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The performance of gross pollutant trap for water quality preservation: a real practical application at the Klang Valley, Malaysia

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ABSTRACT

The performance of a gross pollutant trap (GPT) was investigated at 51 catchments of the most polluted river in Malaysia, Klang River and its major attributes, Gisir River, Kemensah River, and Sering River for the entrapment of gross pollutants over the operation period of 10 months. The specific characteristics of gross pollutants generated from the different catchments were measured, and sorted into litter classification. The wet loads collected at the catchments ranged between 14 and 111 kg/ha, with majority of them was contributed by a significant amount of sediment and plastic. The water quality at the inflow and outflow channels was examined. GPT responded effectively for chemical oxygen demand, biological oxygen demand, ammonical nitrogen, and total suspended solids removal, reaching the maximum removal of 88, 94, 94, and 97%, respectively. The water quality index of the influent river water falls in Class V, derived as "very polluted," while the downstream river water lies in the intermediate between Class IV and III, defined as "polluted" and "average," respectively. These findings strongly supported the real practical applications of GPTs for the effective management and preservation of urban river systems.

Keywords: Gross pollutant trap; River water; Stormwater; Water quality index; Wet load

1. Introduction

Stormwater is the surface flow collected along the path of urban runoff into the receiving waterways [1]. The term "gross pollutants" derived as large pieces of silt, trash, and particulate matters, either as floating or bed loads in urban conveyance system, are the primary targeted pollutants for water quality preservation. It consists of mainly litter, debris, and coarse sediments, with the mesh size of greater than 5 mm [2]. Urban litter, defined as visible solid waste emanating from the urban environment, is the human-discarded waste accumulates in the vicinity of shopping centers, car parks, fast food outlets, railway, bus stations, roads, schools, public parks and gardens, garbage bins,

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landfill sites, and recycling depots. Litter in the stormwater system includes manufactured materials such as papers, bottles, cans, plastic, polystyrene, metals, glass, cloth, used car parts, and rubble from construction sites that have been dumped illegally into the waterways or drains [3]. Debris is defined as any organic material transported by stormwater such as leaves, branches, seeds, twigs, and grass clipping, while coarse sediments are eroded soil particles or inorganic breakdown products originating from diffused sources, such as construction sites, pavement, land clearing sites, and agricultural areas [4]. Table 1 summarizes a simplified classification of gross pollutants, and the contributing factors which affect the composition of gross pollutants are given in Table 2 [5].

These accumulated pollutants are not only esthetically unattractive, but also demonstrate environmentally threatening and devastating effect to the natural equilibrium, and impede hydraulic performance of the urban drainage system [6]. In particular, aquatic fauna are at risk of becoming entangled in, or suffocating from, litter ingested in the course of their search for food; while pathogenic organisms or toxins could interfere with the biota terrestrial ecosystems, resulting in food chains imbalance [7]. A study conducted in Melbourne, Australia has noted that urban areas contribute 20–40 kg of gross pollutants per hectare to the stormwater, equivalent to approximately 60,000 tons or 230,000 cubic meters of gross pollutants, with the generation of 2 billion tons of litter annually [8]. The growing population density, built-up areas, industrialization, and seasonal variation could directly or indirectly affect the hydrological processes through the alteration of flow characteristics, stream flow regime, and changes of the rivers' amenities [9]. Eventually, the eroded sediment would be deposited in the waterways and contribute to the surface imperviousness.

The rising awareness about the degradation of river water quality by gross pollutants has led to the implementation of gross pollutant management strategies as a holistic approach for water quality improvement [10]. Integration of both structural and non-structural measures is important to ensure the effectiveness of gross pollutant management. Structural measures are constructed in-transit treatments which separate and contain pollutants. The introduction of gross pollutant traps (GPTs) as a pretreatment for stormwater flow is an excellent method of reducing and handling gross pollutants before entering to the receiving water such as pond, wetland, and river. This structural measure is based on the concept of "control-at-source" with the objective to control stormwater quantity and quality [11]. Literally, GPT is an engineered sediment trap designed to treat stormwater and reduce the flow energy through their "self-cleansing ability." It combines the mechanism of gross solids interception and retention. This mechanism utilizes the energy from the inflow to separate floatable particles with non-floatable materials. With proper modifications, GPTs have been documented to provide the reduction of particulate nutrients, trace metals, oil and grease, bacteria, and dissolved oxygen-demanding substances prior to the release of stormwater into natural waterways [12].

The operation of gross pollutant devices is governed by a number of confounding factors, including catchment size, pollutant load, type of drainage system, and cost. However, the performance of GPTs is not fully tested on real practical applications under the influence of tropical climate where high rainfall intensity in short duration prevails. With the aforementioned, this study aims to develop an understanding of the type, source, characteristics, and amount of gross pollutants generated from the most polluted river in Malaysia, Klang River and its major attributes,

Table 1
A simplified classification of gross pollutants

Main categories	Sub-categories	Example of item
Plastic	Packaging, polystyrene, containers	Shopping bag, polystyrene, containers, bottles, straws, syringes
Paper	Packaging, stationary, cardboard	Wrappers, serviettes, newspaper, brochures, bus tickets, food, and drink containers
Metal	Cans, bottles	Foil, bottle tops
Glass	Bottles	Drink container
Vegetation	Leaves and branches, food	Garden debris, rotten fruit, and vegetables
Sediment	Sand	
Miscellaneous	Animal, construction material, cloth, fiber glass	Dead animal, lumps of concrete, old clothing, cigarette butts, tyres

Table 2
The contributing factors which affect the composition of gross pollutants [5]

Factors	Description
Type of development	Generally commercial and industrial areas produce higher amount of gross pollutant
Population density	Permanent of transient residences
Rainfall pattern	Intensity, stormwater runoff
Management practices	Enforcement of street sweeping, garbage collection service, law enforcement on littering
Community profile and behavior	Income level, environmental awareness
Seasonal variation	Longer dry periods may accumulate more pollutants
Physical catchment characteristic	Size, slope, surface characteristic, type of vegetation
Drainage system	Size and geometry of inlet and pipe networks

Gisir River, Kemensah River, and Sering River. To achieve the objective, the gross pollutants collected from different catchments were measured, and sorted into litter classification during a 10-month operation. The water quality at the inflow and outflow channels was examined. Additionally, the effectiveness of the installation of GPTs for biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonical nitrogen (AN), and total suspended solids (TSS) removal, and overall water quality improvement were outlined.

2. Methodology

2.1. Study area

Klang River basin, located within the states of Selangor and Kuala Lumpur, Malaysia, one of the most heavily polluted rivers within the region has been selected as the location of study (Fig. 1). The Klang River drains an area of 1,288 km^2 from the steep mountain rainforests of the main central range along Peninsular Malaysia to the river mouth in Port Klang, spanning a distance of 120 km. The basin encompasses the Federal territory of Kuala Lumpur (Federal territory), parts of Gombak, Hulu Langat, Klang, Petaling districts in the Selangor State, and the municipal areas of Ampang Jaya, Petaling Jaya, with seven different main land uses: settlements, industry, rubber and oil palm plantations, forests, industry, water bodies, and agricultural land.

It is joined by 11 major tributaries, mainly Gisir River, Kemensah River, and Sering River passing through the Federal territory and the area downstream of Kuala Lumpur, before amalgamating with the Strait of Malacca at Port Klang. There are two major dams upstream of the river; Batu Dam and Klang Gates Dam, which provide water supply to the people of Klang Valley and mitigate floods. The Klang river basin is the most densely populated area in the country, with a population of 3.6 million people, or approximately 18% of the nation's total population. The water quality along the river basin is significantly degrading due to remarkable development, with an

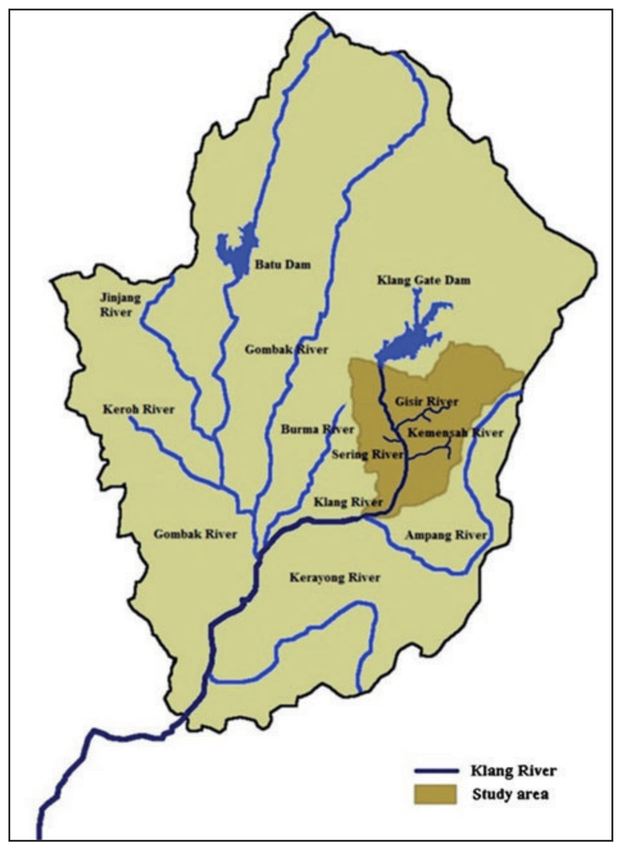

Fig. 1. The river catchments of Klang River and its major attributes, Gisir River, Kemensah River, and Sering River.

average of 80 tons of solid waste is collected daily along the river and its tributaries. The climate in the study area is characterized by high average and uniform annual temperatures, rainfall, and humidity, with the annual rainfall of 3,000 mm. This climate has a dominant impact on the hydrology and geomorphology of the study area.

2.2. Gross pollutant traps

The GPT unit, a design requirement set to serve for a catchment area up to a 3-month average recurrent interval event, has been applied in this study (Fig. 2). The primary traps are features designed to slow down the stormwater before it enters into the ground directly or into the combined or separated sewer system. The average catchment area for each GPT unit is about 1.8 hectares, while the maximum runoff distance on the surface is 50–80 m. These highly urbanized catchments with different forms of commercial and residential lots were selected to reflect the local pollution sources, and possible environmental loads along the Klang Valley.

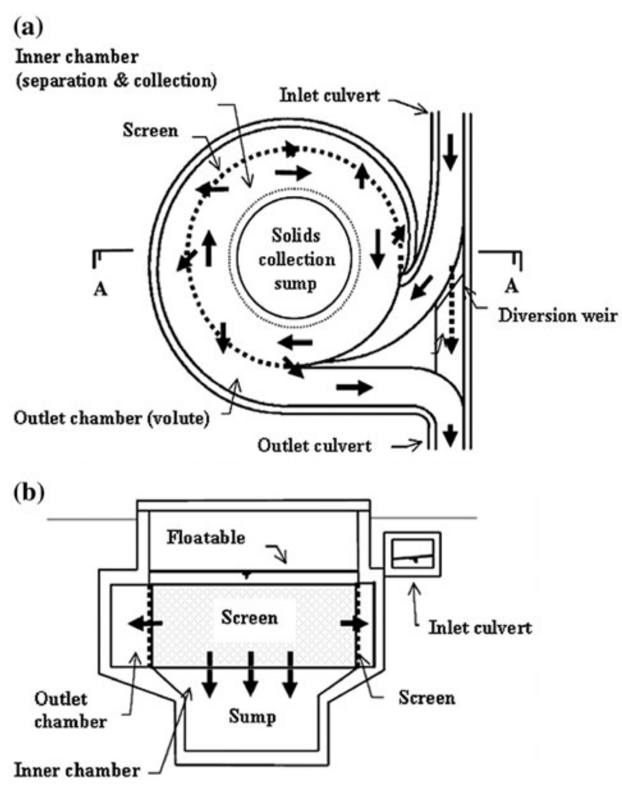

Fig. 2. Horizontal (a) and vertical (b) sections through the GPT device.

2.3. Gross pollutant monitoring

Gross pollutants from 51 catchments located in the impervious urban were sampled from April 2012 to January 2013. The gross pollutant monitoring was conducted according to the guideline as suggested by the American Society of Civil Engineers [13]. The collection was performed monthly, and analyzed with regard to the total mass loads. Anthropogenic litter and sediment trapped within the GPT were removed. The trapped gross pollutants were collected, oven-dried, weighed, and subjected to gross pollutant classification: plastic, paper, metal, glass, vegetation, sediment, and miscellaneous.

2.4. Water samplings

The water quality monitoring was conducted at the upstream and downstream zones of the catchments during the 10-month operation period. Water sampling was scheduled at least twice per week. Chemical analysis was performed according to the Standard Method of Water and Wastewater [14]. The temperature, dissolved oxygen level, and pH were measured using a handheld multiparameter instrument (YSI 6920). The analytical determination of biological oxygen demand (BOD_5), COD, AN, and TSS concentration was determined according to the luminescence measurement, closed reflux colorimetric, salicylate, and gravimetric standard methods, using a visible spectrophotometer (HACH DR3900). All measurements were undertaken in triplicates.

2.5. Performance analysis

The GPTs were examined with regards to their capability for COD, BOD_5, AN, and TSS removal defined as:

$$R = \frac{(C_i - C_o)}{C_i} \times 100\% \quad (1)$$

where C_i and C_o (mg/L) are the liquid-phase concentrations at the inlet and outlet zone, respectively, and overall water quality index (WQI) improvement derived as:

$$\begin{aligned} WQI = {} & 0.22\,SIDO + 0.19\,SIBOD_5 + 0.16\,SICOD \\ & + 0.16\,SISS + 0.15\,SIAN + 0.12\,SIpH \end{aligned} \quad (2)$$

where WQI is the water quality index, SIDO is the sub-index of DO, $SIBOD_5$ is the sub-index of BOD_5, SICOD is the sub-index of COD, SIAN is the sub-index of AN, SISS is the sub-index of TSS, and SIpH is the sub-index of pH.

Sub-index for DO (in % saturation):

$$\text{SIDO} = 0 \quad \text{for DO} < 8 \tag{2.1a}$$

$$\text{SIDO} = 100 \quad \text{for DO} > 92 \tag{2.1b}$$

$$\text{SIDO} = -0.395 + 0.030\,\text{DO}^2 - 0.00020\,\text{DO}^3 \quad \text{for } 8 < \text{DO} < 92 \tag{2.1c}$$

Sub-index for BOD$_5$:

$$\text{SIBOD} = 100.4 - 4.23\,\text{BOD}_5 \quad \text{for BOD}_5 < 5 \tag{2.2a}$$

$$\text{SIBOD} = 108e^{-0.055\text{BOD}} - 0.1\,\text{BOD}_5 \quad \text{for BOD} > 5 \tag{2.2b}$$

Sub-index for COD:

$$\text{SICOD} = -1.33\,\text{COD} + 99.1 \quad \text{for COD} < 20 \tag{2.3a}$$

$$\text{SICOD} = 103e^{-0.0157\,\text{COD}} - 0.04\text{COD for COD} > 20 \tag{2.3b}$$

Sub-index for AN:

$$\text{SIAN} = 100.5 - 105\text{AN} \quad \text{for AN} < 0.3 \tag{2.4a}$$

$$\text{SIAN} = 94e^{-0.573\text{AN}} - 5[\text{AN} - 2] \quad \text{for } 0.3 < \text{AN} < 4 \tag{2.4b}$$

$$\text{SIAN} = 0 \quad \text{for AN} > 4 \tag{2.4c}$$

Sub-index for TSS:

$$\text{SISS} = 97.5e^{-0.00676\,\text{SS}} + 0.05\,\text{TSS} \quad \text{for TSS} < 100 \tag{2.5a}$$

$$\text{SISS} = 71e^{-0.0016\,\text{SS}} - 0.015\,\text{TSS} \quad \text{for } 100 < \text{TSS} < 1000 \tag{2.5b}$$

$$\text{SISS} = 0 \quad \text{for TSS} > 1000 \tag{2.5c}$$

Sub-index for pH:

$$\text{SIpH} = 17.2 - 17.2\,\text{pH} + 5.02\,\text{pH}^2 \quad \text{for pH} < 5.5 \tag{2.6a}$$

$$\text{SIpH} = -242 + 95.5\,\text{pH} - 6.67\,\text{pH}^2 \quad \text{for } 5.5 < \text{pH} < 7 \tag{2.6b}$$

$$\text{SIpH} = -181 + 82.4\,\text{pH} - 6.05\,\text{pH}^2 \quad \text{for } 7 < \text{pH} < 8.75 \tag{2.6c}$$

$$\text{SIpH} = 536 - 77.0\,\text{pH} + 2.76\,\text{pH}^2 \quad \text{for pH} > 8.75 \tag{2.6d}$$

3. Results and discussions

3.1. Gross pollutant monitoring and classification

The distribution of wet pollutant loads along the catchments of Klang River and its major attributes, Gisir River, Kemensah River, and Sering River over the operation period of 10 months is displayed in Fig. 3. The wet load collected at the catchments during the sampling period ranged between 14 and 111 kg/ha with Gisir River detected the lowest wet load capture, while Kemensah River marked the peak pollutant load of 110.87 kg/ha/month. The variation was mainly ascribed to the different anthropogenic pollutants, generated from domestic, commercial, industrial, and agricultural activities at different catchment, that are flushed directly or indirectly into the nearby watercourses, resulting in the serious degradation of river body.

Generally, a higher mass load was acquired during the initial operation of the GPT units. The phenomenon was attributed to the accumulation of a series of gross pollutants in the river system, before the installation of GPTs. The collected mass loads from

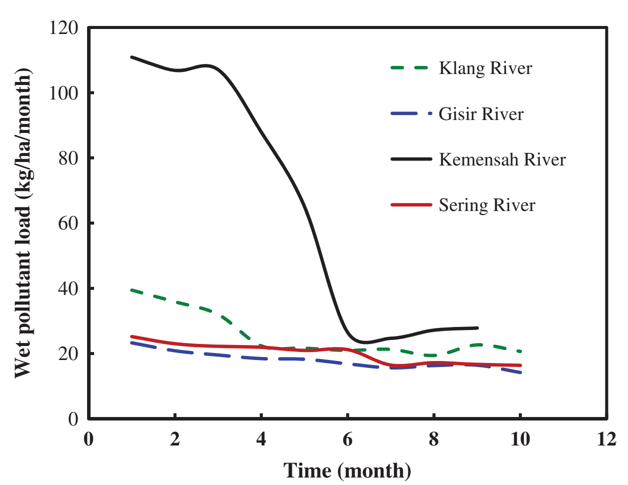

Fig. 3. The distribution of wet pollutant loads along the catchments of Klang River and its major attributes, Gisir River, Kemensah River, and Sering River over the operation period of 10 months.

the river catchments remained almost consistent after the 5-month operation, demonstrating the feasibility of the physical setup for the preservation of river system. The collected samples were dried and characterized into seven respective gross pollutant classifications, as summarized in Fig. 4. As suggested by the result, the trapped gross pollutants contain hetero mixtures of plastic, paper, metal, glass, vegetation, sediment, and miscellaneous. Majority of these gross pollutants recorded a significant amount of sediment and plastic, which accounted approximately 70% of the total dry mass load, while the least amount of paper waste was found from these catchment areas. The wide variation in the compositions of gross pollutants was attributed to the difference of sizes, slope, surface characteristics, activities, vegetation, development density, population, management practice, and percentage of impervious area at different channels, which determine the fluctuation of pollution load. Moreover, other natural factors that contribute toward the movement, volume, and types of gross pollutants include the seasonal changes, rate of rainfall, runoff, and flow velocity of the river water [15].

3.2. BOD_5 and COD

BOD_5 and COD are two different surrogate parameters measuring the oxygen content of water to the recipients [16]. BOD_5 quantifies the amount of dissolved oxygen during the oxidation of organic components by micro-organism in the water effluent [17]. Conversely, COD is a measurement of the oxygen equivalent of the organic matter content of a water sample that is susceptible to oxidation by a strong chemical oxidant [18]. The variation of the BOD_5 and COD concentrations of the inlet and outlet catchments of the Klang River and its major attributes, Gisir River, Kemensah River, and Sering River over the operation period of 10 months is provided in Fig. 5(a) and (b).

Along the study, the BOD_5 and COD concentrations of the influent river water varied between 138 and 1,475 mg/L, and between 107 and 4,840 mg/L, with an average concentration of 601 and 1,748 mg/L, respectively. The BOD_5 level of the outlet zone ranged within 23 and 170 mg/L, and the corresponding COD was 62–304 mg/L during the operation. Regardless on the variation of influent concentration, surface characteristics, slope, area, and location of the catchment zones, the consistency of the BOD_5 and COD concentrations at the outlet channels has proven the high flexibility of this gross pollutant system for various river catchments.

The BOD_5 and COD removal efficiency, R fluctuated considerably throughout the study, ranging from 55 to 88%, and 61 to 94%, respectively. High fluctuation of the removal efficiency was due to the variations of influent concentration, as well as with the changes in biodegradability of organic compounds. However, no obvious relationship between variation of influent concentrations with the COD and BOD_5

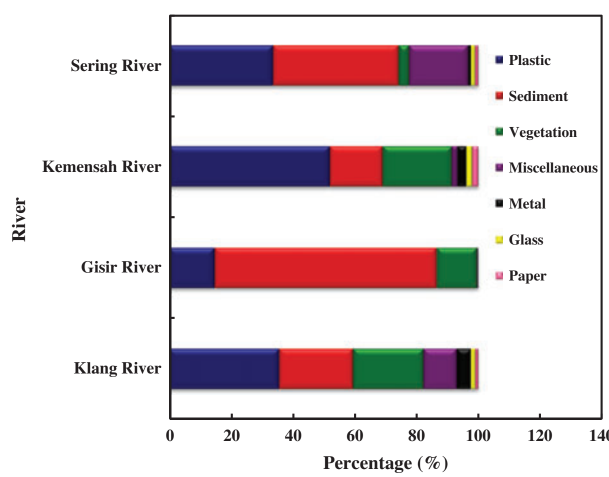

Fig. 4. The classification of gross pollutants loads along the catchments of Klang River and its major attributes, Gisir River, Kemensah River, and Sering River over the operation period of 10 months.

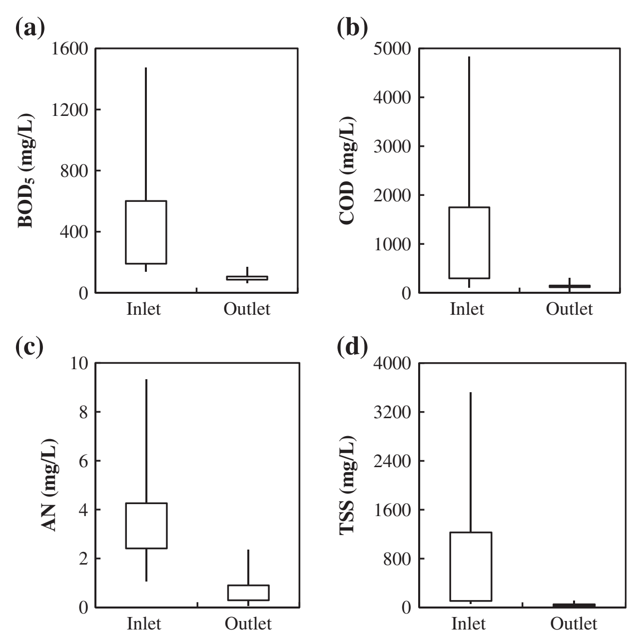

Fig. 5. The variation of (a) BOD_5, (b) COD, (c) TSS, and (d) AN concentrations at the inlet and outlet along the catchments of Klang River and its major attributes, Gisir River, Kemensah River, and Sering River over the operation period of 10 months.

removal was detectable, even though the influent COD levels, on average, showed a greater fluctuation than the BOD_5 concentration.

3.3. Ammonical nitrogen

In surface water, nitrogen could exist in many forms, including organic nitrogen, ammonia nitrogen, nitrite, and nitrate nitrogen, with AN being the major form. AN is one of the most important water quality parameters applied to assess a water supply source as it affects the pre-chlorination and disinfection of the wastewater treatment plants [19]. The variation of AN concentration of the inlet and outlet catchments of the Klang River and its major attributes, Gisir River, Kemensah River, and Sering River is plotted in Fig. 5(c).

Despite the influent concentrations were extremely low (1.1–9.3 mg/L), the installation of GPTs could effectively discriminate AN from the river systems, with greater than 74% of removal rate. Over the operation period of 10 months, the AN concentration at the outlet catchments was ranged within 0.06 and 2.36 mg/L, with the peak removal efficiency, R of 94%. Although the nitrite concentration in the river water was not continuously monitored, random checks illustrated that the nitrite concentrations in the outlet zones were lower than the upper stream, indication of the presence of biological nitrification. Additionally, the dissolved oxygen in the outlet catchments was varied from 3 to 9 mg/L. This root oxygen release has been postulated to account for the purification of AN by stimulating nitrification, and aerobic oxidation of AN to nitrate and nitrite.

3.4. TSS

TSS describes the impurities present in the water body, from soil erosion, runoff, discharges, stirred bottom sediments or algal blooms, and is a direct quantification of sedimentation rates [20]. It is the most visible indicators of water quality, with identical measurement on the dry weight of particles trapped by a Millipore filter with a pore size of 0.45 μm. As the levels of TSS increase, a water body begins to lose its ability to support a diversity of aquatic life. The lower TSS would allow the penetration of light from reaching to the submerged vegetation, to enhance the photosynthetic activities and dissolved oxygen level of the water body. Some cold water species, such as trout and stoneflies, are especially sensitive to the changes of TSS, dissolved oxygen, and water turbidity [21].

The variation of TSS concentration at the inlet and outlet catchments of the Klang River and its major attributes, Gisir River, Kemensah River, and Sering River is depicted in Fig. 5(d). Generally, the GPT unit demonstrated a high potential to trap suspended particles, particularly sediment and the associated contaminants, with a beneficial effect on the downstream water quality [22]. Dependent on the particle size distribution of the solids, sedimentation, organic material breakdown activities, biochemical transformation of nutrients contained in the trapped material, and geological difference of the catchment zones, the TSS concentration varied between 57 and 3,520 mg/L. However, the removal of TSS remain at the efficiency greater than 68%, recorded the peak removal, R of 97%.

The correlation is in agreement with the research finding by Walker et al. [23], who reported that the GPT unit retains nearly all gross pollutants, and hence the majority of the organic material transported from the catchment was retained within the GPT containment sump. In addition, the presence of micro-organisms or algae might contribute to TSS removal by aerobic degradation of organic and inorganic compounds and photosynthesis processes. This is the most likely reason for the higher dissolved oxygen saturation in the outlet zones, which is known to be caused by the high levels of micro-organisms or algal activities [24].

3.5. WQI improvement

WQI serves as the basis for environmental assessment of a watercourse in relation to pollution load categorization and designation of classes of beneficial uses as provided by the Interim National Water Quality Standards for Malaysia (INWQS) [25]. It combines the measurement of several water quality variables in such a way to produce a single score to represent the quality impairments or suitability of use (Table 3). WQI is applied to determine the water quality status: clean, slightly polluted, or polluted category (Table 4), and to classify the rivers in Class I, II, III, IV, or V.

The values of WQI of the influent river water at the inlet catchments of the Klang River and its major attributes, Gisir River, Kemensah River, and Sering River, were <31, while the effluent water at the outlet zones reached to the WQI reading of 45.2–72.8. According to the Classification of WQI given by INWQS, the value of WQI of the influent river water falls in Class V (<31.0), derived as "very polluted," and the downstream river water lies in the intermediate between Class IV and III, defined as "polluted"

Table 3
The water quality classification according to WQI

Class	Uses
Class I	Water supply-practically no treatment necessary Fishery-very sensitive aquatic species
Class IIA	Water supply-conventional treatment required Fishery-sensitive aquatic species
Class IIB	Recreational use with body contact
Class III	Water supply-extensive treatment required Fishery-common, of economic value and tolerant species; livestock drinking
Class IV	Irrigation
Class V	None of the above

Table 4
Classification of water classes and their uses

Water quality index (WQI)	Class	Condition
>92.7	I	Very good
76.5–92.7	II	Good
51.9–76.5	III	Average
31.0–51.9	IV	Polluted
<31.0	V	Very polluted

and "average," respectively. This fact indicated the promising capability of the GPT in the regulation of BOD_5, COD, TSS, pH, dissolved oxygen, and AN for water quality improvement. Along the study, gross pollutants are retained within the chamber by a perforated plate that allows water to pass through to the outlet pipe. The water and associated pollutants contained within the separation chamber are kept in continuous motion by the energy generated by the incoming flow. This has the effect of preventing the separation plate from becoming blocked by the gross solids captured from the inflow. Heavier solids settle into the containment sump and much of the neutrally buoyant material eventually sinks, while floating material accumulates at the water surface [23].

4. Conclusion

The performance of the GPT units was investigated for the entrapment of gross pollutants, purification of BOD_5, COD, AN, and TSS, and overall WQI improvement, from 51 catchments located at the impervious urban in Klang Valley over the operation period of 10 months. The wet load collected at the catchments ranged between 14 and 111 kg/ha, with Gisir River detected the lowest wet load capture, while Kemensah River marked the peak pollutant load of 110.87 kg/ha/month. Majority of these gross pollutants were contributed by a significant amount of sediment and plastic. High removal efficiencies of BOD_5, COD, AN, and TSS were detected throughout the operation period, reaching the maximum removal rate of 88, 94, 94, and 97%, respectively. The WQI of the influent river water falls in Class V, derived as "very polluted," whereas the downstream river water lies in the intermediate between Class IV and III, defined as "polluted" and "average," respectively. The new structural setup represents a promising alternative to the removal of a wide spectrum of gross pollutants from the river system, for the effective remediation of urban stormwater pollution problem.

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