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Characterization of Storm Runoff Quality from a Highway in Selangor and Conceptual Design of Constructed Wetland

Abdullah Al Mamun, Nurzuliana Abdul Latiff, Mohammad Nor Salleh

Bioenvironmental Engineering Research Centre (BERC), Department of Biotechnology Engineering, Kulliyyah of Engineering, International Islamic University Malaysia.

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ABSTRACT

Quality of storm runoff from different urban landuses contains different types of pollutants at various concentrations. Not much data is available on the characteristics of highway runoff quality in Malaysia, where the highways play significant roles in the transportation industry. The storm runoff samples were taken from KL-Karak Highway at Gombak Toll Plaza located in Selangor. The samples were analyzed to determine event mean concentration (EMC), which is required to determine the quality of the storm runoff. The parameters analyzed were TDS, TSS, VSS, BOD, COD, DO, TN, TP, pH, turbidity, oil and grease, Pb, Zn and Cu. From the analysis, the EMC value of TSS and TDS exhibited the highest concentration Cu has been determined as the lowest concentration. Therefore, it can be concluded that the main pollutants contributing to the storm runoff at Gombak Toll Plaza are both TSS and TDS. Based on the result, constructed wetland was designed with the objectives to remove 80% TSS, 50% TP and 40% TN from the current pollutant loads.

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INTRODUCTION

Water pollution sources can be categorized into point sources (PS) and nonpoint sources (NPS). A point source of pollution discharges to the environment from an identifiable location, whereas a nonpoint source of pollution enters the environment from a widespread area. Nonpoint source pollution does not result from one specific traceable source. Generally, it results from land runoff, precipitation, atmospheric deposition, drainage and seepage. Nonpoint source pollutants include nutrients, sediment, heavy metals, petroleum products, bacteria, organics and toxic substances [1].

Roads and highways constitute a significant portion of the urban landscape. Runoff from highways and surrounding development may contain contaminants such as oil, dirt, grease, and metals that can significantly impact the quality of receiving waters [2]. Various types of pollutants are deposited, built-up and wash-off from the road surfaces [3,4]. Areas located in the tropical region are more susceptible to high NPS pollution due to high amount of annual rainfall. As the highways are one of landuses which is continuously used by people and a source of NPS pollution, it is very essential to conduct a detail study to determine the storm runoff from a highway. This study is intended to determine the runoff quality from a highway located at the States of Selangor, to determine the event mean concentration (EMC) of the main pollutants and to use the data for the conceptual design of a constructed wetland to treat the pollutants.

Pollution Process in Highway:

Pollutant accumulation is a complex process since it involves many variables such as surface type, surface roughness, slope, antecedent dry days and land-use. It can be said that roads and highways are the important sources of pollutant due to their continuous usages by the traffics. Theoretically, pollutant deposition on road surface is uniform, in relation to spatial uniformity of distribution of traffic and dry deposition. However the traffic impact and wind cause the movement of the pollutants from the turbulent area to the kerb areas. The probability of pollutants lost from the system by deposition in previous area or being re-entrained into the

Corresponding Author: Abdullah Al Mamun, Bioenvironmental Engineering Research Centre (BERC), Department of Biotechnology Engineering, Kulliyyah of Engineering, International Islamic University Malaysia (IIUM).
E-mail: mamun@iium.edu.my

atmosphere is high. Due to this re-distribution process, the proportion of total solids is high and concentrated in the kerb and near kerb area [3]. This type of pollutant re-distribution of pollutant is usually happened where the traffic volume is high. Traffic volume and wind are the main factors that affect the pollutant re-distribution.

Due to the wide variation of different particles size ranges in association with other pollutant, method of transport and the impact on the natural water environment, the composition and particles size distribution of accumulated pollutant on road surfaces are important parameters in determining the water quality. Pollutant accumulation on the road surfaces varies with the land use of the surrounding area and its function of antecedent dry days. Below is the pollutant accumulation curves based on the different land uses. These curves are the basis for most urban storm water quality models [5].

During the initial period of rainfall, the catchment surfaces become wet therefore the soluble pollutants started to dissolve. Due to the energy of the falling raindrops, some of the materials are loosened and suspended in the water film together with the dissolved solids. As the water film builds up and begins to flow down slopes, it also develops an ability to hold pollutants in suspension and flow together into water bodies or water catchment.

The amount of pollutants wash-off from impervious surfaces is dependent on the available supply of particulates and the capacity of the runoff to transport the loosened material [6]. However, the influence of the amount of available supply is limited. The rainfall and runoff parameters are more likely have the higher influence on the amount of the pollutant in the wash-off. While the rate of wash-off removes particulate pollutants from road surface mainly depends on the rainfall intensity. Other factors that affect the rate of wash-off are road surface characteristics, rainfall characteristics and particles size [3].

Generally, storm runoff only removes a fraction of the pollutant from the catchment surface. From previous research, only about 30% of the total pollutants were washed off [6]. The following rainfall event reduced total pollutant load by 45%. Based on these, the researchers have two possible wash off concept; source limiting and transport limiting. According to these concepts, pollutant wash-off from impervious surfaces that are subjected to more frequent rainfall events is more close to the source limiting process.

Pollution Treatment by Wetlands:

Wetland is a generic term used to describe ‘wet land’ - marsh and swamp environments which emergent macrophytes such as rushes, reeds and sedges are the dominant features. Swamp environments are typically distinguished by the presence of woody vegetation and marsh environments by herbaceous vegetation [7]. Wetlands have been used for water treatment since many years ago. This method is considered as one of the effective methods as the wetlands are ecosystems that are dominated by aquatic plants that have natural ability to cleanse water. Wetland is capable for high removal of typical urban storm runoff pollutants and significant reductions in nutrients.

MATERIALS AND METHODS

There are several highways or expressways located in Selangor and Kuala Lumpur. Karak highway is one of those highways, which is located in the States of Selangor and used by the travelers to visit east coast of the Peninsular Malaysia. The study was conducted at Gombak Toll Plaza of Karak highway, which is operated by the MTD Prime Sdn. Bhd.

Runoff samples were collected during the rain storm only. It was made sure that the selected roadside drains were dry during the non-rainy periods. Samples were collected at 5 minuters interval. However, the first samples were collected in glass bottles to study the concentartion of oil and grease (O&G). International practices were followed for the sampling, preserving and testing of the water samples [8].

Flow-weighted samples were prepared and tested for the following parameters:

1. pH;
2. Dissolved Oxygen (DO);
3. Turbidity;
4. Total Dissolved Solids (TDS);
5. Total Suspended Solids (TSS);
6. Oil and Grease (O&G);
7. Biochemical Oxygen Demand (BOD);
8. Chemical Oxygen Demand (COD);
9. Total Nitrogen (TN);
10. Total Phosphorus (TP);
11. Lead (Pb);
12. Zinc (Zn); and
13. Copper (Cu).

Wetlands design criteria:

Every design of any system or process has several objectives that need to be met in order to produce the desired system or system. To accomplish the objectives, there are many requirements that might come into consideration. The design criteria discussed below are the required criteria which were used in this study.

Allocation of surface area and depth:

Allocation surface design and the depth of the wetland are the essential criteria in maximizing pollutant removal performance. Determination of the area and depth were done based on the following criteria:

Inlet Zone: Sediment basin or forebay is functioned to capture the coarse to medium sediments from the inflow to allow the macrophyte zone to focus on the finer particulate and other pollutants. The size of sediment forebay usually around 25 to 30% of the total wetland area whiles the depth of 1.5 to 2.0 m.

Macrophyte Zone: The marcrophyte should be planted in the shallow area and at the edge of the wetland to filter the pollutants and also provide barrier to the surrounding. It also should be arranged in the arrangement that allowed the water in the open water zone to circulate through microphyte zone. Macrophyte zone take 50 to 80% of the total wetland area while the depth is 0.3 to 1.2 m and shallower than the inlet zone.

Open Water Zone: At least comprised of 5% from the total wetland area while the depth 1.0 to 2.0 m.

Design geometry:

Length to width ratio: Generally, wetland should be long relative to allow optimum flow circulation. Range of length to width ratio (L:W) of 2:1 to 5:1.

Vegetation or macrophyte zone bathymetry: Macrophyte zone comprises of four marsh zones which are defined by water depth. Typical detail of the macrophyte zone is given in Table 1.

Table 1: Four marsh zone of Macrophyte zone.

Zone	Description
Ephemeral zone	- 0.20 m above the pool or water surface elevation - Located above the permanent pool - Supports a number of species that can survive flooding
High marsh zone	- 0.30 m below the pool to the normal pool elevation - Support a greater density and diversity of wetlands species than the low marsh zone - Have a higher surface area to volume ratio than the low marsh zone
Low marsh zone	- 0.30 to 0.60 m below the pool or water surface elevation - Suitable for the growth of several emergent wetlands plant species
Deep mash zone	- 0.60 to 1.2 m deep - Includes the outlet micropool and deepwater channels through the wetlands facility - Supports little emergent wetlands vegetation, but may support submerged or floating vegetation

RESULTS AND DISCUSSION

The catchment area of the highway up to the sampling location was calculated to be 187 m^2. This information was necessary to design the wetlands. Three events for the site at MTD Gombak Toll Plaza along Kuantan highway. The event mean concentration (EMC) values were calculated and a few selected values are given in Table 2.

Table 2: EMC of the Selected Pollutants from the Highway.

Parameter	EMC Values (mg/L)	NWQS (Class II)	EQA (Standard-A)
BOD	18.4	1 - 3	20.0
COD	73.0	10 - 25	50.0
TSS	215.0	25 - 50	50.0
Turbidity	75.4	5 - 50	-
Pb	0.038	-	0.1
Zn	0.064	-	1.0
Cu	0.006	-	0.2
O & G	4.3	-	Not Detectable

Constructed wetland design:

The conceptual design of the constructed wetlands was done based on the second edition of the Urban Stormwater Management Manual for Malaysia [9]. The pollutant reduction chart, as shown in Figure 1, was particularly used to determine the area requirement for the proposed constructed wetlands and the detail proportioning of the zones was done following the information given in Table 1.

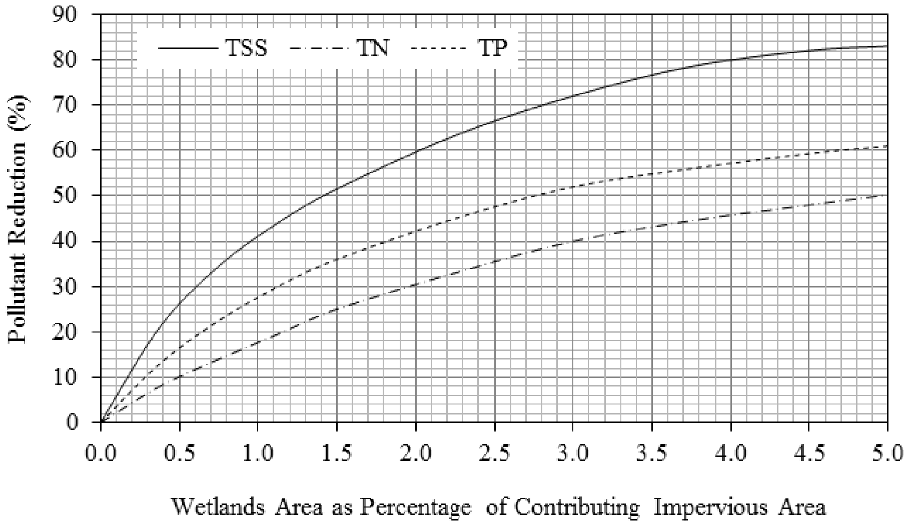

Fig. 1: Design Chart for Conceptual Sizing of the Wetlands (Adapted from [10]).

Constructed wetland is designed with an objective to mimic the natural environment in overall structure while fostering those wetland processes that able to improve water quality. In order to build an effective and functional constructed wetland, a lot of aspect should be considered and must be planned wisely. The design of constructed wetland in this study was based on the flow surface constructed wetland design.

Table 3: Detail of the Proposed Wetlands for Highway Runoff Treatment.

Zone	Values
Total Wetland	
- Required Area, A	410.0 m^2
- Width, W	9.1 m
- Length, L	45.5 m
- Provided Area	414.0 m^2
- Depth	1.2 m
- Side slope	1:3
- Wetland volume	748.3 m^3
Macrophyte Zone	
- Area, A	328.0 m^2
- Width, W	9.1 m
- Length, L	36.4 m
- Surface area	331.2 m^2
- Embankment height	0.6 m
- Side slope	1 : 3
Open Water	
- Area, A	82.9 m^2
- Depth	2.0 m

Conclusions:

Despite having huge amount of road and highway network, no detail study is conducted yet in Malaysia. Therefore, this study was intended to determine the runoff quality (in terms of EMCs) from selected roads and highways located in the Klang Valley. The sampling and testing of collected storm runoff revealed that, in relation to selected common but important water quality parameters, runoff from the roads and highways are inferior to the Class II of the National Water Quality Standard (NWQS), with respect to BOD, COD, TSS and Turbidity. This indicates that, in order to maintain good quality water in the rivers, the road runoff must be treated (similar to runoff from other landuses) before allowing to flow into the rivers. The size of the proposed constructed wetlands was 414.0 m^2, with 45.5 m length and 9.1 m width. The constructed wetland was designed to achieve 80% TSS removal, 50 % TP removal and also 40% TN removal from the highway runoff.

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