UNIVERSITI PUTRA MALAYSIA

MODELING THE EFFECT OF LAND USE AND LAND COVER CHANGES ON LONG-TERM RAINFALL/RUN-OFF AND NON-POINT SOURCE POLLUTION IN THE UPPER KELANTAN RIVER BASIN, MALAYSIA

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By

JABIR HARUNA ABDULKAREEM

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

September 2018

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DEDICATION

This thesis is dedicated to my late parents, Mallam Haruna Abdulkarim and Hajiya Asmau Talatu Haruna through whom Allah brought me into this world. May your souls continue to rest in peace and may Aljannah Firdaus be your final resting home, Ameen.

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

MODELING THE EFFECT OF LAND USE AND LAND COVER CHANGES ON LONG-TERM RAINFALL/RUN-OFF AND NON-POINT SOURCE POLLUTION IN THE UPPER KELANTAN RIVER BASIN, MALAYSIA

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JABIR HARUNA ABDULKAREEM

September 2018

Chairman : Wan Nor Azmin Sulaiman, PhD
Faculty : Environmental Studies

Kelantan River basin, Malaysia is a tropical catchment receiving heavy monsoon rainfall coupled with intense land use and land cover (LULC) changes making the basin consistently flood prone. A study was conducted to model the effect of LULC changes on long-term rainfall-runoff and non-point (NPS) pollution in the upper portion of the basin. First, LULC maps corresponding to 1984, 2002 and 2013 were analyzed. The basin was delineated into four catchments (Galas, Pergau, Nenggiri and Lebir) due to it's and size for improved results accuracy. Flood hydrographs corresponding to 1984, 2002 and 2013 LULC condition were simulated using HEC-HMS. Relative changes in the peak flow of the three subsequent conditions were determined for different return periods (2, 5, 10, 20, 50 and 100 years). By using flood response approach, flood source areas were identified and ranked based on the values given by gross flood index (*F*), per unit area index (*f*) and flood area index (*fa*) where different results were obtained for each index. Long-term runoff dynamics due to LULC changes was determined using NRCS-CN model and its modifications. NPS pollution estimation was carried out using numeric integration in a GIS environment. Soil loss was estimated using RUSLE model. Result of land use analyses showed that deforestation for logging activities, agricultural purposes and urbanization were the major land use changes observed in the basin from 1984-2013. Lebir (48557.3 m^3/s) was the catchment with greatest contribution of peak discharge at the outlet under 2013 LULC condition. This is followed by Galas (43357.7 m^3/s), Pergau (33126.4 m^3/s) and Nenggiri (16729.1 m^3/s) in that order. The use of *fa* index gives better ranking and is therefore, recommended in ranking sub-basins with respect to their contribution to the outlet. Results of runoff dynamic reveal that proposed modified NRCS-CN model V (MNM V) was found to give the best runoff estimation based on model goodness of fit evaluation criteria. Thus, the MNM V was selected for runoff estimation from 1984-2014. It was observed from the results that runoff estimation increased with changes in LULC from 1984-2014 in all the selected runoff events and in all catchments.

Results of spatio-temporal variation of pollutant loads in all the catchments increased with changes in LULC condition as one moves from 1984-2014, with 2013 LULC condition found as the dominant in almost all cases. NPS pollutant loads among different LULC changes also increased with changes in LULC condition from 1984-2013; while urbanization was found to be the dominant LULC change with the highest pollutant load in all the catchments. This reveals the clear effect LULC changes on NPS pollution. Soil erosion results from RUSLE showed that 67.54% of soil loss is located under low erosion potential or 0-1ton ha-1 yr^{-1} otherwise known as reversible soil loss in Galas, 59.17% in Pergau, 53.32% in Lebir and 56.76% in Nenggiri all under the 2013 LULC condition. These results are higher than that of 1984 and 2002 LULC conditions.The novel methodologies developed in this study can be incorporated for regional hydrological studies and early warning systems for flood control.

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

PERMODELAN KESAN PERUBAHAN GUNATANAH UNTUK JANGKA MASA PANJANG HUJAN/LARIAN DAN SUMBER PENCEMAR BUKAN TITIK DI LEMBANGAN SUNGAI KELANTAN

Oleh

JABIR HARUNA ABDULKAREEM

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Lembangan Sungai Kelantan di Malaysia adalah kawasan tadahan tropika yang menerima hujan monsun yang tinggi. Perubahan guna tanah (LULC) yang pesat menjadikan kawasan tersebut terdedah kepada ancaman banjir. Satu kajian telah dijalankan di bahagian hulu Sungai Kelantan untuk memodelkan kesan perubahan guna tanah terhadap pencemaran air hujan jangka panjang dan pencemaran NPS. Pertamanya, peta guna tanah bagi tahun 1984, 2002 dan 2013 dianalisa. Lembagan Sungai Kelantan dibahagikan kepada empat sub-lembangan iaitu Galas, Pergau, Nenggiri dan Lebir. Hidrograf banjir pada tahun 1984, 2002 dan 2013 disimulasikan dengan menggunakan perisian HEC-HMS dan perubahan relatif pada aliran puncak bagi tiga keadaan berikutnya ditentukan untuk tempoh pulangan yang berlainan (2, 5, 10, 20, 50 dan 100 tahun). Dengan menggunakan pendekatan respon banjir, kawasan sumber banjir telah dikenal pasti dan disenaraikan berdasarkan nilai diberi oleh indeks (*F*) banjir, setiap indeks kawasan (*f*) unit dan indeks luas banjir (*fa*) di mana kesan berbeza telah diperolehi untuk setiap indeks. Dinamik larian air yang jangka panjang disebabkan perubahan LULC ditentukan menggunakan NRCS-CN model dan pengubahsuaian pengubahsuaiannya. Anggaran pencemaran NPS dijalankan menggunakan integrasi angka dalam persekitaran GIS. Kadar hakisan tanah dianggarkan menggunakan model RUSLE. Analisis penggunaan tanah menunjukkan bahawa penebangan hutan untuk kegiatan pembalakan, tujuan pertanian dan urbanisasi adalah perubahan penggunaan tanah utama yang dilihat di kawasan lembangan dari tahun 1984-2013. Bagi tahun 2013, Lebir merupakan kawasan sub lembangan yang paling tinggi menyumbangkan luahan air puncak dengan 48557.3 (m^3/s). Ini diikuti oleh Galas (43357.7 m^3/s), Pergau (33126.4 m^3/s) dan Nenggiri (16729.1 m^3/s). Penggunaan indeks fa disarankan dalam pengkelasan sub lembangan berdasarkan sumbangan setiap sub lembangan di outlet. Keputusan dinamik larian air menunjukkan bahawa model NRCS-CN yang dimodifikasi V (MNM V) yang dicadangkan didapati memberi larian air terbaik. Oleh itu, MNM V telah dipilih untuk anggaran larian air

dari 1984-2014. Hasil kajian menunjukkan bahawa anggaran larian air meningkat dengan perubahan dalam LULC dari 1984-2014 dalam semua peristiwa larian terpilih dan di semua kawasan tadahan. Keputusan variasi spatial-temporal beban pencemar di semua kawasan tadahan meningkat dengan perubahan keadaan LULC dari 1984-2014, dengan keadaan LULC 2013 didapati sebagai dominan dalam hampir semua kes. Beban pencemar NPS dengan perubahan LULC yang berbeza juga meningkat dengan perubahan dalam keadaan LULC dari tahun 1984-2013; manakala urbanisasi didapati perubahan LULC yang dominan dengan beban pencemar tertinggi di semua kawasan tadahan. Keputusan kajian ini jelas menunjukkan bahawa perubahan LULC memberi kesan terhadap pencemaran NPS. Keputusan hakisan tanah dari RUSLE menunjukkan bahawa 67.54% kehilangan tanah terletak di bawah potensi hakisan yang rendah atau 0-1 ton ha^{-1} yr^{-1} atau kehilangan tanah di Galas, 59.17% di Pergau, 53.32% di Lebir dan 56.76% di Nenggiri di bawah keadaan LULC 2013. Metodologi novel yang dibangunkan dalam kajian ini boleh digunakan untuk kajian hidrologi serantau dan sistem amaran serantau untuk kawalan banjir.

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I certify that a Thesis Examination Committee has met on 4 September 2018 to conduct the final examination of Jabir Haruna Abdulkareem on his thesis entitled "Modeling the Effect of Land Use and Land Cover Changes on Long-Term Rainfall/Run-Off and Non-Point Source Pollution in the Upper Kelantan River Basin, Malaysia" 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.

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LIST OF ABBREVIATIONS

A	Soil erosion rate
AMC	Antecedent moisture condition
AN	Ammonia nitrogen
ANOVA	Analysis of variance
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
C	Constant of channel maintenance
C	Land cover and management factor
C_k	Kurtosis
CN	Curve number
C_s	Skewness
D_d	Drainage density
DEM	Digital elevation model
DID	Department of Irrigation and Drainage
DOA	Department of Agriculture
EMC	Event mean concentration
F_f	Form factor
FR	Frequency ratio
GIS	Geographic Information System
H	Basin relief
HRU	Hydrologic response unit
HSG	Hydrologic soil group
IDW	Inverse distance weighted
K	Soil erodibility factor

K-S	Kolmogorov-Smirnov
L	Length of overland flow
LS	Terrain factors (slope length and steepness)
L_{sm}	Mean stream length
L_u	Stream length
LULC	Land use/land cover
MAE	Mean absolute error
MSE	Mean square error
NPS	Non-point source pollution
NRCS-CN	Natural Resource Conservation Service-Curve Number
NSE	Nash-Sutcliffe coefficient of efficiency
N_u	Stream number
PBIAS	Percent bias
P	Conservation practices factor
P_m	Mean
PMF	Probable maximum flood
P_r	Range
R^2	Coefficient of determination
R_{ann}	Rainfall runoff erosive factor
R	Correlation coefficient
R_b	Bifurcation ratio
RE	Relative error
R_e	Elongation ratio
R_h	Relief ratio

R_L	Stream length ratio
RMSE	Root mean square error
R_n	Ruggedness number
SD	Standard deviation
SEM	Standard error of mean
SSE	Sum squared error
T_c	Time of concentration
t_L	Lag time
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
u	Stream order

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Distribution of water within a watershed is subject to complex spatio-temporal hydrological processes that are in turn related to several meteorological, surface and subsurface characteristics governed by land use and land cover (LULC) changes (Beighley et al., 2004; Entwisle, 2005). LULC changes due to deforestation, rapid increase in agriculture or urbanization have led to massive transformation of global landscape. Even though land use practices differ from one part of the world to another, the major aim is usually the same. It involves the possession of natural resource for instant human wants without repercussion to the environmental conditions and these have transformed a nearly 50% of planet's land surface (Foley et al., 2005; World Bank, 2008). In other words it is one of the major factors through which man impacts the environment (Lausch & Herzog, 2002). LULC transformation with time is among the life-threatening issues inducing various constituents of the hydrologic budget such as runoff, evaporation, surface infiltration, and groundwater recharge. As such, it is regarded as a major factor in various applications such as water resources management problems, flood prediction analyses, assessing of soil degradation and nutrient loss, and biodiversity conservation studies (DeFries & Eshleman, 2004; Thanapakpawin et al., 2006).

LULC changes have substantial influence on runoff and related hydrological characteristics of a watershed. Runoff process is particularly vital in urban areas due to the intensification of impervious surfaces. Weng (2001) and Ali et al. (2011) reported that LULC changes can have profound effect on runoff generation and flow patterns by changing hydrological features such as interception, infiltration and evaporation and thus causes changes in the frequency and intensity of surface runoff and flooding. The effect of LULC on runoff generation is very complicated. Several studies in the past have identified that LULC as having a strong impact on water quality (e.g Thanapakpawin et al., 2007; Zaimes et al., 2008; Shen et al., 2010) predominantly because of non-point source pollution (NPS). Therefore, a better understanding and assessment of LULC change impacts on watershed hydrologic process, is of great importance for predicting flood potential and mitigation of hazards has become a crucial issue for planning, management, and sustainable development of a watershed (Vorosmarty et al. 2000; DeFries & Eshleman, 2004; Wang et al. 2007; Chen et al. 2009).

Malaysia has an annual average rainfall of about 2,500 mm with several rivers and streams. This along with the tropical monsoon climate makes the country abundant in water resources making it more prone to the incidence of floods, which is the major natural disaster. Floods occur annually causing damages to lives and properties even though loss of lives is not as severe as that of other countries like Bangladesh. Floods are usually caused by northeast monsoon rain, which occur around November to March and the southwest monsoon rain from late May to September. There are several flood prone rivers in the country; and one of them is Kelantan river basin.

1.2 Statement of Research Problem

LULC change and climate change affects the natural hydrologic cycles in different parts of the world (Pachauri et al., 2014; Nobre et al., 2016). Changes in rainfall pattern alters the natural hydrologic cycle, which in turns affect the quantity and quality of water resources (Mujere & Moyce, 2016; Petersen et al., 2017). According to IPCC, (2014), effects of climate-related disasters such as floods expose the vulnerability of ecosystem as well as human lives to climate change.

Floods occurrence are common to Kelantan River and its tributaries. Noticeable dates include those that occurred in 1886, 1926, 1967, 1971, 2006, 2007, 2008, and 2014. The 1926 flood, regarded as “The storm forest flood” was responsible for the destruction of several areas of lowland forest located on the valleys of Kelantan state. In another incident, a flood caused by heavy rains in 2000 led to the death of about 15 people in Kelantan and Terengganu states and affected the lives of several thousand people by forcing them to evacuate their shelters (Chan, 2012). The most recent occurrence of flood is that of late December 2014, where heavy rainfall occurred for many days that resulted in catastrophic flooding in several parts of the west coast state of Peninsula Malaysia specifically Kelantan, Terengganu, Perak, Johor and Pahang. The flooding is one of the greatest in history that happens in Kelantan and its tributaries, which drains approximately 13,100 km^2 watersheds. There are several factors contributing to flood such as climate change, mismanaged drainage system, unpredictable nature of weather conditions and unplanned development by human activities. LULC changes and climate change have significant impact on the hydrologic conditions and ecological process of the watershed. LULC changes increase the occurrence of flooding, presenting a significant management problem. In addition, prolific LULC changes from the 1980s to 2000s, especially in relation to deforestation (for logging activities) and transformation to agricultural land (mostly for rubber and oil palm production) have been reported by several authors (Wan, 1996; Adnan & Atkinson, 2011). There is no concrete data to support or refute this argument for the basin. Hence, there is need for a comprehensive study of flood characteristics in the region to analyze and identify flood sub-basins that contribute the least and the most magnitude of flow downstream for further flood control and planning.

Runoff water draining during flood has the tendency to carry along with it residues of several types to the land. Under the first flush phenomena, surface runoff is a major source of NPS pollution. The type of contaminant depends on the runoff that is associated with the LULC and the event mean concentrations (EMC) of the pollutant load (Engel, 2001; Novotny, 2003; Choi, 2007). EMC quantifies the volume of pollutants conveyed per unit volume of runoff. For example, the major contaminants from runoff from agricultural land use will be nutrients (mostly nitrogen and phosphorus) and sediments. While runoff from highly urbanized areas may be polluted with rubber fragments, heavy metals, in addition to sodium and sulfate from road (Tong & Chen, 2002). The problem of NPS pollution is an issue of great concern as it poses a great risk to water quality in developed countries Malaysia inclusive (U.S EPA, 2009). To tackle this risk, it is vital to have precise simulations and estimations of NPS pollutants (Shen et al., 2012).

The tolerable rate at which soil erosion occurs in Kelantan River basin need to be ascertained. Since many parts of the watershed are under continuous development for over three decades (land clearing for logging, agricultural activities and urbanization as outlined earlier), coupled with the fact that the basin is under the influence of northeast monsoon characterized with extremely heavy rainfall. Although the rains are needed for agriculture, particularly for the wet paddy rice cultivation, they are also largely responsible for bringing seasonal floods in the region (Pradhan & Youssef, 2011). According to Pradhan, 2010; Pradhan & Buchroithner, 2012, very high rain splash erosion and surface runoff erosion are recorded in the equatorial areas. Since tropical rains are characteristically of high intensity with short duration, this gives their erosivity, the power to make the soil particles lose, thereby weakening slopes and increase rates of sediments in water bodies. This will eventually yield various types of mass movements such as soil creep, landslips and landslides (Pradhan et al., 2011). The massive deforestation carried out in the watershed without concern to the environmental consequences can be the backbone to erosion problems in the catchment. In view of this, the quantitative assessment of land degradation (soil erosion) becomes vital which can be achieved through several ways using detailed and spatially distributed data.

1.3 Research Questions

a. Is there climate change because of changes in long-term rainfall pattern that may significantly affect the hydrology of the watershed?
b. Are there LULC changes large enough to affect the water balance of the watershed?
c. Is there any effect of LULC change on peak flow and runoff volume?
d. How do different sub-basins contribute to magnitude of water to the outlet areas?
e. How do different sub-basins and locations of basins contribute to peak discharge?
f. Do long-term LULC changes have significant impact on runoff, soil erosion and NPS pollution?
g. Does runoff, NPS pollution and soil erosion vary among different LULC changes of the catchment?
h. Does flood problem arise from different LULC changes in the watershed?
i. Is there a way in which flood control in the watershed can be optimized?

1.4 General Objective

The main objective of this research it to model the effect of LULC changes on long-term rainfall/runoff and NPS pollution of Upper Kelantan River basin.

1.4.1 Specific objectives

1. To determine the impact of past and present LULC changes on flood peaks and volumes, particularly changes in flood peaks are of paramount importance in this study.
2. To assess the contribution of various sub-basins in each catchment on peak discharge and volumes under different LULC changes for further flood control planning.
3. To investigate long-term runoff dynamics due to LULC changes as well as how the extent of LULC changes will affect surface runoff generation for long-term watershed monitoring for the basin.
4. To examine the impact of long-term LULC changes on NPS pollution with a view of determining spatial and temporal differences in NPS among different catchments and temporal variation loads among different LULC changes.
5. To evaluate soil erosion risk due to long-term LULC changes and the relationship between soil erosion and different LULC changes in the area.

1.5 Significance of the studies

Ferquent occurrence of flood events, insufficient data and the complex behavior of floods in Malaysia leads to the initiation of this research. Although monitoring activities through forecasting are carried out and are continuously carried out from time to time for rising water using numerous monitoring stations installed around Kelantan River basin by Drainage and Irrigation Department (DID). It is vital to improve on the level of awareness and effectiveness in disaster response using hydrological parameters to study runoff changes due to LULC changes in a GIS environment (Pradhan, 2009; Pradhan & Youssef, 2011; Tehrany et al. 2014). In addition, the Kelantan River basin is known for its flood potential.

Trend analyses on long-term climatic data was conducted to have an idea of rainfall and discharge changes (increase or decrease). These changes are useful in determining whether climate change has occur in the watershed or flood has increase. Land use analyses conducted in the watershed gives an idea of past and present LULC changes that occurred during the period under study. This will give land use planners the knowledge on how to enact proper land use laws in the watershed and also the level as well as frequency of deforestation required for future control planning. This work will assist in analyzing and identifying flood source areas that have detrimental effect on flood peak (flood source areas) and their contribution to the cumulative catchment outlet using the Hydrologic Engineering Centre-Hydrologic Modeling System (HEC-HMS) model. Thus, assisting in reducing the risk of occurrence and consequences of flood. A novel index (*fa*) was developed and tested in this study. The index was found to rank sub-basins better than *f* index because it considers initial peak discharge per unit area and change in peak discharge per unit area occupied by each sub-basin before ranking.

This study will also be of benefit in improving the level of awareness and effectiveness in disaster response using hydrological parameters to study runoff dynamics due to long-term LULC changes in geographic information system (GIS) environment. The use of (GIS) used in this study was deemed as more desirable compared to conventional ways of quantifying surface runoff mainly due to its ability to store and analyze factors responsible for runoff.

This work also intends to quantitatively assess the spatio-temporal variation of NPS pollution using numerical integration in a GIS environment. Comprehensive knowledge of the areas' topography and NPS sources of each pollutant was identified, as such the identification and location of NPSs of pollution is desirable for pollutant loads.

This research will help in the quantitative assessment of land degradation (soil erosion) using GIS to integrate numerous spatial datasets to evaluate complex and dynamic system such as soil erosion. The use of GIS has proven to be an effective means in predicting soil erosion.

Soil erosion prediction in the watershed is imperative which was aimed at executing the efficiency of accurate forecast of soil conservation measures in a certain area of interest (Bagarello et al., 2012). This will assist in creating effective approaches in erosion control, rehabilitation planning, and accomplishing sustainable productivity on the long-term basis (Hajkowicz et al., 2005; Turpin et al., 2005; Lu et al., 2006).

1.6 Scope and Limitation

The scope of this study is limited to the upper part of the Kelantan River basin. The upper part that is boardered to South China Sea is not included in this study due to high intrusion of seawater that constantly altered the actual runoff activities of the basin. While one of the limitations is that, no feature prediction beyond the 2014 flood was carried out. In addition, low resolution ASTER DEM (with 30 m resolution) and SPOT 5 images were used in extracting the physiographic characteristics of the basin. Furthermore, hypothetical data was utilized in validating of NPS pollution prediction due to the absence NPS monitoring stations in the study area.

1.7 Thesis Outline

This thesis consists of five chapters. Chapter 1 gives the background of the study, the research problem, general and specific objectives, research hypothesis and the significance of the study. The literature review is presented in chapter two, which gives an insight on related literature on effects of LULC changes on hydrology as well as different hydrological models utilized in achieving the research objectives. Classification of hydrological models developed by Refsgaard (1996) was adopted and discussed fully in this chapter. The various processes involve in hydrological modelling and model performance and evaluation criteria were reviewed based on how they were applied in previous literatures. Literatures related to researches conducted with HEC-HMS models from Malaysia were critically reviewed giving emphasis on the various methods involved pointing out their limitations and strengths as well the research problems they were applied upon. The Natural Resource Conservation Service-Curve Number (NRCS-CN) model, which is a one othe most widely used models in runoff prediction, was also reviewed. The effect of LULC change and sources of NPS were critically examined in chapter two. The types of models used in predicting NPS pollution were also discussed. Problem of land degradation caused by soil erosion and how it is influenced by LULC changes has all being highlighted in this chapter. The USLE model and its various modifications were pointed out as they are applied in different parts of the world to proper solutions to different problems.

Chapter three discusses the detailed description of all the methodologies utilized in the study. The general description of the study area was clearly stated in this chapter. Data analysis that include missing data analysis and Mann Kendal and Sen slope's estimator were were explained. A brief description of digital elevation (DEM) used as well as its accuracy and validation procedures were assessed in this chapter. Morphometric analyses conducted in this study were discussed. The process of basin delineation and preprocessing, land use analyses and hydrologic soil group (HSG) were all highlighted. Methods of calibration and validation of HEC-HMS model that include selection of measured hydrograph, rainfall data collection, spatial distribution of rainfall, lag time calculation, flood routing etc. were all pointed out. A detailed describtion of how long-term runoff dynamics due to LULC changes carried out using NRCS-CN model in this study was discussed in this chapter. Various stages include determination of CN values, antecedent moisture condition (AMC), description of NRCS-CN model and its various modifications etc. Different procedures involved in pollutant load estimation were described in this chapter for determining the impact of long-term LULC changes on NPS pollution. Soil erosion prediction with RUSLE model, soil erosion prognosis and temporal assessment of soil erosion were all fully explained. The results and discussion of all the analyses described were discussed in chapter four. Comparisons were made with similar researches conducted from around the world. Lastly, chapter five presents the summary, conclusion and recommendations based on findings of the study.

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