STORMWATER RUNOFF QUALITY CONTROL
IN GREEN HIGHWAY PROJECTS

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DEDICATION

To my beloved son

Ephraim Denison Yaovi BIGAH

To my lovely heart

Nathalie DONOUVOSSI

To the only friend I ever trust

Dany Xolali AYITE

To my beloved parents

Suzane Afiwa AKODA & Apollinaire Komlan BIGAH

To my brothers and sisters

And to all the project group partners

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ABSTRACT

Stormwater runoff quality (SWRQ) within a city is influenced by the dual effect of the hydromodification and the pollutant loadings. Highway and road corridors increase impervious surfaces and generate several pollutants which contributory affect SWRQ. The aim of this study is to investigate sustainable highway features in order to protect SWRQ. Specifically, the study identifies green/sustainable highway requirements in terms of criteria and sub-criteria which are weighted and Best Management Practices (BMPs) capable of achieving better control of SWRQ. Discussion with experts in highway development, water resources management, and sustainable development have allowed the study to formulate the theoretical framework of the research and a questionnaire was administrated to professionals in those disciplines to provide their level of agreement using five-level Likert scale rating system. The average index and the factors analysis methods are used to assess and weight the importance of criteria and sub-criteria using the Statistical Package of Social Sciences (SPSS) tool. The study identifies three main criteria, Instrumentation and Monitoring Runoff Quality, Storm Runoff Treatment, and Pollution Reduction Practices for SWRQ control. Those criteria scored an average of 30% of water and environment protection. The most significant sub-criteria are Instrumentation to monitor and analyze pollutants, Ensure entire waste water treatment, and use structural BMPs to treat 90 percentile of annual rain fall. Furthermore, the study reveals that a combination of non structural and structural BMPs has to be adopted to exert better control over SWRQ. Most significant BMPs are Vegetation and Landscaping using native ground cover, Runoff Quality/Peak Rate BMPs, and Minimization of land disturbance by fitting the project into the site.

Keywords: *Green Highway, Stormwater runoff Quality, water resources protection, Best Management Practices*

ABSTRAK

Air Ribut Larian Berkualiti (ARLB) dalam bandar dipengaruhi oleh kesan dwi hydromodification dan beban pencemar. Koridor lebuh raya dan jalan raya meningkatkan permukaan kedap dan menjana beberapa pencemar yang penyumbang menjejaskan ARLB. Tujuan kajian ini adalah untuk menyiasat ciri-ciri lebuhraya mampan untuk melindungi ARLB. Khususnya, kajian mengenal pasti keperluan lebuh raya hijau atau bertahan dari segi kriteria dan sub-kriteria yang wajaran dan Pengurusan Amalan Terbaik (PAT) mampu mencapai kawalan yang lebih baik daripada ARLB. Perbincangan dengan pakar dalam pembangunan lebuh raya, pengurusan sumber air, dan pembangunan mampan telah dibenarkan kajian untuk merumuskan kerangka teori kajian dan soal selidik telah diedarkan kepada profesional dalam mereka disiplin untuk menyediakan tahap mereka perjanjian yang menggunakan skala Likert lima peringkat sistem penarafan . Indeks purata dan kaedah analisis faktor digunakan untuk menilai dan berat kepentingan kriteria dan sub-kriteria menggunakan Pakej Statistik Sains Sosial alat. Kajian ini mengenal pasti tiga utama kriteria, Instrumentasi dan Pemantauan Kualiti Larian, Ribut Rawatan Larian, dan Amalan Pengurangan Pencemaran untuk kawalan ARLB. Mereka kriteria menjaringkan purata 30% perlindungan air dan alam sekitar. Yang paling ketara sub-kriteria Instrumentasi untuk memantau dan menganalisis bahan pencemar, Pastikan rawatan air sisa keseluruhan, dan menggunakan PAT struktur untuk merawat 90 persentil kejatuhan hujan tahunan. Tambahan pula, kajian mendedahkan bahawa gabungan PAT struktur dan bukan struktur untuk diguna pakai untuk mengenakan kawalan yang lebih baik ke atas ARLB. PAT paling penting adalah Tumbuhan dan Lanskap menggunakan penutup bumi asli, PAT Larian Kadar Kualiti atau Puncak, dan Mengurangkan gangguan tanah dengan pemasangan projek ke dalam laman web.

Keywords: *Lebuhraya Hijau, larian Air Ribut Kualiti, perlindungan sumber air, Amalan Pengurusan Terbaik.*

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a	weighting constant
F	latent variable
FS_{ed}	factor scored for each element
FS_{sc}	factor score for each sub-criteria
FS_{c}	factor score for each criteria
J	variable
X_j	variables j
λ_j	loading" for variable j
π_k	weightage factor
$\Pi_{element\ description}$	weightage factor for each element description
$\pi_{sub\ criteria}$	weightage factor for each sub-criteria
$\%_{ed}$	element weight
$\%_{sc}$	sub-criteria weight
$\%_{c}$	criteria weight

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Water resources is one of the four main historical natural resources (water (surface and underground), earth (materials and ecosystems), energy (sun and wind), and the ambient condition (air/atmosphere)), which the surge of environmental protection systems worldwide nearly two decades strive to protect from the development of cities. Several green/sustainable buildings assessment systems worldwide have addressed broadly issues over water resources protection (BREEAM, 1995; LEEDS 1999, GBI, 2009).

According to United Nation Environment Protection – Global Water Monitoring System (UNEP GEMS/water, (UNEP GEMS/Water (2006), water quality can be diversely appreciated as there is no single answer to the question of 'what is water quality'. Water quality may be assessed in terms of, among others, 'quality for life' (e.g., the quality of water needed for human consumption), 'quality for food' (e.g., the quality of water needed to sustain agricultural activities), or 'quality for nature' (e.g., the quality of water needed to support a thriving and diverse fauna and flora in a region). This study focuses on Stormwater runoff quality (SWRQ) control by means of highway features as the development of cities and particularly that of highways and roads construction do affect SWRQ.

Green highway development is a new concept which has emerged this last decade in developed countries. It steers towards construction and implementation of sustainable highways in order to minimize and control to some extent the impact of highway on its environmental, social and economic climate. Bryce (2009) suggested that Green highways should embrace more sustainable practices and maximizes the highway lifetime than current construction technology and put forth a new concept of Green Highway which includes five key areas among which watershed-driven Stormwater runoff management. Several attempts have been made in developed countries mostly in USA to set green highway features in order to protect natural water resources (Greenroads, 2010; I-last, 2010; Bryce, 2009; Envision 2009).

The Transportation Association of Canada Urban Transportation Council (2009) defines road/highway corridor as a cluster of functional components instead of just an infrastructure within the right of way. Highway corridor includes the roadway and medians, the Right of Way (ROW) edge, road hardware, furniture and safety features, services and utilities, and the adjacent lands which include the lands adjacent to the ROW with a varying distance from urban to rural perspective. The interconnectivity of a set of highway is referred to as highway system or highway network which is often categorized into rural, interurban and urban highway segments (online dictionary, LLM/GP/T18-10, 2010).

Beside buildings, highways and roads construction interfere with Stormwater runoff (SWR). They have two main impacts. They generate more runoff and pollutants while they contribute to the increase in impervious surfaces in the watershed and intensify activities. Regarding the increase of impervious surfaces, United States Environmental Protection Agency (US EPA, 1995), states that roads occupy one third to two third of the land portion of the city (mostly impervious surfaces) while the US National Resource Defence Council (US NRDC, 1995) argues that when impervious cover reaches between 10 and 20 percent of a watershed, ecological stress becomes clearly apparent.

The resulting effects of the hydromodification effects are increased volume of the runoff, increased peak flow and its duration, increased stream temperature, decreased base flow, and change in sediment loadings (Shueler, 1992). The hydromodification induce flooding, habitat loss (riparian), erosion, channel widening and streambed alteration (US EPA, 1999; Greenroads, 2010). From undeveloped area to developed zone with 30 to 50% of road impervious surface, the storm runoff rate increases from an average of 10% to 30% of the rain fall (Envision, 2009).

Regarding the generation of pollutants, highway and road corridors are identified as source of pollution by intensifying human activities around water resources. Highway pollution issue arose toward the end of the 20th century when US National Resource Defense Council (1995) states that it accounts for more than 20 per cent of diffuse water bodies pollution (rivers, lakes estuaries and bays). Various sources within highway corridor contribute to runoff pollution. The pollution sources are namely: dumping of parts of vehicles, leaking or spill of vehicle oil, grease, and antifreezes, vehicle exhaust, pavement and tires wear, vehicle repair workshops in open spaces, accidents and spills, street litter and garbage, construction sites, erosion and sedimentation, household gardens, public open spaces, domestic and wild animals, wastewater discharges, illicit sanitary connection to storm water sewers, industry and industrial processes, commercial activities (US NRDC, 2005).

Kansas Department of Health and Environment (1997) exhaustively listed water pollution indicators as ammonia, TSS, bacteria, BOD, chlorophyll a, DO, dissolved solids, heavy metals, minerals, nitrates, pesticides, pH, phosphorus, temperature, and turbidity. Barrett et al. (1995a) and Washington State department of Transportation (WSDOT, 2007) identifies constituents such as suspended solids, nutrients, heavy metals, organic compounds, petroleum products, and bacteria as typical components in highway runoff. Those highway pollutants are from three categories, that is, organic, inorganic and microbial pollutants and influence the runoff quality variously.

Degradation of organic pollutants (grasses, oil and grease, nutrients) in highway runoff deplete the amount of oxygen in the water body; biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are the most usual indicator calculated for highway pollution monitoring and control (US EPA, 1983; Pitt et al., 1993). Inorganic Pollutants (most common heavy metals: Zinc (Zn), Lead (Pb), Copper (Cu), Chromium (Cr), Cadmium (Cd), Nickel (Ni) and the group of nutrients (herbicides, pesticides)) are toxic in high concentration and tend to amass into the tissue of aquatic flora and fauna (Pitt et al. 1993; Lee and Lee, 1993). Coliform bacteria are the ordinary microbial pollutants encountered in storm runoff. They are of meticulous interest due to their easy access into the runoff either through anthropogenic sources or illicit connections to stormwater sewer system. Waterborne diseases originating from non-point sources (NPS) pollution are alleged to be more detrimental than sedimentation issues in developing countries (Field et al., 1993; Wanielista and Yousef, 1993).

Additionally, erosion and sedimentation process contribute to Stormwater runoff pollution. Sediment sources from roadways include road sanding, runoff from unpaved roads and areas where soil has been exposed during construction. Novotny and Olem (1994) state that heavy metals and nutrients can form complexes with the clay minerals in fines sediment, contributing to lakes eutrophication and toxicity to aquatic organisms that live in or feed on bottom sediments. Sedimentation also contributes to increased turbidity (poor light penetration) in down gradient (receiving) water bodies. This reduces photosynthesis by phytoplankton and aquatic plants, and can contribute to anoxic (low oxygen) conditions that are harmful to aquatic organisms (US EPA, 1995).

Traditionally, point source pollution is statutorily regulated while non-point source pollution was considered trivial up to toward the end of the 20^{th} century when nonpoint source pollution from highway runoff is considered as relevant to natural water quality pollution (US NRDC, 1995). The process of pollutants accumulation in water bodies can lead to a serious threat to the population and the ecosystem depending on the nature of the carried pollutants their concentration, and the specific needs of the water body.

1.2 Problem Statement

According to official data from Malaysia Highway Authority (MHA) in Malay Lembaga Lebuhraya Malaysia (LLM), the expressway network in Malaysia is considered the best expressway network in Southeast Asia and also in Asia after Japan and China. They were twenty seven highways in the country with a total length of 1,630 kilometers (1,010 mi), and another 219.3 kilometres (136.3 mi) is still under construction.

Historically, world population tends to settle around natural water resources and Malaysia is no exception. Nowadays, Malaysia is a fast growing country with significant increase of population. As a consequence, more cities with higher population and intense activities have been observed around water catchment areas, polluting the natural water quality which subsequently distresses plants and living organisms as well as people health and the country's economy, as unfortunately the same water is needed for consumption (Bao K. L. J., 2010).

Nonpoint source pollution particularly highway Stormwater runoff is a contributor to surface water pollution. The quality of the Stormwater runoff watching away pollutants over impervious surface land is one of the pollution causal factors identified in a catchment area. In fact, roadways runoff loaded with pollutants from human activities does not receive any treatment and are discharged into surface water bodies (rivers, lakes and bays) through the Stormwater sewage system.

Moreover, beside human activities garbage, surface water pollution within a watershed is substantially influenced by the erosion and sedimentation phenomenon in Malaysia. As a matter of fact, the total suspended solids (TSS) index used to measure the sediment load in a water body has been strengthened as a result of several years' water quality monitoring outcomes in many of Malaysian Peninsular Rivers (Water Resources Publication (JPS), 2009).

Malaysia is a fast growing country with an objective of being a fully developed country by 2020. Among the objectives stated in Malaysian's 10th Master Plan (2010-2020) reducing water resources pollution and providing quality water to urban population which is expected to grow over 70% of the total population is a major concern of the government (10th Malaysian Master Plan). Furthermore, develop long-term strategy for water resource management is a priority in Malaysia where more than 90% of water supply is from rivers and lakes (10^{th} Malaysian Master Plan 2010-2020). With regard to the growing impetus of sustainable culture along with the Low Impact Development (LID) and the Best Management Practices (BMPs), the prevention and/or control of highway Stormwater runoff pollution has become essential.

1.3 Aim and Objectives of the Study

The aim of this study is to investigate sustainable highway development by identifying and weighting sustainable requirements in terms of criteria and sub-criteria, and BMPs in order to control Stormwater runoff quality.

The objectives of the study are to:

1. To identify criteria and sub-criteria in Green Highway development in order to control Stormwater runoff pollution;

2. To determine the importance of criteria and sub-criteria; and

3. To identify Best Management Practices (BMPs) that can achieve better quality of Stormwater runoff.

1.4 Scope and Significance of the Study

This study focuses on the operation phase of highway infrastructures to suggest features and practices in highway implementation in order to control Stormwater runoff pollution. Provisions under existing Green/Sustainable highway/roads systems are explored to gain insight from current practices in developed countries mostly in USA. Malaysia environmental conditions are considered by exploring existing local regulatory requirements, management guides and frameworks such as Urban Stormwater Manual (MASMA), Environmental Management System (EMS), Guide for Highway Construction (Lembaga Lebuhraya Malaysia (LLM)), Department of Irrigation and Drainage Malaysia (Jabatan Pengairan dan Saliran Malaysia (JPS)), Guidelines Toll Expressway Malaysia, Green Building Index (GBI).

1.5 Research Justification

Malaysia is a growing country with an objective of being a fully developed country by 2020. Among the objectives stated in Malaysian's 10th Master Plan (2010-2020) increasing water resources pollution and providing quality water to urban population which is expected to grow over 70% of the total population is a major concern of the government (10th Malaysian Master Plan). Beside controlling water pollution, developing long-term strategy for water resource management is a priority in Malaysia where more than 90% of water supply if from rivers and lakes (10th Malaysian Master Plan 2010-2020). As a matter of fact, highway/roads have been identified as a non point source potential threat to water quality, and developed countries are moving forward in curbing highway-related water pollution through establishment of highway assessment framework. The outcome of this project will provide, respective of Malaysian environment, requirements against which highway performance can be measured and consequently provide means to construct highway development toward more sustainable practices. The specific outcomes of this study are:

1. The identification of requirements in terms of criteria and sub-criteria that highway projects should fulfilled in order to control Stormwater runoff pollution; and

2. The identification of Best Management Practices (BMPs) to achieve better control of Stormwater runoff quality.

The implementation of the findings of this paper will contribute in reducing pollution load in storm runoff before discharging them into surface water bodies and consequently enhance water bodies (rivers, lakes, bays and estuaries) quality.

1.6 Brief Research Methodology

This section focuses on the methodology of this research. The methodology adopted consists of six main stages which are outlined as follow:

i. First stage - Literature Research
ii. Second stage – Experts Discussion
iii. Third stage - Data Collection
iv. Fourth stage - Data Analysis
v. Sixth stage - Conclusion and Recommendation

1.6.1 First Stage - Literature Research

The early stage of this research work was to document and gain deep insight on the topic of concern through previous research works. Those readings were interposed with discussions with supervisor, other lecturers and project group members to steer rightfully the project and delineate its boundaries. This step was very important in understanding the topic and laying out the first draft of theoretical framework of the study which allowed us to tackle the second step.

1.6.2 Second Stage – Experts Discussion

Discussion with Malaysians experts in highway, water resources management and sustainable development practices was organized after laying out the hypothetical structure of what could be the primary data collection tool. The discussion with experts allowed us to evaluate the technical quality of the study theoretical framework, that is, its relevance, description accuracy and consistency with Malaysian environment.

1.6.3 Third Stage – Data Collection

Data collection is one of the most valuable stages in conducting a research work. It holds the potential to generate through other processes (analysis and interpretation) the final outcome of the project. It is composed of primary and secondary data:

- **Primary Data Collection**

Using the outcome from the first expert discussion, primary data were collected from respondents across Malaysian. Several institutions, governmental agency, construction companies and highway concessions were visited to collect input from practitioners. Those collected data served as means in analyzing collected information.

- **Secondary Data Collection**

Secondary data collection is the very beginning stage of a research project. It is done through consultation of previous research works from various sources (books, journals, thesis and electronic resources) in the topic under investigation for a better understanding of the issue. It also counts on discussion with experts, experienced professionals, lecturers as well as colleague in the field of research.

1.6.4 Fourth Stage - Data Analyzing

At this stage, collected data were analyzed doing discussion and findings. Data were analyzed using statistical software SPSS and Excel. They were entered and screened in detail. Several statistical parameters were used for the analysis; they are average/mean, frequency, percentage, and so on. Quantitative data were then output in form of tables, charts, graphs, diagrams to draw out findings and interpretations.

1.6.5 Sixth Stage - Summary and Recommendation

At this stage, summary and recommendation for the research will he prepared based on the outcome of the study and also the analysis that have been carried out. Besides, the problem of research, implication of research and recommendation for future research is also reported. Conclusion and recommendation is the final stage in writing. The report submission will close down the project.

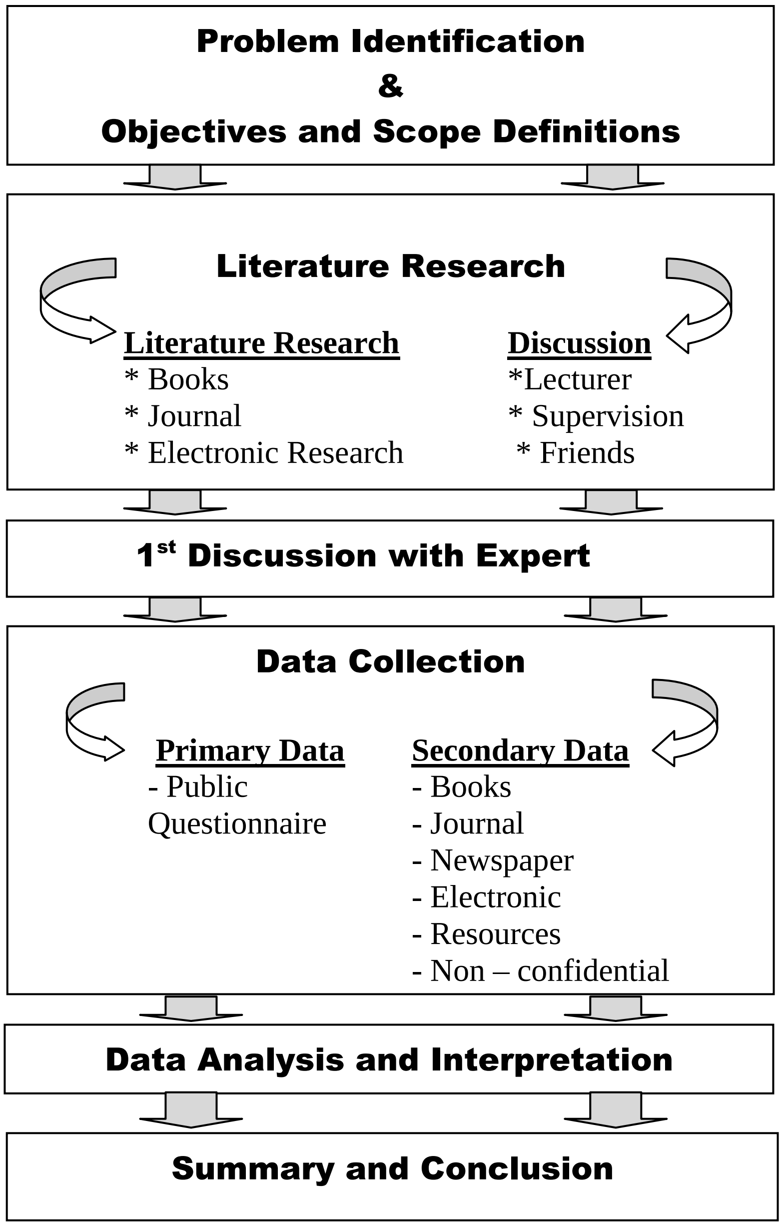

Figure 1.1: Study Flow Chart

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