The use of treatment train for stormwater quality control in urban areas in Malaysia: A short review

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Abstract. Water pollution is a major challenge in urban areas. The main source of water pollution is the runoff accelerated from impervious areas and agricultural land. In recent years, planning and designing of urban water management in Malaysia is moving away from the conventional thinking of designing for flooding to balancing the impact of urban drainage on flood control and quality management. In order to minimize the environmental impact of water pollution, Best management practices (BMPs) and Low impact development (LID) approaches have been used to manage runoff as close as possible to its source. The individual practices often have a low ability to provide consistent pollutant removal. Therefore, the arrangement of several LID-BMPs is recommended. This arrangement in series is called a treatment train. There is a need to review findings in the use of treatment train for water quality control. Therefore, this review paper discussing the ability of the treatment train for water quality control of runoff in urban areas in Malaysia. In addition, it compares a single treatment with the treatment train. The use of treatment train was very effective for stormwater control when compared with a single treatment practice. However, the use of treatment train for treating other types of runoff such as agricultural runoff still not implemented yet. It is recommended to use this system for treating other types of runoff such as agricultural runoff in the future work.

1. Introduction
Urban area is constantly expanding in terms of space and density [1, 2]. However, development of urban areas ultimately results in a greater load of sediment and nutrients entering water bodies [3]. The runoff from urban areas considered to be a critical source of water pollution [4]. It has been recognized as a source of nonpoint pollutants that can accumulate in the watersheds. It can cause chemical, physical, and biological damage to the environment. It further contributes to ecological degradations and health risks [5]. In Malaysia, the rapid development and urbanization produced great amounts of wastes including domestic, commercial, industrial and transportation wastes which ends up in the water bodies [6]. The excessive wastes impact water quality when water and soil containing pollutants wash into nearby waters or leach into ground waters [7]. Therefore, the proper management of runoff from urban area is essential and plays a critical role in the environment. Thus, the reduction of nutrients transport to watersheds is necessary for water pollution control [8]. Recently, Malaysia is more focusing on flood control and runoff quality management [9]. Best management practices (BMPs) and Low impact development (LID) are a water management approaches that manage runoff...
as close as possible to its source [10]. The arrangement of several selected LID-BMPs in a series is called a treatment train. This arrangement is recommended to maximize the integrated effectiveness on runoff control [11]. There is a need to review findings in the use of treatment train for water quality control. Therefore, this review paper discussing the use of treatment train for water quality control of runoff in urban areas in Malaysia. It also compares the single treatment with the treatment train.

2. Literature review

The Non-point source pollution has become a leading source of water pollution [12]. It mainly caused by urban stormwater, agricultural runoff, and atmospheric deposition [13]. According to 2000 Annual Report by the Department of Environment (DOE), more than 63% of the rivers in Malaysia are classified as moderately to highly polluted [14]. A number of 52 river basins were polluted with suspended solid because of uncontrolled urban development. 18 river basins contained lower dissolved oxygen (DO) because of effluent from the industrial and 33 rivers were polluted by ammoniac nitrogen from the animal farming and domestic waste [6].

2.1. BMPs and LID management practices

In the past few decades, water management has been practiced traditionally to transport runoff as quickly as possible in order to prevent flooding. In recent year, planning and designing of urban runoff in Malaysia is moving away from the conventional thinking of designing for flooding to balancing the impact of urban drainage on flood control and quality management [9].

In order to minimize the environmental impact of urban runoff, it was necessary to establish water quality monitoring and intelligent watershed management [10, 15]. LID-BMPs commonly used for pollutants mitigation by promoting water infiltration and evapotranspiration to improve water quality [16]. Such practices include, filter strips, infiltration trenches, vegetated roofs, permeable pavement, rain gardens, bioretention and swales [17]. The use of these practices for water quality control considered to be a cost-effective [18]. They take advantage of natural processes such as infiltration to reduce the volume and rate of runoff at the same time improve water quality [19]. The advantages of infiltration process include groundwater recharge, runoff volume reduction, and water quality enhancement [20]. Water quality enhancements can be obtained through infiltration and sedimentation. Filtration through vegetation is the primary mechanism for pollutant removal. Then settling of particles, and infiltration into the subsurface zone. As runoff travels through the system, the vegetation reduces peak velocity while infiltration reduces flow volume which promotes pollutant removal [21]. In addition to direct plant nutrient uptake, vegetation increases microbial activity through nitrifying and denitrifying process which lead to increase nutrient removal [22].

2.2. Treatment train build

To date, there has been a great deal on the LID-BMPs practices for urban runoff control. But the individual LID-BMPs often has low ability to provide consistent pollutants removal. For example, swales as standalone treatment systems, their ability for pollutant removal is limited but their conveyancing capability allows them to be one component of treatment trains [23]. The use treatment train has several advantages over implementing a single treatment which include enhancing of pollutant removal with the number of different processes [11, 24]. Some studies have demonstrated that, treatment train was effective for stormwater quantity and quality control. A field test of selected treatment train (bioretention and swale) was conducted in China by Jia et al. [25]. Results indicated that, peak flow rate and runoff reduction of stormwater of a bioretention cell was more than swale. For water quality, the bioretention in general showed better removal efficiency than swale.

When considering the treatment train system, it showed excellent removal for NH$_3$-N, TN, and TP and fair removal for COD and TSS. A study of treatment train of pervious concrete with bioretention in series by Brown et al. [26]. They achieved more hydrologic benefits and pollutants reduction with two LID-BMPs practices (Pervious Concrete with bioretention) in-series compared with a single practice.
2.3. The use of treatment train in Malaysia

In Malaysia, USM implemented Bio-Ecological Drainage Systems (BIOECODS) project, which consisted of series of different LID-BMPs practices as treatment train for stormwater management. This project was the first treatment train in Malaysia. The components of treatment train included swales, dry and wet ponds, detention ponds, wetlands/wading river to Kerian river [27] as shown in Figure 1.

![Figure 1](image-url)  
**Figure 1.** The components of treatment train in USM, Malaysia.

This combination reduced runoff volume through additional infiltration opportunities by different processes, increased pollutants removal through settling and increasing retention time which lead to more enhancement in the runoff quantity and quality [28]. The integrated design performed effectively for stormwater quantity and quality control. It became a flood protector and runoff controller by attenuation of runoff and minimizing pollutant load entering the waterways [27, 29]. There are some studies on individuals and integrated LID-BMPs practices in Malaysia for urban stormwater management as shown in Table 1.
| Study location                  | Type of study | Type of LID practice             | The use of treatment train | The purpose of study                                                                                           | Summary of result                                                                                     | Ref.   |
|--------------------------------|---------------|----------------------------------|---------------------------|-----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|--------|
| Kota Damansara, Petaling District, Selangor, Malaysia | Field study   | Dry detention pond               | No                        | Evaluation of detention pond for stormwater quantity control                                                  | The result demonstrated that the detention pond achieved the goal by catering the flow and protecting against flooding | [30]   |
| Engineering Campus Universiti Sains Malaysia USM, Nibong Tebal, Penang, Malaysia | Field study   | Constructed wetland              | No                        | To use constructed wetlands for stormwater quality control                                                    | The concentration of nutrients such as nitrogen, phosphate nitrite, nitrate, ammonia was significantly reduced. The removal efficiency ranged between 27.7 to 80% | [31]   |
| Putrajaya city, Malaysia       | Pilot and Field study | Constructed wetland             | No                        | To use constructed wetland to treat surface Runoff from developed urban area                                  | The removal efficiency of nutrients was satisfactory for Total nitrogen, nitrate and phosphate.            | [14]   |
| Engineering Campus Universiti Sains Malaysia USM, Nibong Tebal, Penang, Malaysia | Column study  | Enhanced Bioretention with carbon source additive | No                        | The use of bioretention for stormwater nutrients removal                                                      | The results showed high ability of bioretention in removing nutrients (TN, TP)                             | [32]   |
| Engineering Campus Universiti Sains Malaysia USM, Nibong Tebal, Penang, Malaysia | Mesocosm study | Enhanced Bioretention with carbon source additive | No                        | The use of bioretention for nutrient rich stormwater in mixed land area                                        | The study proved that bioretention has a potential application for nutrient rich stormwater in mixed land | [33]   |
| Engineering Campus Universiti Sains Malaysia USM, Nibong Tebal, Penang, Malaysia | Prototype     | Green roof                       | No                        | green roof tested for high intensity stormwater runoff for quantity and quality control of metals (Lead       | The results showed that reduction in the runoff for high intensity stormwater was very promising. Nevertheless, the system was incapable to remove Lead and potassium. | [34]   |

Table 1. Individuals and integrated LID-BMPs practices in Malaysia.
The previous studies concluded that, LID-BMP treatment train is very effective for runoff control. However, the implementation of LID-BMPs treatment train for runoff control in Malaysia is relatively few. Thus, the Malaysian experience on integrating LID-BMPs practices is still in an early stage [38].

### 3. Conclusion

This study reviewed the existing literature and highlighted the key advancement in the use of treatment train for water quality control in urban area. The use of treatment train practices in-series was very effective in peak flow and outflow reduction when compared with a single treatment practice. However, field tests of integrated treatment train systems are still relatively few. On the other hand, the use of treatment train for treating other types of runoff such as agricultural runoff still not considered yet due to the high concentration of pollutants in this water. It is recommended to use this system for treating other types of runoff such as agricultural runoff in the future work. Further, more work is required on the hydraulic characteristics, pollutants removal of runoff in the treatment train system.

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