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RESEARCH ARTICLE

Understanding of stormwater runoff dynamics before and after rainfall at a Malaysian public university

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Abstract - Rainfall influences stormwater runoff, either reducing pollutant concentrations to improve water quality or carrying high pollutants during the first flush. The study aims to identify and quantify the key contaminants in campus runoff, evaluate the impacts of rainfall on stormwater runoff pollution levels before and after rainfall, and compare water quality parameters against the National Water Quality Standard (NWQS). The study was conducted at Kolej Kediaman 2, Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA). Samples 1, 2, and 3 were collected before and after rainfall on different dates and at different rainfall rates. Key parameters evaluated include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), turbidity, and selected heavy metals (copper, nickel, and zinc). BOD increases in some samples, such as sample 2 and sample 3, which rise from 19.5 to 21.3 mg/L and 27.6 mg/L to 30.6 mg/L, respectively, suggesting that runoff can also mobilise substantial organic matter. Conversely, the COD decreases in sample 1, from 437 mg/L to 56 mg/L, and TSS falls from 30.0 mg/L to 4.0 mg/L, concurrently with the decreases in turbidity. Heavy metals before and after the rainfall have shown a slight difference for all heavy metals studied, with the maximum recorded concentrations for copper (1.71 µg/L), nickel (2.23 µg/L), and zinc (5.72 µg/L). Based on the overall findings, regardless of rainfall conditions, the water quality falls under Class V, which is poor and polluted. Therefore, the water requires treatment before use as stipulated in the standard.

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1. Introduction

Water pollution is one of the most serious global concerns, threatening aquatic ecosystems and human health. Stormwater runoff originates from various land uses, including residential, commercial, and industrial areas, as well as roads and highways. These land uses and associated human activities largely determine the nature and level of pollutants. Typical contaminants in stormwater include heavy metals, polycyclic aromatic hydrocarbons (PAHs), nutrients, and suspended solids. These contaminants come from traffic, industrial activities, agricultural activities, and land modification for domestic use [1]. The presence of contaminants such as PAHs, biocides, and heavy metals in stormwater runoff can be hazardous to aquatic environments and adversely affect natural water bodies [2]. The presence of heavy metals and PAHs in stormwater poses a threat to human health, particularly when it is reused for recreational or potable uses. These contaminants can cause harm to various organs and systems in the human body, even at low exposure levels [3,4]. Stormwater runoff pollution in Malaysia can be a complex issue influenced by a range of land-use patterns, industrial discharges, and climatic conditions. Commercial areas with high population density in Malaysia have been extensively studied for stormwater runoff pollution, with findings indicating significant contributions of pollutants such as total suspended solids (TSS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) from both dry- and wet-weather flows [5].

University campuses, with their diverse land-use patterns, can contribute to unique pollutant profiles in stormwater runoff. The mix of academic, residential, and recreational activities can lead to a variety of contaminants, including nutrients from landscaped areas and hydrocarbons from parking lots [6]. Landscaped areas, parking lots, laboratories, cafeterias, and sports facilities on campuses create a mixed set of contaminants that vary in concentration and type depending on seasonal rainfall patterns and land-use distribution. Seasonal rainfall patterns and runoff movement influence contaminant concentrations [7]. Rainfall acts in a dual role in stormwater pollution, serving as either a diluent or a mobilizer of pollutants. Contaminants in the rainfall can be diluted by increasing the volume of water. Hence, reducing contaminant concentrations. This is particularly evident in the initial stages of rainfall, when contaminant concentrations are high but decrease as rainfall continues, further diluting them [8]. The first-flush phenomenon, in which initial stormwater runoff contains high concentrations of contaminants, is more pronounced in urban areas with extensive impervious surfaces [9]. Conversely, rainfall can mobilise pollutants by washing accumulated contaminants from surfaces into drainage systems. This is influenced by factors such as rainfall intensity, duration, and antecedent dry days, which determine the total of contaminants washed off surfaces [10].

The dual role of rainfall is well documented in urban and suburban environments, but its investigation in institutional settings, such as large public universities in tropical climates, remains underexplored. Understanding this relationship is crucial for predicting contaminant fluxes and implementing effective stormwater management strategies. Public

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universities often have diverse land uses, including carparks, green spaces, cafeterias and buildings, each contributing differently to stormwater pollution. The presence of impervious surfaces, such as carparks, can lead to higher contaminant loads [11]. Effective stormwater management in educational settings requires tailored strategies that consider the specific land use and rainfall characteristics. This may include implementing sustainable drainage systems and regular maintenance to reduce pollutant build-up [12]. Even though urban and industrial stormwater pollution in Malaysia has been widely studied, research on institutional campuses remains limited despite their diverse land uses. This study aims to address the knowledge gap regarding stormwater runoff quality at Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA) by analysing the effects of rainfall on runoff before and after rainfall events. The objectives of this research are to identify and measure key contaminants in campus runoff, to assess how rainfall impacts pollution levels and composition, and to compare water quality parameters against the National Water Quality Standard (NWQS) [13] for Malaysia. The water quality parameters include biochemical oxygen demand, chemical oxygen demand (COD), total suspended solids, turbidity, and selected heavy metals (copper, nickel, and zinc). This study provides a better understanding of stormwater behaviour, specifically in a campus environment, which may serve as a foundation for mitigation strategies to improve the water quality in Malaysian public universities.

2. Materials and Methods

2.1 Site Description

This study was conducted at Kolej Kediaman 2, UMPSA, 26300 Kuantan, Pahang. The sampling site was located at the main gate drainage system (3.729355° N, 103.124773° E), which serves as the primary exit point for stormwater runoff from the residential area. Figure 1 shows the location of the study at UMPSA. This location was chosen because it represents the overall runoff from the entire drainage system. The area is characterised by medium levels of human and industrial activity, primarily driven by the high-density student residential blocks and the central cafeteria, which contribute a consistent load of organic and greywater constituents to the system.

Figure 1. The location for the rainfall study

2.2 Sample Collection

Water samples were collected directly from the runoff stream using 500 mL open-mouth containers. The samples were collected in replicate before and after rainfall on different dates and under different harvest conditions, as shown in Table 1. Samples were denoted as Sample 1, Sample 2, and Sample 3 based on the dates of collection at different rainfall rates. The rainfall rate in this study is categorised as light rainfall [14]. The rainfall rate was measured by collecting rainfall volume over 1 hour using a rain gauge located in an open area near the sampling site. Samples were transported to the laboratory within 24 hours and stored in a chiller at 4 °C for further analysis.

Table 1. Sample collection design

Date	Sample name	Dry period of rainfall between samples, days	Rate of rainfall, mm/h
28/11/2024	Sample 1	3	5.8
29/11/2024	Sample 2	1	4.9
03/12/2024	Sample 3	3	4.4

2.3 Analysis

Organic pollutants in the samples were measured by determining BOD and COD. The BOD was measured following the American Public Health Association (APHA) [15] method 5210B, a standard method for water and wastewater. The samples were neutralised to a pH range of 6.5 to 7.5 by using sulfuric acid (1 N) or sodium hydroxide (1 N) before analysis. The sample was further diluted (if required), and dissolved oxygen (DO) was measured with a calibrated DO meter (YSI 5100, YSI). Each sample was then incubated in a sealed BOD bottle at 20 °C for five days. The final DO was then measured. The BOD was calculated using Eq. (1):

$$BOD\ \ , mg/L = (D_1 - D_2)/P \tag{1}$$

where D_1 is the initial DO (mg/L), D_2 is the final DO (mg/L), and P is the decimal volumetric fraction of the sample used. The COD of the sample was determined following the Hach Method 8000. A 2 mL sample was pipetted into a COD digestion reagent vial and heated in a digestion reactor (DRB200, Hach) at 150°C for 2 hours. After cooling to room temperature, COD concentrations were measured using a uv-vis spectrophotometer (DR6000, USA). The wavelengths for the COD low-range (3–150 mg/L) and high-range (20–1500 mg/L) vials are preprogrammed at 420 nm and 600 nm, respectively.

The TSS was determined using the APHA 2540D method [15]. A 50 mL sample was filtered through a pre-weighed glass microfiber filter (Whatman, size 47 mm in diameter). The filter was then dried at 103-105 °C for one hour and reweighed. The TSS concentration was calculated using Eq. (2):

$$TSS\ \ (mg/L) = \frac{(A - B)\ x\ 1000}{V} \tag{2}$$

where A is the weight of the filter with residue (mg), B is the weight of the filter (mg), and V is the volume of water filtered (mL). Turbidity was measured with a portable turbidimeter (2020T&I, La Motte). A 10 mL sample was pipetted into a clean, scratch-free vial. The turbidity readings were averaged over three readings for accuracy. The measurements are in Nephelometric Turbidity Units (NTU).

Water samples for heavy metal analysis were diluted with 1 % nitric acid (HNO_3) and transferred to a 100 mL volumetric flask. Standard solutions of metals, including copper (Cu), nickel (Ni), and zinc (Zn), at concentrations of 1, 5, 10, 15, and 20 mg/L were prepared. Heavy metals were determined by inductively coupled plasma mass spectrometry (ICP-MS) (NexION 300x, Perkin Elmer). The values of BOD, COD, TSS, and heavy metals (Cu, Ni, and the Zn) were compared with NWQS to evaluate the water quality. The NWQS categorises water quality into five classes, namely Class I, Class IIA, Class IIB, Class III, Class IV, and Class V, depending on the uses of water [13]. For this study, the water quality standard is simplified in Table 2.

Table 2. National water quality standard [13]

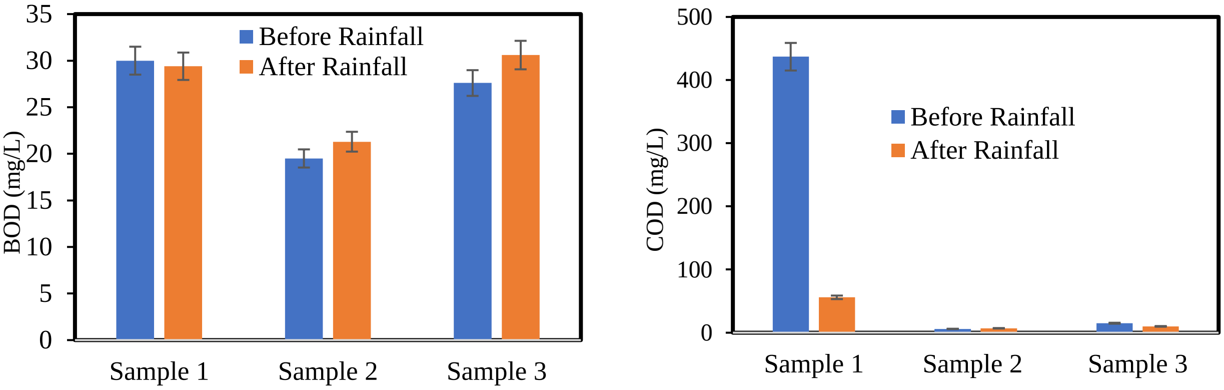
Parameter study	Unit	CLASS				
		I	IIA/IIB	III	IV	V
Biochemical oxygen demand (BOD)	mg/L	1	3	6	12	>12
Chemical oxygen demand (COD)	mg/L	10	25	50	100	>100
Total suspended solids (TSS)	mg/L	25	50	150	300	300
Turbidity	NTU	5	50	-	-	-
Copper (Cu)	mg/L	Natural level or absent	0.02	-	0.2	Level above IV
Nickel (Ni)	mg/L		0.05	0.9	0.2	
Zinc (Zn)	mg/L		5	0.4	2	

*Uses of water by Class: (I) Conservation of natural environment, Water supply (no treatment necessary), Fishery 1 (very sensitive to aquatic species, (IIA) Water supply II (conventional treatment needed for drinking water), Fishery II (sensitive aquatic species), (IIB) Recreational use with body contact, (III) Water supply III (extensive treatment needed), Fishery III (livestock drinking), (IV) Irrigation and (V) None of the above (highly polluted).

3. Results and Discussion

3.1 Biochemical Oxygen Demand and Chemical Oxygen Demand

Figure 2(a) and (b) show a change in BOD and COD concentration before and after rainfall, respectively. For Sample 1, the BOD before rainfall is 30.0 mg/L, and after rainfall, it decreases slightly to 29.4 mg/L. The slight reduction in BOD indicates dilution of the organic pollutants by rainfall, which is present in the water. The rainfall intensity for this sample is 5.8 mm/h, and it is preceded by a 3-day dry period, which could have allowed organic matter to accumulate on surfaces. However, the relatively high rainfall intensity likely dispersed these pollutants, resulting in a marginal decrease in BOD levels. In this case, rainfall functions more as a diluent than a carrier of additional organic pollution. In contrast, the BOD before rainfall is measured at 19.5 mg/L for sample 2, while the BOD after rainfall increases slightly to 21.3 mg/L. This increase suggests that rainfall may have contributed to a rise in organic pollutant concentrations, most likely by washing accumulated contaminants from surfaces into the receiving water body. The rainfall intensity recorded for this sample is 4.9 mm/h, with only a 1-day dry period before the event. The short dry spell might have limited pollutant buildup, but the rainfall still acted primarily as a carrier of organic material, resulting in a marginal increase in BOD levels after the rainfall. For Sample 3, the BOD before rainfall is 27.6 mg/L, which increases to 30.6 mg/L after the rainfall event. This represents a more noticeable rise in BOD, suggesting that the rainfall has a stronger wash-off effect, transporting organic matter into the water system. The rainfall intensity is 4.4 mm/h, following a 3-day dry period, potentially allowing more pollutants to accumulate on surfaces. During the rainfall event, these materials are likely flushed into the drainage system, significantly increasing BOD levels and highlighting rain's pollutant-carrying role in this instance. The first-flush effect was more pronounced for TSS, BOD, and zinc than for total dissolved solids and COD, indicating that pollutants are more effectively removed from surfaces by rainfall's washing action [16]. However, all post-rainfall BOD values exceed the class V limit of 12 mg/L prescribed by NWQS. Consequently, while rainfall may introduce organic pollutants, increases in BOD in some samples indicate a risk of organic pollution via runoff, especially where large quantities of organic matter from land are washed into rivers.



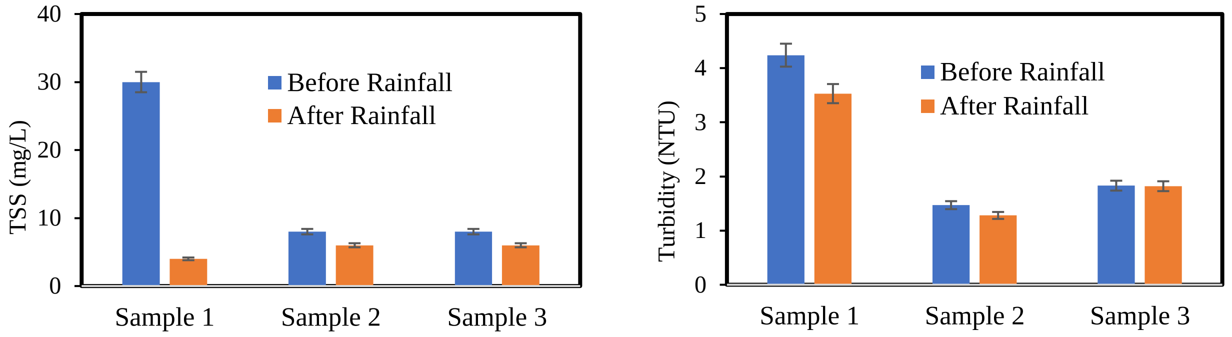
(a) (b)

Figure 2. (a) BOD and (b) COD of sample 1, sample 2, and sample 3

As shown in Figure 2(b), the COD varies sharply before and after rainfall for Sample 1. The COD decreases from 437 mg/L to 56 mg/L after the rainfall. This significant reduction shows the strong dilution effect of rainfall, increasing the volume of water and decreasing the concentration of chemical pollutants. This is caused by scouring of pollutant surfaces during the first-flush event [17]. Similarly, Sample 3 shows a decrease in COD from 15.0 mg/L to 10.0 mg/L after the rainfall, further demonstrating the positive effect of rainfall on reducing chemical pollutant levels. On the other hand, Sample 2 shows an increase in COD concentration from 6.0 mg/L to 7.0 mg/L before and after rainfall, respectively, indicating that runoff carries minor chemical pollutants into the water body during rainfall. In urban areas, a pronounced first-flush effect typically involves the early discharge of pollutants such as TSS, BOD, COD, phosphorus, nitrogen, and others during storms [18]. However, all post-rainfall COD values are well within the regulatory limit of 200 mg/L, thus compliant with water quality standards. The above findings illustrate that, while rainfall generally dilutes COD levels, specific factors such as land use and rainfall intensity may result in significant variation in pollutant dilution or introduction.

3.2 Total Suspended Solid

The TSS was also significantly affected by rainfall. In Figure 3(a), substantial reductions are observed in all samples. In Sample 1, TSS decreased from 30.0 mg/L to 4.0 mg/L after the rainfall, indicating a substantial reduction in suspended solids, including silt, organic debris, and other particulates. Sample 3 shows a similar reduction trend, with a sharp decline in TSS levels after the rainfall. Such reductions in TSS may indicate that rain helps increase water clarity by diluting and dispersing suspended solids. The consistent decline in TSS across samples therefore underscores rainfall's positive contribution to water quality, particularly by reducing sediment loads that can seriously degrade aquatic ecosystems. Similarly, Zhao et al.[19] states that higher road-deposited sediments were observed before three rainfall events, thereby confirming that a higher percentage of washed-off coarser particles led to higher TSS concentrations. Turbidity values show the same trend as TSS, with highly significant reductions after rainfall. Based on Figure 3(b), Sample 1 shows a significant reduction in turbidity, reflecting improved water clarity due to the dilution of suspended particles. The reduction in turbidity across all three samples closely corresponds to the decrease in TSS levels, reflecting the strong relationship between turbidity and suspended particulate matter in runoff, which had been removed or dispersed by the rain. Lower turbidity values indicate better-quality water, as clearer water allows more light to penetrate, which is essential for aquatic organisms to carry out photosynthesis. Turbidity results can be used to estimate TSS, avoiding lengthy gravimetric analysis, using a correlation equation developed by Al-Yaseri et al. [20].

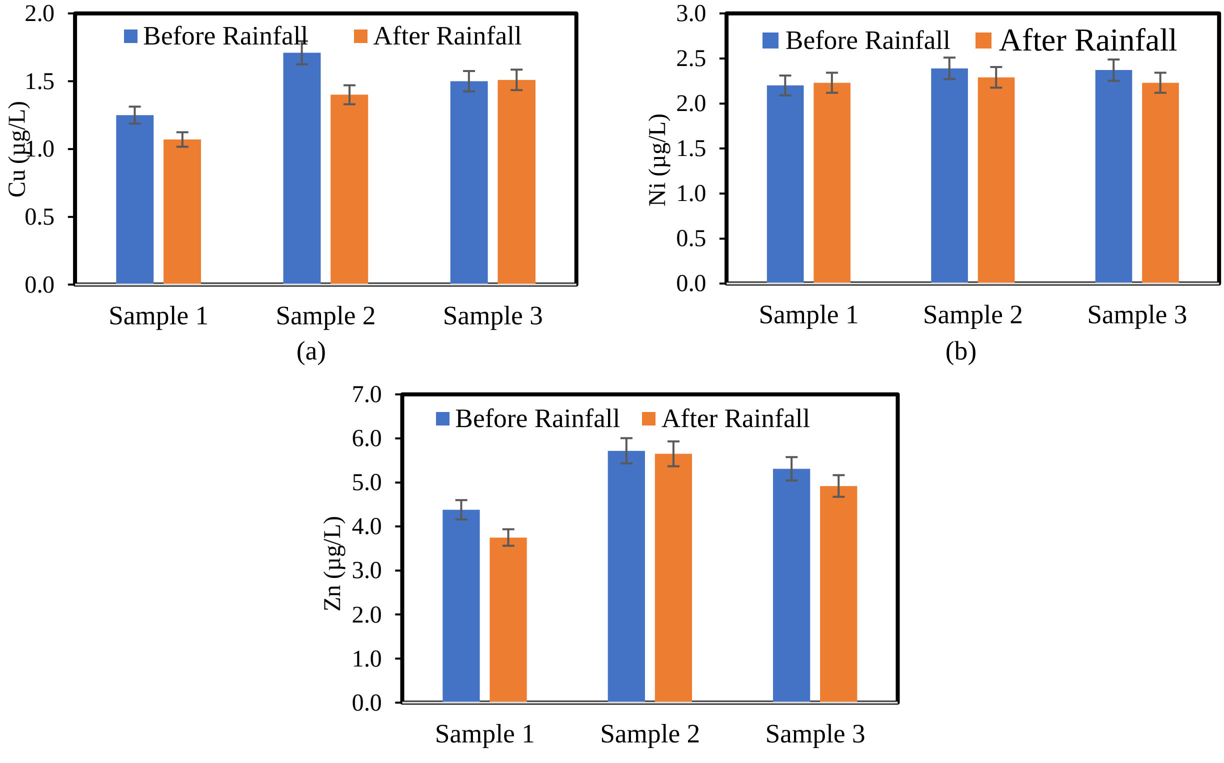


(a) (b)

Figure 3. (a) TSS and (b) Turbidity of sample 1, sample 2, and sample 3

3.3 Metal Analysis

Figure 4(a) shows the reduction value before and after the rainfall for samples 1 and 2 of copper, except for sample 3, with just a slight increase. In sample 1, the values recorded before the rainfall are 1.25 µg/L and 1.07 µg/L, respectively, while sample 2 shows a reduction from 1.71 µg/L to 1.40 µg/L. This reduction in copper concentration indicates dilution of the water body by rainfall. In sample 3, the result shows a slight increase in copper concentration from 1.50 µg/L to 1.51 µg/L. This slight increase in copper concentration suggests a potential new source of pollution during rainfall, as rainfall can also carry runoff.



(a) (b)

(c)

Figure 4. (a) Copper, (b) Nickel and (c) Zinc in sample 1, sample 2, and sample 3

As shown in Figure 4(b), the bar graph highlights a significant reduction in nickel in samples 2 and 3 after rainfall. This trend shows the characteristic of rainfall as a diluting agent for nickel concentration in the water body, as the water volume increases more than the nickel concentration. For sample 1, the result slightly increases from 2.20 µg/L to 2.23 µg/L. The increasing nickel concentration in sample 1 indicates that rainfall can carry more nickel into runoff after rainfall. Nickel is released from vehicular emissions, tyre wear, and road surface degradation. These pollutants accumulate on roads and are washed into stormwater systems during rainfall events. High-traffic areas, such as roads and parking lots on campuses, are significant contributors to nickel contamination [21]. Figure 4(c) shows a reduction in all the samples before and after the rainfall of zinc. For sample 1, the pre-rainfall concentration is 4.38 µg/L, and the post-rainfall concentration is 3.75 mg/L. In sample 2, the zinc concentration before rainfall is 5.72 µg/L and then decreases to 5.65 µg/L, while in sample 3 it decreases from 5.31 µg/L to 4.92 µg/L. Referring to the NWQS, under any condition, the concentrations of copper, nickel, and zinc are well within the permissible limits. This finding indicates no contamination of the water sample by heavy metals (copper, nickel, and zinc) from human activities such as residential runoff, kitchen waste, or construction. Runoff from water catchments flows into rivers and coastal areas in Malaysia. A review study by Yunus et al. [22] concluded that certain coastal areas in Peninsular Malaysia exhibit low, moderate, and heavy contamination due to heavy metal pollution.

4. Conclusions

This study analysed the quality of stormwater runoff before and after rainfall at Kolej Kediaman 2, UMPSA, with key parameters evaluated, including biochemical oxygen demand, chemical oxygen demand, total suspended solids, turbidity, and selected heavy metals (copper, nickel, and zinc). Rainfall slightly affects BOD levels: sample 2 rises from 19.5 mg/L to 21.3 mg/L, and sample 3 rises from 27.6 mg/L to 30.6 mg/L. This rise suggests the mobilisation of organic matter. However, reductions are observed in COD (from 437 mg/L to 56 mg/L) and TSS (from 30.0 mg/L to 4.0 mg/L). Turbidity also tallies with the reduction in TSS results. Similarly, the concentrations of the heavy metals studied (copper, nickel, and zinc) are well within the standard, with the maximum values being 1.71 µg/L for copper, 2.23 µg/L for nickel, and 5.72 µg/L for zinc. Based on the data, the key contaminant in the campus runoff is BOD, which falls under Class V in the NWQS, indicating that the rainfall rate in this study does not significantly affect water quality. Consequently, the water requires extensive remediation to meet the Class IIA drinking water standards under the NWQS.

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Declaration of Competing Interest

The authors declare no conflicts of interest.

CRediT Authorship Contribution Statement

Wan Azmirul Izran Wan Mohd Mirza: Writing – original draft, methodology, investigation;
Mohd Shahril Abu Hanifah: Writing – review and editing; Izirwan Izhab: Writing – review and editing;
Mohamad Zaki Sahad: Writing – review and editing, methodology, validation;
Wan Zaiton Wan Sulaiman: Conceptualisation, writing – review and editing, visualisation, data curation, validation, supervision.

Conflict of Interest

The authors declare no conflicts of interest.

Availability of Data and Materials

Data will be made available from the corresponding author on request.

Generative Artificial Intelligence Declarations

The authors declare the use of Gemini AI as a supportive tool for language refinement during the preparation of this manuscript. All content was critically reviewed and revised by the authors, who bear full responsibility for the originality of the final version of the publication.

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