MODELLING THE IMPACTS OF LAND-USE AND CLIMATE CHANGE IN SKUDAI RIVER WATERSHED

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I dedicated this work to

Late Dr. Noor Baharim bin Hashim

and

Late Danladi Bello Guga

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ABSTRACT

Predicting the impact of land-use, climate change and Best Management Practices (BMPs) on a watershed is imperative for effective management of aquatic ecosystems, floods, pollutant control and maintenance of water quality standard in a tropical climate. Based on the prediction, unique information can be derived that is critical to the watershed management under dynamic environmental conditions. The study seeks to evaluate how land-use and climate change influences the hydrology, sediments, and water quality of an urbanized tropical watershed in which the land-use is controlled by urban development as observed from historical and projected land covers. Therefore, the response of a tropical watershed and its river system under climate and land-use changes were evaluated using Skudai River watershed as a case study. Seven land-use scenarios from the year 1989 to 2039 were developed using remote sensing techniques, and nine projected climate change scenarios were derived using dynamically downscaled model from the based projection under representative concentration pathways (RCPs) scenarios. These scenarios were integrated into the Hydrological Simulation Program FORTRAN (HSPF) model to determine the impact of land-use, climate change, and pollutants control via best management practices in a tropical watershed system. The model was calibrated and validated from 2002 to 2014, and the performance coefficients showed a good correlation between simulated and observed streamflow, water temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), and orthophosphate (PO_4) concentrations. The output of the validated model under land-use changes showed that the hydrological water balance of the watershed changes with total runoff as the primary source of water loss. For streamflows and in-stream concentrations (NH_3-N, NO_3-N, and PO_4), as the streamflow increases, NH_3-N and PO_4 concentrations increase while NO_3-N concentration showed low response as compared to the other two concentrations. As urban development increased from 18.2% to 49.2%, nutrient influx such as total nitrogen (TN) and total phosphorus (TP) loads increased from 3080 to 4560 kg/yr and from 130 to 270 kg/yr, respectively. Furthermore, TN to TP ratio changed from 8.3:1 to 7:1, an indication that the rivers are receiving excess nutrients flows which might result in eutrophication at the downstream of the watershed. The amount of sediment load produced in the watershed decreased by approximately 17.8% as a result of the changes in land-use derived from urban development. Further analysis of the results showed that climate change with high rainfall and increase in air temperature do not affect DO concentration and water temperature in comparison to climate change with low rainfall. Implementation of multiple detention pond BMPs in identified Critical Source Areas (CSAs) reduced pollutant loads by 14% to 27% as compared to watershed without any BMPS, independent of climate and land-use changes. Analysis of BMPs using existing and future land-use is very important to ensure their effectiveness to control and maintain water quality. This study provides a basis to develop water resource management in an urban watershed and be resilient to land-use and climate changes.

ABSTRAK

Ramalan impak guna tanah, perubahan iklim dan Amalan Pengurusan Terbaik (BMPs) di kawasan tadahan air adalah penting untuk pengurusan ekosistem akuatik, kawalan pencemaran dan penyenggaraan kualiti air dalam iklim tropika. Berdasarkan ramalan tersebut, maklumat unik boleh diperoleh untuk pengurusan tadahan air di bawah keadaan persekitaran dinamik. Kajian ini bertujuan untuk menilai bagaimana penggunaan tanah dan perubahan iklim mempengaruhi hidrologi, sedimen, dan kualiti air di kawasan tadahan air tropika bandar di mana penggunaan tanah dikawal oleh pembangunan bandar seperti yang diperhatikan dari sejarah guna tanah dan guna tanah terunjur. Oleh itu, tindak balas dari kawasan tadahan tropika dan sistem sungai di bawah perubahan iklim serta penggunaan tanah dinilai menggunakan kawasan tadahan air Sungai Skudai sebagai kajian kes. Tujuh senario guna tanah dari tahun 1989 hingga 2039 telah dibangunkan dengan menggunakan teknik penginderaan jarak jauh, dan sembilan senario perubahan iklim terunjur diperolehi menggunakan model skala turun dinamik daripada unjuran asas senario di bawah *representative concentration pathways* (RCPs). Senario ini telah diintegrasikan ke dalam model Program Simulasi Hidrologi FORTRAN (HSPF) untuk menentukan kesan guna tanah, perubahan iklim, dan kawalan pencemaran melalui amalan pengurusan terbaik dalam sistem tadahan air tropika. Model ini telah ditentukan dan disahkan dari tahun 2002 hingga 2014, dan pekali prestasi menunjukkan korelasi yang baik antara keputusan simulasi dengan data cerapan untuk kadaralir sungai, oksigen terlarut (DO), kehendak oksigen biokimia (BOD), ammonia nitrogen (NH_3-N), nitrat nitrogen (NO_3-N), dan kepekatan *orthophosphate* (PO_4). Hasil analisis daripada model yang telah disahkan di bawah perubahan penggunaan tanah menunjukkan bahawa perubahan imbangan air hidrologi dengan sumber utama kehilangan air adalah daripada air larian. Untuk aliran sungai dan kepekatan kadaralir (NH_3-N, NO_3-N dan PO_4), kepekatan NH_3-N dan PO_4 meningkat manakala kepekatan NO_3-N menunjukkan tindak balas yang rendah berbanding dua kepekatan yang lain. Oleh kerana pembangunan bandar meningkat daripada 18.2% kepada 49.2%, jumlah nutrien seperti jumlah nitrogen (TN) dan jumlah fosforus (TP) meningkat daripada 3080 kepada 4560 kg setahun dan daripada 130 kepada 270 kg setahun. Tambahan pula, nisbah TN ke TP berubah dari 8.3:1 hingga 7:1, menunjukkan bahawa sungai-sungai menerima aliran nutrien yang berlebihan yang boleh mengakibatkan proses eutrofikasi di kawasan hilir tadahan air. Jumlah beban enapan yang dihasilkan di kawasan tadahan air menurun sebanyak 17.8% akibat perubahan penggunaan tanah yang diperoleh daripada pembangunan bandar. Analisis lanjutan menunjukkan perubahan iklim yang meningkatkan keamatan hujan dan suhu udara tidak memberi kesan kepada kepekatan DO dan suhu air apabila dibandingkan dengan perubahan iklim dengan hujan yang berkeamatan rendah. Implementasi kolam penahan air untuk tujuan BMPs di kawasan sumber kritikal (CSAs) telah mengurangkan beban bahan cemar daripada 14% kepada 27% berbanding kawasan tadahan air tanpa BMPs, tanpa perubahan iklim dan perubahan guna tanah. Analisis BMPs menggunakan guna tanah sedia ada dan guna tanah masa depan adalah sangat penting untuk memastikan keberkesanannya untuk mengawal dan memelihara kualiti air. Kajian ini menyediakan suatu dasar untuk membangunkan pengurusan sumber air di kawasan tadahan air bandar dan berdaya tahan terhadap perubahan guna tanah dan perubahan iklim.

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LIST OF ABBREVIATIONS

DO	-	Dissolved oxygen
BOD	-	Biochemical oxygen demand
PO4	-	Ortho-phosphate
NH4-N	-	Ammonia nitrogen
NO3-N	-	Nitrate nitrogen
TN	-	Total nitrogen
TP	-	Total phosphorus
SED	-	Sediment
L_n	-	Land-use scenarios
S_n	-	Climate change scenarios
LU/LC	-	Land-use/land cover
T_w	-	Water temperature
HSPF	-	Hydrological simulation program FORTRAN
CAT	-	Climate assessment tools
BASINS	-	Better assessment science of integrated point and nonpoint sources
NPS	-	Nonpoint sources
R^2	-	Coefficient of determinant
UCI	-	User control input
WDMUtil	-	Weather data management utility
PBIAS	-	Percent bias
KRMSE	-	Kriging root mean square error
GIS	-	Geographic information system
LCM	-	Land change model

MCE	-	Multi criteria evaluation
SEN	-	Sensitivity
NSE	-	Nash-Sutcliffe coefficient of efficiency
HRU	-	Hydraulic response unit
BMPs	-	Best management practices
CSAs	-	Critical source areas

NOTATION OF MODEL PARAMETERS

ACQOP	-	Accumulation rate of quality constituent
AGWETP	-	Fraction of remaining evapotranspiration from active groundwater
AGWRC	-	Base groundwater recession
ANAER	-	Concentration of dissolved oxygen below which anaerobic condition exist
BASETP	-	Fraction of remaining evapotranspiration from baseflow
BENOD	-	Benthal oxygen demand at 20°C
BRBOD1	-	Benthal release of BOD at high oxygen concentration
BRBOD2	-	Incremental to benthal release of BOD under anaerobic conditions
BRNIT1	-	Benthal release rate of inorganic nitrogen under aerobic conditions
BRNIT2	-	Benthal release rate of inorganic nitrogen under anaerobic conditions
BRPO41	-	Benthal release rate of ortho-phosphate under aerobic conditions
BRPO42	-	Benthal release rate of ortho-phosphate under anaerobic conditions
CEPSC	-	Interception storage capacity
CFSAEX	-	Correction factor for solar radiation
DEEPFR	-	Fraction of groundwater inflow to deep groundwater
DENOXT	-	Dissolved oxygen concentration threshold above which denitrification ceases
ELEV	-	Mean reach elevation
EXPOD	-	Exponential factor in the dissolved oxygen term of the benthal oxygen demand equation
EXPRED	-	Exponent to depth used in the calculation of the reaeration coefficient
EXPREL	-	Exponential factor in the dissolved oxygen term of the benthal BOD release equation
EXPREV	-	Exponent to velocity used in the calculation of the reaeration coefficient

EXPSND	-	Exponent of sandload input power function formula
INFEXP	-	Exponent in infiltration equation
INFILD	-	Ratio between maximum and mean infiltration capacities
INFILT	-	Index to infiltration capacity of the soil
INTFW	-	Interflow inflow parameter
IRC	-	Interflow recession parameter
KATRAD	-	Longwave radiation coefficient
KBOD20	-	BOD decay rate at 20ºC
KCOND	-	Conduction-convection heat transport coefficient
KEVAP	-	Evaporation coefficient
KGRND	-	Heat conductance coefficient between the ground and the mud layer
KMUD	-	Heat conductance coefficient between water and the ground
KNO220	-	Unit oxidation rate of nitrite at 20ºC
KNO320	-	Unit denitrification rate of nitrate at 20ºC
KODSET	-	Rate of BOD settling
KSAND	-	Coefficient of sandload input power function formula
KTAM20	-	Unit oxidation rate of total ammonia at 20ºC
KVARY	-	Variable groundwater recession
LSUR	-	Length of overland flow plane
LZETP	-	Lower zone evapotranspiration parameter
LZSN	-	Lower zone soil nominal storage
M	-	Erodibility coefficient of the sediment
MALGR	-	Maximal unit algal growth rate for phytoplankton
MUDDEP	-	Depth of mud layer
NSUR	-	Manning's n (roughness) for overland flow plane
PETMAX	-	Temperature below which evapotranspiration is reduced
PETMIN	-	Temperature below which evapotranspiration is zero
REAK	-	Empirical constant for equation used to calculate the reaeration coefficient
SLSUR	-	Slope of overland flow plane
SQOLIM	-	Limiting storage of quality constituent
SUPSAT	-	Allowable dissolved oxygen supersaturation
TAUCD	-	Critical bed shear stress for deposition
TAUCS	-	Critical bed shear stress for scour
TCBEN	-	Temperature correction coefficient for benthal oxygen
TCBOD	-	Temperature correction coefficient for BOD decay
TCDEN	-	Temperature correction coefficient for the denitrification rate
TCGINV	-	Temperature correction coefficient for surface gas invasion
TCNIT	-	Temperature correction coefficient for the nitrogen oxidation rates

TGRND	-	Ground temperature
UZSN	-	Upper zone nominal soil moisture storage
WSQOP	-	Rate of surface runoff which will remove 90% of stored quality constituent

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Watersheds are changing systems which are in a constant state of transformation due to human activities or natural occurrences [1].What we do in a watershed can improve the amount and quality of water that is available [2]. Advance in technology provides insightful information about watershed systems under various multiple stressors. Understanding the significance of each stressor in a watershed is essential for adequate water resources management. Prior researches in rivers have revealed that stressors frequently interrelate, resulting in complex, unclear result that cannot be projected based on the impact of the specific stressors involved [3]. The introduction of technologically based approach provides some improvement in this regard by integrating spatial and temporal properties of a watershed (i.e. topography, climates, land-use, etc.) to predict the likely responses at different watershed conversion stage using measured data.

Climate change and land-use/land-cover (LU/LC) are two significant stressors for small rivers or streams and have common effects on stream ecosystem, and these are best presented on a watershed scale. This two stressors have the potential to significantly alter the hydrologic cycles and consequently increases transport of diffuse pollutants to the receiving streams and rivers. They are directly related to the amount of diffuse pollutants discharge into the rivers and water quality conditions within a watershed [4]. Climate and LU/LC changes are predetermined conditions that must be incoorporated in the planning and management of water resources at watershed-scale. In the future, watershed management will depend on the ability of the existing best management practices (BMPs) to reduce nonpoint sources pollutants generated from land areas under different climatic and LU/LC variations.

This research focused on the application of a hydrological and water quality model (Hydrological Simulation Program – FORTRAN, HSPF) for hydrological, water quality and best management practices in a watershed scale under the influences of climate and LU/LC changes. It is used to simulate watershed hydrology and water quality on the land surface and in the river. The model contains hydrological and water quality tools to simulate the impact of climate change and LU/LC variation on the watershed system. This study presents the application of HSPF model to Skudai River watershed (Johor, Malaysia), and it was used to evaluate present and projected LU/LC and climate change effects on hydrology, sediments, and water quality. It also evaluates the effectiveness of targeted best management practices under climate and LU/LC changes.

1.2 Background of the Study

Malaysia falls in a region characterized by high constant temperatures, abundant rainfall, and humidity [5]. This characteristics weather conditions usually result to environmental problems of which solid understanding of the natural conditions is critical. Like many other government initiatives, Malaysian government introduces policies and regulations to protect and improve surface water conditions that is shouldered under different departments and agencies at both local and federal level [6]. Since the inception of these policies, a little improvement was observed, particularly at the watershed level. It was due to the rapid development taking place in the watershed land areas coupled with the changing weather conditions.

The existing and future urban development are certain human activities, but it negative impacts on the stream ecosystem need to be evaluated for environmental and human safety. Examining the effects can inform decisions, planning, and policies affecting freshwater resources by studying the interactions between watersheds and stream conditions [7]. The amount of nutrients and pollutants produced from urban areas are among the leading causes of stream impairment in most urbanized watersheds [8-10]. For example, as urban development grows, vegetation and wetland areas are converted to impervious surfaces (buildings, roads, etc.), which changes hydrologic regimes, ecosystem distribution, and nutrient dynamics [11, 12]. These changes adversely affect water quantity and quality, aquatic habitat, functions of stream ecosystems [13] and socioeconomic concerns [14]. The estimation of watershed potential LU/LC has become an important driver in urban planning and watershed management and it is strongly related to future development stressors, because it can be identified and controlled [15-18]. Detecting the impact of LU/LC are important to stream regulation and management since top decisions and guidelines are relatively built on finding environmental consequences resulting from watershed disturbance [7]. A wide range of studies on water quality and quantity at watershed scale examine the effects of past variation in LU/LC on the hydrology and water quality conditions [19-23], but integrating them into future perspective is relatively low.

On the other hand, climate change due to increased variability in weather conditions, with extreme events such as floods, have been predicted to have significant impacts on water quantity and quality [24-30]. The impact of climate change on human health and aquatic ecosystems can be viewed through water quality impairment resulted by higher water temperatures, increased/decreased precipitation, moderate and extreme flow conditions [31]. The relationship of climate change affecting water resources have been identified [32, 33]. Water quality impairments due to extreme weather events have demonstrated how climate change is generating a significant threat to both the quantity and quality of freshwater resources [34, 35], and could result in societal and economic costs [36]. Some studies have shown the capability of climate change to alter the characteristics of the surface water, and influence land surface processes that controls the generation, discharge, and transport of toxic materials and anthropogenic contaminants to both ground and surface waters [37-41].

However, there is an apparent lack of understanding of accurate LU/LC change (both historical and future) in analyzing the potential water quality impacts in tropical watersheds. The reactions of water quality to climate changes in a tropical climate remain unclear. Furthermore, the prediction of future LU/LC from the historical LU/LC characterizations are either unutilized or often ignored, or are not directly connected to the present LU/LC category when doing the projection. Consequently, the effects of projected urban LU/LC forms and trends, under different climate emission scenarios, on surface water quantity and quality at the watershed scale and sub-watershed levels are currently uncertain in tropical regions like Malaysia.

Adequate water resources use and protection under dynamic physical settings require the application of watershed models that can simulate different flow systems. The implementation of watershed management actions required details understanding of the watershed hydrological and water quality behaviour under different anthropogonic conditions. Doing this is possible by application of watershed models, because watershed models are suitable technical tools used in the management of watersheds. They are computer-based models that relate the origins and transport of multiple pollutants from both point and non-point sources in the whole catchment drained by a river [42]. Identifying the complexity of the entire hydrologic system; pollutants transport using these models, input data such as soil types, topography, LU/LC category, type of watershed management practices, meteorology, atmospheric depositions and point sources are needed. Also, an additional task is usually brought in when these models are used to forecast the impacts of various stressors [43].

1.3 Problem Statements

Prior research have indicates that tropical river system were the most diverse freshwater ecosystems on earth [44] and the most expected to be impacted by climate change and other human activities [45]. Due to their geographical location, rivers in the tropics regions are exposed to solar radiation more frequently coupled with low inter-annual and inter-seasonal climatic variation [46]. The anthropogenic impacts are more serious in tropical countries [45], increasing the likelihood of both water quality and ecosystem malfunction. Due to all these factors acting simultaneously and affecting the aquatic ecosystem, and watershed physical setting, it is likely that relationship between natural and chemical variables with biological communities in tropical streams will result in responses differently to that observed in temperate rivers. As the predicted high temperatures that is expected to manifest earlier than any other climatic groups [40], these will directly affect tropical watersheds in terms of water availability and climatic complexity such as frequent storms events, and water quality degradation (such as eutrophication). Consequently, these will result in changes in the aquatic system and its composition, distribution, and habitats [47]. A lot of studies on climate change and LU/LC have acknowledged its impact on many scales, but its influence under regular high temperatures area in a LU/LC and climate changes scenarios is limited [40]. There is need for awareness on the significances of these physical variables which might result to an unproductive aquatic ecosystem inducing the risks for freshwater aquacultural practices and economic crisis [48]. Hence, the adequate knowledge on the relatives interaction between LU/LC and climate changes in tropical watersheds is required.

Furthermore, the location of a watershed and linked of its land boundary with the sea creates an extreme pressure gradient that caused a lot of rainfall. The combination of this effect and extremes temperature in equatorial regions in the course of maritime exposure produces extreme weather conditions and frequent occurrence of floods and this will increased water pollution [49]. Studies by Salarpour *et al.* [50] shows that 12% of the Skudai River watershed was likely to flood for 100 years recurrence interval and 8% for 2 years recurrence interval and this will be more critical given the planned development under Iskandar Malaysia development plan with a projection of about 80% urban dominated areas [51] whereby Iskandar Malaysia controls the whole of the Skudai River watershed. A detail hydrological and water quality study of the watershed is critical, as it will guide decision making and improvement of the existing management practices. Recent research shows that about 50% of the sub-watersheds in the Skudai River watershed have a negative watershed sustainability index based on measured potential flood damages (PFD) and potential water quality deterioration [52]. Muhammad [53], shows that rivers in Skudai watershed are prone to water quality degradation due to rapid development, industrialization and increase population.

Malaysia environmental quality report shows that some of the rivers in Johor watersheds have persistently maintained their poor water quality status compared with the previous reports of 2008 and 2013 [54]. Melana River (in Skudai River watershed) was among the rivers identify in the report, and studies have shown that in the future the conditions might be deteriorated [52]. The degradation of water quality is a product of multiple LU/LC activities and climate conditions, including both at point sources (with a single waste load allocation) and non-point sources areas from a diffused pollution loads. Harnessing these sources using modelling approach will provide an information that is critical for sustainable water resources managament in a tropical watershed system.

1.4 Objectives

This study involves the development of water quantity and quality model of a tropical watershed based on its background conditions. The developed model is aim to assess the influences of land-use and climate change on a watershed system using Skudai River watershed as a case study. A proposed mitigation action via best management practices are presented alongside the impacts of land-use and climate changes. The objectives of this study were outlined as follows.

i To develop the hydrological and water quality model of a tropical watershed using Skudai River watershed as a case study;

ii. To assess the impact of land-use changes on the hydrology, sediment, total nitrogen and phosphorus pollutants in the watershed;

iii. To evaluate the impact of the projected temperature variations and its effects on water temperature and dissolved oxygen concentrations in the watershed;

iii. To estimate the effectiveness of the targeted best management practices under land-use and climate change scenarios on the identified critical sources areas in the tropical watershed system.

1.5 Scope of Study

In order to achieve the study objectives, several specific tasks were performed. The following are the specific tasks and assumption which were used in this study:

i. The case study was limited to Skudai River watershed;

ii. The historical and future land-use of the study area were produced using remote sensing techniques and were used as land-use scenarios;

iii. Application of hypothetical land-use scenarios that are different to the remote sensed developed land-use scenarios to evaluate the interaction between catchment land-use variation and climate change on small tropical rivers within the watershed;

iv. Application of geostatistical estimation method to capture the spatial rainfall distribution of the study area and integrates it into the model to mimic the spatial variability of rainfall in the watershed;

v. Determination of the sensitivity of the model calibration parameters to reduce uncertainty on the modelling results;

vi. The impact of land-use considered in this study are based on water balance variability, sediment loads and changes on the non-point sources pollutants;

vii. Two land-use scenarios were used in the identification of critical source areas for targeted best management practices in the study area.

1.6 Significance of the Study and Contribution

Water resource managers need to utilize cutting edge tools to fulfill their management interests with high efficiency, as water resource management practices will be affected due to lack of this tools. Inputs for critical decision making requires data monitoring that is limited by human resources and short-term sampling studies and sporadic monitoring programs that are commonly observed. The flexibility in managing enormous quantities of dynamic data input, transferring data from similar gauged environment or by extrapolating the available data to ungauged environments reduce these problems for water resources expert and simplify alternatives for decision making, hence the application of modeling approach. Watershed modeling estimates the hydrology and pollutant dynamics derived from a point and non-point sources to water bodies utilizing different algorithms that depend on measured data [55]. Skudai River watershed required such approach due to its influence and significant for water quality control and management of the Johor Strait. This approach aimed at identifying the watershed hydrological and hydro-chemical components that controls the watershed hydroenvironmental properties which will be utilized for effective management of the watershed or similar watershed.

In the other hand, the application of semi-distributed models is still relatively new in Malaysia, even though they have been used widely in other countries [56]. There is no detailed study that considered the impact of climate and temporal land-use/land cover (LU/LC) changes on the hydrology, soil erosion (sediment), water temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), nutrients. Furthermore, evaluating the effectiveness of best management practices under this conditions (climate and land-use) at watershed scale is also relatively low in tropical regions. The effects of multiple stressors on the tropical rivers are poorly understood, and this study present the impact of two important stressors; LU/LC and climate change. Effects of urbanization on the river system and the shift of the river trophic class were illustrated, as prior studies do not demonstrated the trends and changes in the trophic class of tropical river systems under an increased urban development. The efficiency of the targeted best management practices (BMPs) in the reduction of water pollutions under the influence of climate and LU/LC changes were predicted, as previous studies in Malaysia focused on specific BMPs type and its performance, which is centered on flood attenuation with few on water quality control in a localized condition. While there are a lot of studies addressing the effectiveness of BMPs at a local stage (either confine residential areas or isolated complex in Malaysia), no available information shows an attempt to determine the effectiveness of BMPs in the reduction of water pollution using identified critical sources areas (CSAs) at a sub-watersheds or watershed-scale. In fact, the concept of identified CSAs for targeted BMPs implementation using watershed modelling is relatively new, and its application in an urban dominated watershed and in a tropical climate are yet to be elucidated. The urban stormwater manual of Malaysia (MSMA) does not include it in the conditions required for stormwater management system implementation and siting [57]. Furthermore, it is imperative to evaluate the impact of BMPs to interrupt nonpoint source pollution at sources and treat the pollutant considering future LU/LC and climate scenarios. This approach will guide relevant policies to manage small tropical rivers and watersheds under climate and LU/LC change which are absent or poorly informed.

1.7 Thesis Structure and Organization

This study is designed to model the impact of climate change, LU/LC and the effectiveness of targeted best management practices under climate and LU/LC scenarios in a watershed system. Skudai watershed was chosen as a case study due to its location, planned future development, and mixed LU/LC. A measured data with different resolution, measurement and scale were used for the development and application of the watershed model. This thesis was structured and designed in six chapters to present the study designed, analysis, results, discussion and recommendation. Chapter 1, represent the study objectives, statement of problems, scope, and contribution to knowledge. Chapter 2, provides the general backgrounds and reviews of literature relevant to the research methodology and materials used. In Chapter 3, the materials and methods used to achieve the study objectives were presented. The model parameter estimation, calibration, and validation of the model with the development of LU/LC scenarios are presented in Chapter 4. The result and analysis of the model output under climate changes, LU/LC and BMPs effectiveness are presented in Chapter 5. Also, the discussion of the results analysis and comparing the results with other findings of other researchers were included in the same chapter. Finally, in Chapter 6, the conclusion of the findings of the study and recommendation for future works were presented

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