INFLUENCE OF RAINFALL CHARACTERISTICS TOWARDS FIRST FLUSH BEHAVIOUR

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Urban stormwater runoff has been recognised as one of the main contributor in degradation of water quality as it wash-off varies pollutants on impervious surface to receiving water. One important characteristic of urban stormwater runoff is that pollutant discharge in the early phase of runoff is significantly higher than that in later phase of the runoff and this process is identified as first flush phenomenon. The understanding of first flush is important to provide information on pollutant control and water quality management. This research investigates the influence of rainfall characteristics toward first flush behaviour. This study involved field work, sampling of stormwater runoff, laboratory testing and data analysis. A total of 115 stormwater runoff samples were collected from 11 rainfall events in the study area, located at School of Civil Engineering, Universiti Teknologi Malaysia, Johor. Rainfall characteristics and runoff data were collected from May 2017 to April 2018. Stormwater quality parameters analysed were total suspended solid (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and zinc (Zn). In order to analyse first flush occurrence, two methods were employed; concentration-based First Flush (CBFF) method (using data from pollutant's concentration and hydrograph) and mass-based First Flush (MBFF) method (distribution of M(V) curves). CBFF confirmed that rainfall events with peak pollutant concentration which occurred before peak flow-discharge indicated the occurrence of first flush phenomenon. In contrast, first flush was absent when peak concentration occurred after peak flow-discharge. It was found from the distribution of M(V) curves that the percentage of first flush occurrence is different for each pollutant. Based on the mean value of M(V) curve for each pollutant, the relative strength of the first flush was COD>TSS>Zn>BOD>TDS. Detail analysis on the influence of rainfall characteristics on first flush behaviour was carried out by PROMETHEE and GAIA software. Result of rainfall characteristics showed that rainfall duration and intensity were significant in controlling the wash-off of pollutants while antecedent dry period (ADP) is important for understanding the build-up process of pollutants. In addition, high rainfall depth and intensity have influenced the behaviour of first flush for TSS, TDS and BOD. For COD, longer rainfall duration and ADP play a significant role in influencing the first flush behaviour. Meanwhile, Zn was influenced by longer duration of rainfall. Therefore, it is concluded that the behaviour of first flush varied due to variations in the characteristics of rainfall events.

ABSTRAK

Larian air ribut bandar telah dikenal pasti sebagai salah satu sumber utama yang menyumbang kepada kemerosotan kualiti air kerana ia membersihkan pelbagai bahan cemar di atas permukaan tidak telap kepada air. Salah satu ciri penting larian air ribut bandar ialah pelepasan bahan cemar pada fasa awal larian air adalah lebih tinggi dari larian air pada fasa kemudian dan proses ini dikenal pasti sebagai fenomena siraman pertama. Pemahaman berkenaan siraman pertama adalah penting untuk menyediakan maklumat mengenai kawalan pencemaran dan pengurusan kualiti air. Kajian ini menyiasat mengenai pengaruh ciri-ciri hujan terhadap siraman pertama. Kajian ini melibatkan kerja lapangan, pengambilan sampel larian air ribut, ujikaji makmal dan analisis data. Sebanyak 115 sampel larian air ribut telah dikumpulkan dari 11 kejadian hujan di kawasan kajian, iaitu di Sekolah Kejuruteraan Awam, Universiti Teknologi Malaysia, Johor Bahru. Ciri-ciri hujan dan data larian hujan dikumpulkan dari Mei 2017 hingga April 2018. Parameter kualiti air ribut yang dianalisis adalah jumlah pepejal terampai (TSS), jumlah pepejal terlarut (TDS), permintaan oksigen biokimia (BOD), permintaan oksigen kimia (COD) dan zink (Zn). Untuk menganalisis kejadian siraman pertama, dua kaedah digunakan; kaedah siraman pertama berasaskan kepekatan (CBFF) (menggunakan data dari kepekatan pencemar dan hidrograf) dan kaedah siraman pertama berasaskan jisim (MBFF) (pengagihan lengkung M(V)). Hasil keputusan ujikaji, CBFF mengesahkan bahawa kejadian hujan dengan kepekatan pencemar paling tinggi yang berlaku sebelum pelepasan aliran puncak menunjukkan telah berlakunya kejadian siraman pertama. Sebaliknya, siraman pertama tidak terjadi apabila puncak kepekatan pencemar berlaku selepas perlepasan aliran puncak. Di samping itu, didapati dari pengagihan lengkung M(V) bahawa peratusan kejadian siraman pertama adalah berbeza bagi setiap faktor pencemar. Berdasarkan nilai purata bagi lengkung M(V) bagi setiap faktor pencemar, kekuatan relatif dari siraman pertama adalah COD> TSS> Zn> BOD> TDS. Analisis terperinci mengenai pengaruh ciri-ciri hujan pada perilaku siraman pertama telah dilakukan dengan menggunakan perisian PROMETHEE dan GAIA. Keputusan dari ciri-ciri hujan menunjukkan bahawa tempoh hujan dan keamatan hujan adalah penting dalam mengawal pembersihan pencemar sementara tempoh kering yang terdahulu (ADP) adalah penting untuk memahami proses pembentukan bahan pencemar. Di samping itu, kedalaman dan keamatan hujan yang tinggi telah mempengaruhi perilaku siraman pertama untuk TSS, TDS dan BOD. Untuk COD, tempoh hujan yang lebih lama dan ADP memainkan peranan penting dalam mempengaruhi perilaku siraman pertama. Sementara Zn dipengaruhi oleh tempoh hujan yang lebih lama. Oleh itu, dapat disimpulkan bahawa perilaku pelbagai siraman pertama adalah disebabkan kepelbagaian dalam ciri-ciri kejadian hujan.

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LIST OF ABBREVIATIONS

a	-	First Flush Coefficient
ADP	-	Antecedent Dry Period
Ar	-	Arsenic
BOD_5	-	5-day Biochemical Oxygen Demand
Cd	-	Cadmium
COD	-	Chemical Oxygen Demand
Cr	-	Chromium
Cu	-	Copper
EBFF	-	Empirically-Based First Flush
EMC	-	Event Mean Concentration
Fe	-	Iron
FFE	-	First Flush Effect
GAIA	-	Graphical Analysis for Interaction Assistance
Hg	-	Mercury
MCDM	-	Multi Criteria Decision Making Method
Mg	-	Magnesium
MV	-	Pollutant load distribution curve
MBFF	-	Mass Based First Flush
NO_3^-	-	Nitrogen oxide
NWQS	-	National Water Quality Standards
Pb	-	Lead
PCA	-	Principal Component Analysis
PO_4^{3-}	-	Phosphate
PROMETHEE	-	Preference Ranking Organization Method For Enrichment Evaluation
TDS	-	Total Dissolved Solid
TSS	-	Total Suspended Solid
TKN	-	Total Kjeldahl Nitrogen
Zn	-	Zinc

LIST OF SYMBOLS

Φ	-	Net Out Ranking Flow
V	-	Volume
M	-	Mass
Q	-	Flow Rate
C	-	Concentration
L	-	Litre
π	-	Decision Axis, P
SD	-	Standard Deviation

CHAPTER 1

INTRODUCTION

1.1   Introduction

Urbanisation and industrialisation have benefit in terms of socio economic development. Nevertheless, these phenomena also have negative impact on the quality and quantity of urban stormwater runoff that caused by deforestation, agriculture activities and other activities involving of land use changes (Li *et al*., 2013). As a result, urbanisation leading to the increase in the amount of pollutant in the receiving water and these pollutants are mobilized by physical and chemical processes to the waterways during rainfall events (Papiri *et al*., 2003).

Development of urban areas is synonymous with an increase in effective impervious area (Gruber and Shuler, 2013). Urbanisation and industrialisation replaced most of the natural ground to impervious surface such as driveways, parking lots, buildings, and roadways. Increased in impervious area reduced infiltration rate into the natural ground, causes greater volumes of runoff and higher flow velocities. Sources of urban stormwater runoff pollutant are various and related with both human and natural activities. Each year, the crisis is growing worse and make threats to Malaysia's water security.

In addition, rainfall characteristics are included as the influential factors that caused degradation of urban stormwater quality (Goonetilleke *et al*., 2005; Nazahiyah *et al*., 2007; Liu *et al*., 2012; Zafra *et al*., 2008; Morgan *et al*., 2017). Rainfall characteristics mainly include rainfall intensity, rainfall depth, rainfall duration and antecedent dry days. Therefore, it is necessary to identify how rainfall characteristics responds to first flush behaviour in a higher education institution area.

1.2 Problem Background

It has become a reasonable assumption that the initial part of a runoff event in urban catchments transport high pollutant levels during rainfall events. This phenomenon is known as first flush (Bertrand-Krajewski *et al*., 1998; Xichao *et al*., 2018; Sansalone *et al*., 1997; Lee *et al*., 2002; Sansalone *et al*., 2004; Alias *et al*., 2013). It is important to have an in-depth understanding of a first flush behaviour since most stormwater treatment system are designed to hold the initial part of runoff events (Deng *et al.*, 2005). According to previous research, there are many factors that influence the occurrence of first flush such as rainfall characteristics and catchment characteristics (Lee *et al*., 2004; Stenstrom *et al*., 2005; Zafra *et al*., 2008; Morgan *et al*., 2017).

There are few studies have been conducted to determine the influence of rainfall characteristics on first flush behaviour (Taebi *et al*., 2004; Li *et al*., 2007; Lee *et al*., 2002; Bertrand-Krawjeski *et al.,* 1998; Huang *et al*., 2012; Desta *et al*., 2007; Zhang *et al*., 2013). However, based on the current state of knowledge, there is no consensus regarding the influential parameters such as rainfall characteristics due to inconsistent findings. There are studies reported the stormwater runoff quality of such study area in a higher education institution area with a medium population density, however the information on the influence of rainfall characteristic on first flush behaviour in such area are still limited. Understanding these interactions would be helpful for improving design criteria and strategies for controlling urban stormwater runoff pollution (Li *et al*., 2015). Therefore, there is a need to examine the influence of rainfall characteristic toward first flush behaviour in order to improve management of stormwater runoff pollution in a higher education institution area.

1.3   Hypothesis

The research was conducted based on the following hypotheses;

(a)   Rainfall characteristics such as rainfall intensity, rainfall depth, rainfall duration and antecedent dry period (ADP) play an important role on first flush behaviour.

(b)   Earlier part of the runoff event referred to as first flush is more polluted compared to the later stage of runoff.

(c)   First flush behaviour varies with the pollutant characteristics either the pollutants are in the dissolved or particle form.

1.4   Aim and Objectives of the Study

The aim of this study was to examine the influence of rainfall characteristics toward first flush behaviour in order to improve urban stormwater management systems. The objectives of this study are:

(a)   To identify the characteristics of rainfall such as rainfall depth, intensity, duration and ADP.

(b)   To investigate the quality of stormwater runoff.

(c)   To determine the occurrence of first flush phenomenon.

(d)   To investigate the influence of rainfall characteristic on first flush behaviour using multi criteria decision making method.

1.5   Scope of the Study

This research study primarily focused on investigating the influence of rainfall characteristics on first flush behaviour. The study is limited to this scope:

(e)   The rainfall characteristics and the first flush influence parameters are only valid for the study area which is School of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru.

(f)   The water quality parameters tested in this study are limited to total suspended solid (TSS), total dissolved solid (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and zinc (Zn).

(g)   The rainfall characteristics that influence first flush were analysed using multicriteria decision making method, PROMETHEE and GAIA.

1.6   Significance of the Study

Stormwater runoff as a nonpoint source pollution has been identified as one of the leading causes of degradation in the water quality. In order to protect the quality of receiving water body such as ocean, stream, river, pond and lake, action need to be taken to reduce pollutant loads at their source of origin and it is important to have a deep understanding of the first flush behaviour. Furthermore, there is a necessary to understand how rainfall characteristics responds to first flush behaviour with the purpose of improve management in this study area. This study will contribute to the design of better urban stormwater treatment systems.

1.7   Structure of the thesis

This thesis consists of five chapters. Chapter 1 introduces the research work, which includes the background of the research project, problem statement, and hypothesis, objectives of the study, research scope and the significance of the research. Chapter 2 reviews the literature review, which provides the background theories of the previous works concerning on the stormwater quality and quantity, rainfall characteristics and first flush behaviour. Meanwhile, Chapter 3 describes the research methodology that consist methods used in this research Chapter 4 discusses the analysed result, the data analysis relating to first flush phenomenon. In addition, the influence of rainfall characteristics on first flush behaviour was also determined based on multivariate analysis. Finally, Chapter 5 which is the last chapter concludes this research work and provides recommendations for future research to be done.

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