grace to punishment. Nowadays, this issue also has a major influence on our planet in its rapidly changing face brought about by fast advancements on all frontages, ever-increasing population and quick rate of scientific and industrial developments.

Allah subhanahu wa ta'ala said in Holy Quran in surah Al Anbiya vs 30: “Have not those who disbelieve known that the heavens and the earth were joined together as one united piece, then We parted them? And We have made from water every living thing. Will they not then believe?” (21:30)

قال الله سبحانه وتعالى "أَوَلَمْ يَرَ الَّذِينَ كَفَرُوا أَنَّ السَّمَاوَاتِ وَالْأَرْضَ كَانَتَا رَتْقًا فَفَتَقْنَاهُمَا ۖ وَجَعَلْنَا مِنَ الْمَاءِ كُلَّ شَيْءٍ حَيٍّ ۖ أَفَلَا يُؤْمِنُونَ"

Accelerated land use changes have become a growing interest, especially in the large tropical basin. Tropical forests have been the focus of scientific and political discussions on surface energy fluxes, hydrological and carbon cycles, vegetation dynamics, land use, and human alteration of the biosphere through agriculture, mining, and urbanization (Santose et al. 2018).

Deforestations, urbanization, and other land use activities can significantly alter the seasonal and annual distribution of stream flow within a watershed. 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 land use changes. This underscores the need to dwell more on what land use is all about in Malaysia and Southeast Asia in general.

Land use has been defined regarding syndromes of anthropogenic activities like agriculture, forestry and building construction that change land surface processes which include hydrology and biodiversity. Also, scientists and land managers also define land use to include social and economic purposes and contexts for which lands are managed. According to Meyer and Turner (1992) and Vitousek *et al*., (1997), land use has greatly changed a vast proportion of the earth’s land surface. It has also been referred to as the backbone of agricultural development, with its share of the provision of social benefits. Land use and land-cover changes are also defined to include not only human-induced changes in land cover but all forms of land management such as tillage, fertilizer use, shifting cultivation, selective logging, draining of peatlands, use or exclusion of fire (Houghton et al., 2012).

Due to land development, land covers are subjected to changes. Many watersheds and river basins soils are converted to impervious surfaces which lead to a 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 reservoirs for irrigation water supply, it is very important to have a high base flow so that enough water is available for irrigation during the dry season.

Malaysia has to deal not only with floods and erosion but also the possibility that some streams could experience a large decrease in water level in the dry season; permanent streams may become intermittent and intermittent streams may disappear altogether. While flood damage can be mitigated by stormwater detention practices, the problem of reduced dry season flows can only be approached from a whole watershed perspective with improved water management tools based on sound scientific principles and efficient technologies.

In this study, the Soil and Water Assessment Tool (SWAT) model was used to assess the impacts of land use changes on streamflow in the Upper Bernam River Basin, Malaysia. The developed methodology may help planners and decision makers to take the hydrological impacts into account when formulating plans for land development.

Watershed modeling is one approach to simulate and analyze the effect of land use changes on water quality and quantity. Many researchers have discussed the impact of future land use changes on hydrology and stream stability, with special reference to the urban built-up areas (including impervious surfaces). They used hydrological models to study the effect of land use change in hydrology and implemented trend analysis to the bias between the modeled and the observed runoff to investigate changes in the catchment runoff that might arise due to land use changes. A few more attempts to implement hydrological models to investigate the impact of land use change have been reported in De Roo et al. (2001).

1.2 Model description

Soil and water assessment tool (SWAT) is a physical process based, distributed parameter, continuous time scale model that operates on a daily time step to perform simulations up to 100 years. It was developed at the University of Texas, USA and it is freely distributed on the internet. The academic community has been improving and adjusting the model continually, which allowed it to spread all over the world. SWAT model was developed to quantify the influence of land use practices on large, complex watersheds and to predict the effect of management decisions on water production. The model was developed to predict management impacts on water, sediment, and chemical yields. The major components of the SWAT model include hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, bacteria, agricultural management, channel routing, and reservoir routing. The model is able to simulate the long-term impacts of land use change on water quantity and quality. It has been extensively used and tested since 1993 by mainly hydrologists for soft engineering related issues (Demirel et al., 2009).

1.3 Problem statement

Land use changes are often considered to be the reason for increased runoff results in higher flows during rainfall events, which in turn increases the frequency at which a river floods the adjacent land areas. Likewise, this increase in runoff and channel flow often drastically increases the erosion of river channel beds and banks, potentially threatening bridges and other hydraulic structures. On the other hand, groundwater recharge decreases due to the increase in the impervious surfaces and decrease in the soil infiltration rate. This may lead to a recession in the river base flow especially during the dry season.

Malaysia is rapidly developing, changing from agriculture-based nation to an industrial nation. This change is therefore associated with a series of land use change and land development which favors the use of land for industrial development. Land development can further be associated with increased impervious areas which cause an increase in surface runoff and decrease in groundwater recharge.

The land use in the study area has changed from the year 1984 up to the present. The urban area and oil palm have increased while forest and the rest of land use/land covers have decreased. The study area feed the river which is the main source of irrigation water supply for Tanjong Karang, 20,000 ha rice granary in the downstream. The rapid developments will result in the reduction of the flow during dry season since the required quantity of irrigation water for double cropping of rice should be available at all time. Since rainfed agriculture in Malaysia may not have reservoirs for irrigation water supply, it is very important to have a high base flow so that enough water is available for double cropping irrigation during the year.

Previous studies emphasized the effectiveness of structural best management practices (BMP) such as constructed storage systems (ponds) applications on watershed management. A part of that, it can control the impacts of urbanization in developing watersheds regarding water quantity and quality. Identifying the critical areas and BMP types, locations, and sizes are important to achieve objectives such as decreasing peak flow and pollutions.

Wahab, 2010 developed model to suggest the optimal location, size, and numbers of the ponds but while he put the base flow of the river in his consideration, he didn’t consider the water demand of Tanjung Karang which is very important for rice irrigation. The researcher also found the optimal size, number and operation of ponds but he couldn’t find the best optimal number and operation because he used a mathematical model which cannot calculate all the available options that can provide the best optimal.

Based on these issues, this research has been devoted to bridge the gap through evaluating the impacts of land use changes on the hydrologic response in the watershed. Moreover, a Watershed Best Management Practice model using Machine Learning (WBMP-ML) has been developed to determine the best optimal locations, numbers and operations of ponds to control flood during high flow season, maintain river base flow and supply irrigation water demand during low dry season. In other words, as the impact of land use changes in the basin constitute a great challenge, there is a need to calibrate and validate a hydrologic model such as (SWAT) that can provide a significant assessemt working on simulating the hydrologic response of the basin resulted from land use changes. More significantly, there is a need to predict the impact of future land use change on flood and drought, then the mitigation of that negative impact of land use change on extreme hydrologic events magnitude can be implented through developing a model using Machine Learning and this what is targted by the current study.

1.4 Objectives

The main aim of this study is to evaluate the impacts of land use changes on the Hydrologic response in the watershed, and to develop a Watershed Best Management Practice model using Machine Learning (WBMP-ML) to determine the best optimal locations, numbers and operations of ponds to control flood during high flow season, maintain river base flow and supply irrigation water demand during dry season. The specific objectives of the study are:

1. To calibrate and validate the hydrologic model (SWAT) for assessing the impacts of land use changes in the basin.
2. To simulate the hydrologic response of the basin due to land use changes and predict the impact of future land use change on flood and drought.
3. To develop a model using Machine Learning to mitigate that negative impact of land use change on extreme hydrologic events magnitude.

1.5 Contributions

This study offers an innovative analytical and methodological approach as the following contributions:

i. Best calibrated parameter values were obtained by flow calibration of three years with different land use individually using the corresponding rainfall of that years. Then that calibrated parameters were used for validation using two different years also. The obtained parameter values were able to validate the model of SWAT to simulate and predict the flow at any condition.

ii. Simulation of past land use using SWAT model showed clearly the negative impact of land use changes on streamflow which needed to mitigate.

iii. SWAT model used to predict the future planned land use of 2020 and scenarios of 40% and 50% urban to clarify the impact of land use on stream flow to help planners and decision-makers to take that impacts into account when they formulate future plans for land development

iv. Wahab, 2010 developed model to suggest the optimal location, size, and numbers of the ponds but while he put the base flow of the river in his consideration, he didn't consider the water demand of Tanjung Karang which is very important for rice irrigation. Also, he found the optimal size, number and operation of ponds but he couldn't find the best optimal number and operation because he used a mathematical model which cannot calculate all the available options that can provide the best optimal. This study comes to address the above-mentioned challenges with implications to the local and regional understanding of tropical hydrology system. It deals with the application of modeling that is new and an important aspect in understanding the global hydrological system; Machine Learning was used for this purpose to control flood and drought and be able to provide the best optimal choice with less size, numbers and best operation of ponds and consider the water demand as well.

1.6 The Scope of the Work

This work involved studying the impacts of land use change on the watershed runoff as an important subject in the field of water resources management. As a result of land use change which ranges from agriculture based to industrial based, land covers are subject to different changes. Many catchments and river basins are converted to impervious surfaces which reduce the infiltration rate of the soil and subsequently lead to increase the amount and rate of surface runoff. This underscores need to investigate the relationship between land use changes on the river basin and the stream flow pattern. To achieve this, SWAT model was employed to assess the impacts of land use changes on streamflow in Upper Bernam River Basin, Malaysia. Then, Machine Learning was used to control the extreme hydrologic events as a tool to find the best optimal operation of bonds as BMP.

1.7 Significant of the Research

Around 85% self-sufficient rice production in Malaysia is managed through double cropping method which necessitates that the required water for paddy irrigation to be made available at all times. But as 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. Previous studies such as that by Wahab (2010), suggested ponds to mitigate the impact of flood on the basin. However, while the the study focused on the river base flow, it didn’t consider the water demand of Tanjung Karang which is very important for rice irrigation.

Due to the land use change, land covers are subjected to changes. Many watersheds and river basins soils are converted to impervious surfaces which lead to a decrease in the soil infiltration rate and consequently increase the amount and rate of runoff. Hence, it is important to investigate the relationship between land use changes on the river basin and the river flow pattern.

For this purpose, Wahab (2010) used hydrological model (SWAT) and his own model (WARM) to get the optimal operation, number and size of ponds but he couldn’t find the best optimal number and operation. The reason beyond that is the use of a mathematical model which does not have the ability to calculate all the available options that can provide the best optimal. Consequently, in this study, an integrated methodology based on hydrological and Machine Learning modeling approaches was developed to assess the impacts of land use changes on the magnitude of river flow and mitigate the negative impact of that changes. This practice will be a significant contribution to knowledge to improve the hydrological modeling in the field of water resources engineering. Since this study covers a very important river basin in Malaysia, any other river basin in the country can be modeled after the proposed methodology is applied successfully.

Improving the stream flow simulations and future developments to obtain better estimates for water quantity parameters by simulation are possible. Such developments will prove to be useful for long term water resources planning and watershed management activities. This will be a valuable contribution to flood forecasting applications as well as better irrigation water management, especially in the rice granaries.

1.8 Thesis Organization

This thesis is organized into five chapters. The first chapter is the introduction which includes a background on the land use change and its effects on runoff estimation and rainfall measurements. The chapter also includes an introdution to SWAT application which is a tool for runoff estimation and water quality measurement. The problem statement, objectives, contribution and significance of the study are presented in this chapter. Chapter two presents the Literature Review with in-depth discussions of the concept of hydrological modeling in the studies of watershed hydrology and landuse change. The chapter elaborates on the common methodologies of remote sensing, GIS and computer integrated modeling and their implications to manage watershed hydrology against potential impacts of land development. The land use change and its effects on groundwater recharge and runoff estimation was also presented in Chapter two. The impacts of climate change was also discussed in the chapter.

The description of the study area and the methodology used in this study are presented in Chapter three. Chapter four presents the Results and Discussions of the work highlighted in Chapter three. A general summary of this work is presented in chapter five and some general conclusions and recommendations from the study are highlighted.

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LIST OF PUBLICATIONS

Alhetar, Najeeb, M., Rowshon,M., Thamer, Ahmed, Mohammad., Ghazali, A.H., Amin, M. S. M., Alansi, A. W., Shafri, H. Z. M., Osamah, Hamdn. Temperature Trend Analysis for Bernam River Basin, Malaysia. *Journal of Ethiopian Journal of Environmental Studies and Management*, (Acceptance 2019).

Alhetar, Najeeb, M., Rowshon,M., Thamer, Ahmed, Mohammad., Ghazali, A.H., Amin, M. S. M., Alansi, A. W., Shafri, H. Z. M., Osamah, Hamdn. Impact of Land Use Change on Watershed Management. *International Journal of Business Society*. (Acceptance 2019).

Osamah Hamdn., Amin, M. S. M., Ghazali, A.H., Thamer, Ahmed, Mohammad., Shafri, H. Z. M., Alhetar, Najeeb, M. Climate Change Impact on Water Availability in Upper Bernam River Basin Using Downscaled Global Climate Change Model Data with SWAT Model. *Journal of Ethiopian Journal of Environmental Studies and Management*, (Acceptance 2019).

Conferences

Alhetar, Najeeb, M., Rowshon,M., Thamer, Ahmed, Mohammad., Ghazali, A.H., Amin, M. S. M., Alansi, A. W., Shafri, H. Z. M., Osamah, Hamdn, Adesiji, A.R. "Comparing Methods of Rainfall trend Analysis in Upper Bernam River Basin, Malaysia." *The 7th International Civil Engineering Conference, 2016, Nigeria.*

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11. Latex, UPM, Malaysia.
12. Python, Data Science and Machine Learning, UPM, Malaysia.

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