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Evaluating the water quality of stormwater runoffs in urban area

Yang F.[1,*], Gato-Trinidad S.[1], Hossain I.[1]

[1] School of Engineering, Swinburne University of Technology, Hawthorn, Australia

*corresponding author: Fujia Yang
e-mail: fujiayang@swin.edu.au

Abstract This paper presents the results of stormwater quality monitoring from four constructed wetlands located in residential and industrial catchments. Preliminary results revealed that pollutants' types and concentrations vary depending on the catchments' characteristics. It is found that the residential catchments often hold higher total phosphorus and suspended solids, while the industrial areas are found with high concentrations of Iron and Strontium. Nonetheless, high metal concentrations are observed in both catchments, raising concerns about the effectiveness of stormwater treatment devices and the current guidelines adopted in the design and construction of these systems. While it is found that all catchments displayed exceptional levels of pollutants that are not safe for the freshwater environment, the pollutant concentrations remained below the average concentrations in the Melbourne area. Less commonly discussed metals such as Barium and Strontium were found in all water samples with concentrations greater than the values discussed in the literature. During the investigation, challenges were faced due to the voluntary nature of the guidelines and the lack of data on trace metals. It is, therefore, recommended that further monitoring is required to confirm the changes in stormwater runoff quality and to assess the appropriateness of the current guidelines for improved management.

Keywords: Heavy metals, best practice management, stormwater runoff, water quality

1. Introduction

Increased impervious surfaces in urbanized areas are considered to be the main source of stormwater pollutants. To protect the natural environment and improve livability, it is essential to treat and manage the pollutant concentrations from stormwater runoffs. Currently, the concept of treatment and reuse of stormwater is well adopted across the world. Water Sensitive Urban Design (WUSD), Green Infrastructure or Sponge City are advocated in urban planning that utilizes diverse sources of water and stormwater for reusing and recycling (Feng, Liu, & Gao, 2022).

In Melbourne, Australia, WSUD is well-blended in stormwater management to reduce pollution levels. Consequently, a great variety of WSUD infrastructures including constructed wetlands, biofilters, swales and street tree pits are constructed and distributed across metropolitan Melbourne (Hamlyn-Harris, McAlister, & Dillon, 2019). However, the evaluation of the stormwater infrastructure is often heavily anchored on meeting the reduction targets, and there is a lack of attention to the water quality assessment. Besides the well-known pollutants in stormwater runoff, heavy metals are found in many stormwater catchments in industrialized areas. However, the treatment of metallic pollutants could be inadequate with the traditionally implemented stormwater treatment devices which are constructed to treat the typical pollutants (Yang, Gato-Trinidad, & Hossain, 2022). Moreover, as stormwater volume control has been a significant constraint in the current stormwater management, a substantial amount of stormwater will be bypassed and flowing directly into the streams without treatment (Hart, Francey, Chesterfield, Blackham, & McCarthy, 2022).

Although there are many guidelines in place to assist managers in decision-making, most of the frameworks are often voluntary, and they were developed for risk assessment purposes. As a result, there is a gap in reviewing the impact of urbanization on the treatment of stormwater pollutants. Hence, this paper presents the monitoring results of four constructed wetlands in Metropolitan Melbourne, aiming to disclose the pollutant compositions in stormwater runoffs from different urban environments.

2. Methods

2.1. Study Area

Four constructed wetlands (CWs) were studied, two are in highly industrialized districts, and the rest are all serving major housing developments as denoted in red and blue pins in Figure 1, respectively.

Figure 1. Locations of the Constructed Wetlands in Greater Melbourne are considered in this report.

One of the common purposes of deploying the devices in Figure 1 is to treat stormwater runoffs. Nevertheless, one of the CWs in the industrial region has additional functions in stormwater retention and harvesting so that the treated stormwater could be reused, and the water quality of this wetland should be further evaluated against associated health standards. Furthermore, another studied CW is near the confluence of two natural creeks in Melbourne, aiming to serve as habitats for local flora and fauna. It is crucial to ensure that the water quality is not compromised as within EPA's guidelines for freshwater environment.

2.2. Water Sampling

Water samples were collected mannually at the inlet and the outlet of the CWsbetween September and October 2022, when significant storm events were recorded. The collected water samples were then returned to an independent laboratory for analysis within 48 hours of collection. The collected water samples were analyzed for the three common pollutants: total nitrogen (TN), total phosphorous (TP) and total suspended solids (TSS), as well as 25 total metal concentrations.

2.3. Water Quality Evaluation

Currently, there is no statutory requirement for monitoring stormwater runoff quality. The only standing compliance requirement for CWs is achieving the reduction targets, mainly for TN, TP and TSS, with other pollutants often excluded. It is important to note that the objective of this study is to evaluate the quality of untreated stormwater runoff, as opposed to evaluating the treatment performance of the abovementioned infrastructures, hence the pollutant concentrations at the inlet are evaluated, so the pollutants characteristics of the corresponding catchments will be revealed. It is also pivital to recogonize that inlet concentrations will provide valuable information regarding the succeeding treatment.

Seeing the main purpose of this study is to evaluate the untreated stormwater runoff quality, it is paramount to investigate through several guiding documents as follows with the intention of comparison:

- Urban Stormwater Management Guideline
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality
- Australian Guidelines for Water Recycling (Phase 2) - Stormwater Harvest and Reuse

2.4. Urban stormwater management guideline

This guideline was previously named Urban Stormwater Best Practice Management Guideline (BPMG), and it has been the foundation of stormwater management in Victoria, Australia since its first publication in 1999 (EPA, 2023b). The present guideline aims to improve the management of stormwater in Victoria to maintain human health and the environment. The key purpose of this document is to reduce the risk of stormwater in an urban environment. The guideline determines four performance objectives for stormwater management, and they have become the milestone of the existing WSUD design. The annual reduction of the indicators mentioned below is to be achieved by stormwater management approaches, and the reduction of TN, TP and TSS are of statutory requirements.

- 80% reduction of TSS
- 45% reduction of TP and TN
- 70% reduction of litter

The significance of this document is self-evident because of its well-applauded application over the last two decades. However, there is no compliance obligation under this guideline, and it serves more of a broad and general guideline that may not be applied to specific purposes of use. More specifically, it is addressed in the document that it might not apply to the managers that have an ongoing obligation to the stormwater assets. Hence, guidance regarding stormwater quality assessment is rather limited.

2.5 Australian & New Zealand Guidelines for Fresh & Marine Water Quality and Australian Guideline for Water Recycling

To evaluate the pollutant concentrations in the water samples, two important Australian guidelines are investigated, and the reference values are displayed in Table 2. For the assessment of freshwater quality, benchmark targets are determined in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality, exceeding those values would often trigger the requirement for ecological protection (ANZECC & ARMCANZ, 2000). And for stormwater harvesting and reuse, Australian Guideline for Water Recycling summarized data from 18 studies ranging from 1997 to 2008 (Water Quality Australia, 2023).

It is noticeable that several pollutants are not included in the freshwater guideline, and the number of studies involved in the recycled water guideline is rather limited due to the lack of studies Australian-wide and internationally. However, the impact of the above documents is profound, the values are serving as a reference in the analysis of the results in the later section.

It also reflects the lack of more recent contributions and it calls for more investigations into the stormwater quality as time evolves.

3. Results

To achieve the main concern of this study which is to evaluate the stormwater quality and its impact on the ecosystem, the monitoring results are firstly compared against the two guidelines discussed above, it is brought to attention that all studied areas demonstrated significant accumulation of various pollutants. The pollutant concentrations of the four CWs are visualized in Figure 2 and Figure 3, where the blue line marks the trigger values from the freshwater guideline and the orange dashed line marks the typical pollutant concentrations in Melbourne. The industrialized areas and residential areas are denoted as I1, I2 and R1, R2, respectively. Figure 3 shows that all pollutants concentration in the stormwater runoffs are exceeding the trigger values designed in freshwater guidelines except for Mn concentrations that continuously stayed low. This is due to Mn being mostly the residue of heavy industrial activities such as mining and smelting. In addition, Mn has low toxicity to freshwater species and poses little ecological risks to the receiving environment (ANZZCC & ARMCANZ, 2000). Despite there being no benchmark values for Ba, St and TSS, it can be concluded that water samples collected in all properties failed to meet the standard for protection of the freshwater environment.

However, there is a stark contrast when the samples are compared against the average quality of the untreated stormwater runoffs. All water samples remained below the reference values of the constructed wetlands in the industrialized catchments and displayed higher concentrations of Al and Mn, whilst the rest of the wetlands in residential areas maintained acceptable levels of pollutants.

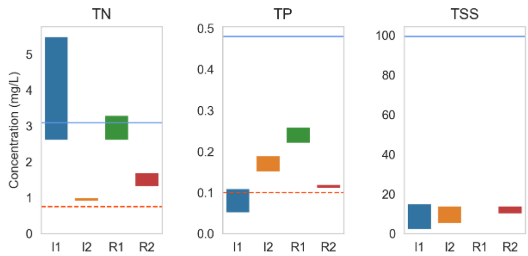

Figure 2. Concentrations of TN, TP and TSS in stormwater runoffs.

In general, it is evident that the two CWs located in residential catchments displayed greater concentrations of TSS and TP as shown in Figure 2. The results matched with Li et al. (2015)' study where the residential area was found with higher event mean concentrations of TP and TSS. In particular, TP ranged from 0.05 to 0.26 mg/L which is quite similar to other studies conducted in the same region (Drapper, Olive, McAlister, Coleman, & Lampard, 2022; Shi et al., 2019). However, the average TN concentrations in the residential catchment (2.225 mg/L) are rather similar to the industrial catchment (2.525 mg/L). Drapper et al. (2022)'s review reported a mean TN concentration of 1.06 mg/L in untreated stormwater runoffs in the Melbourne region, which is lower than the results of this study, however, the study did not specify the catchment characteristics. Meanwhile, Shi et al. (2019) reported higher levels of TN in both industrialized and residential areas, concluding that land use does not influence pollutant concentrations, which supports the results of this study.

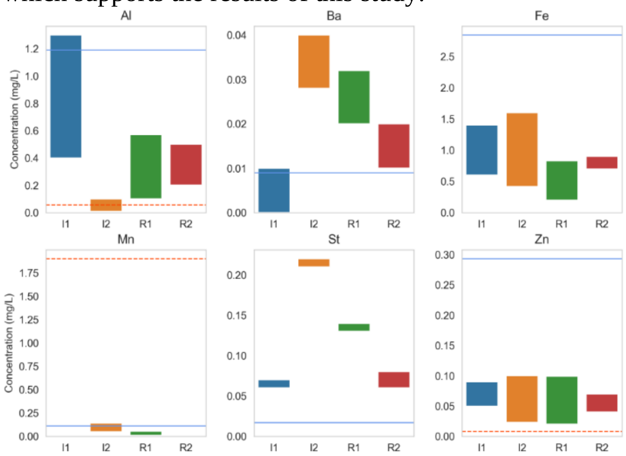

Figure. 3. Concentrations of metal pollutants in stormwater runoffs.

Regarding the metallic pollutants, many common metals such as Copper, Lead, Arsenic and Mercury stayed below detectable levels. It is brought to light that land use will have a distinct impact on the stormwater runoff quality. More specifically, stormwater runoff in residential areas is often nutrients dominant and the number of metals and sediments in the industrial catchments will be more significant (Behrouz, Yazdi, Sample, Scott, & Owen, 2022; Nayeb Yazdi, Sample, Scott, Wang, & Ketabchy, 2021). It is discovered that average concentrations of both St and Fe are relatively higher in the stormwater runoffs collected in industrial areas (0.14 mg/L and 1.00 mg/L) than in the residential areas (0.10 mg/L and 0.66 mg/L). St being one of the less discussed metal pollutants in literature, is also commonly found in Melbourne's catchments. EPA Victoria discovered a higher concentration of St in industrialized areas than in residential areas. However, the concentration of St in this study is more significant as there are only 0.3 to 0.4 mg/L of St under wet weather conditions (EPA, 2013). Although Sr does not pose threat to aquatic species, the average concentration of Sr in the freshwater environment is 0.06 mg/L, and the amount of Sr presented in the stormwater runoff would bring risk to the general public (Yang, Gato-Trinidad, & Hossain, 2022). Regarding Fe, the amount of total iron in the sampled CWs remained lower than 1 mg/L, which is considerably lower than the values reported in various sources (EPA, 2013; Hamlyn-Harris et al., 2019).

According to Figure 3, no compelling differences are observed in other metal pollutant concentrations in different land use. In fact, the metallic pollutant levels are surprisingly high in all of the investigated catchments, and Al and Fe are the two outstanding metals found, followed by St and Zn. In contrast to many studies, the concentration of Zn is not exceptional, with a mean concentration of 0.06 mg/L that is more similar to rainwater collected on the rooftop (0.06-0.09 mg/L) (Imteaz, Boulomytis, Yilmaz, & Shanableh, 2022) than collected in stormwater drains (1.5 mg/L) (Prodanovic, Hatt, Fowdar, Al-Ameri, & Deletic, 2022).

Considering that there are distinct differences among the comparisons made to each of the guidelines, it is difficult to determine when would the stormwater quality be deemed acceptable. This adds to uncertainties in the management of stormwater treatment devices. As stormwater quality is changing rapidly, further comparisons are required between our study and other studies conducted in the Melbourne region.

4. Conclusion

Stormwater quality is deteriorating with pollutant types changing in urban areas. Thus, more appropriate monitoring programs need to be designed, developed and implemented to assess the pollutants reduction capability of the existing treatment devices. In addition to meeting the reduction targets, it is equally and even more important to ensure the stormwater does not pose threat to the environment. This study presents water quality data on four constructed wetlands in Greater Melbourne, aiming to shift the focus away from pollutant reduction and bring more light to water quality assessment. Preliminary results show that some pollutants (heavy metals) do exist in both catchments rather than just in industrial catchments. After comparing the outcomes of this research against several guidelines and research studies, it is found that most of the pollutant concentrations exceeded the trigger values for the protection of the ecosystem. However, they are reasonable when compared to typical untreated stormwater runoffs. It is also found that TP and TSS are of greater levels in residential areas, and St and Fe concentrations are higher in industrialized areas. Long-term monitoring programs should be developed to further reduce the uncertainties in this study and the guidelines should be refreshed with clearly defined or consensus-based values for the management level.

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