Applied Chemical Engineering (2024) Volume 7 Issue 1
doi: 10.24294/ace.v7i1.2224

ORIGINAL RESEARCH ARTICLE

Characterisation of storm runoff contamination from a tropical urban residential area in Malaysia

Abdullah Al Mamun[1,*], Azni Idris[2], Wan Nor Azmin Sulaiman[3], Shahriar Shams[4]

[1] *Department of Civil Engineering, Faculty of Engineering, International Islamic University Malaysia (IIUM), Kuala Lumpur 53100, Malaysia*

[2] *Department of Chemical & Environmental Engineering, Faculty of Engineering, University Putra Malaysia, Serdang 43400, Selangor, Malaysia*

[3] *Department of Environmental Sciences, Faculty of Science and Environmental Studies, University Putra Malaysia, Serdang 43400, Selangor, Malaysia*

[4] *Civil Engineering Program Area, Faculty of Engineering, Universiti Teknologi Brunei (UTB), Gadong BE1410, Brunei Darussalam*

*** Corresponding author:** Abdullah Al Mamun, mamun@ium.edu.my

ABSTRACT

It has been quite a long time since the Malaysian government endorsed the Urban Storm Water Management Manual (USWMM) in 2000. Until now, there is no proper and detailed database on the non-point source contamination characteristics from various land uses in tropical regions of Malaysia. As such this study was conducted to fill part of the information gap pertaining to the nature of runoff quality in the tropical regions. The combined sewer outfall of a 6.14 ha residential area in Malaysia was studied to characterise the urban runoff quality generated due to tropical rain. As the drainage outlet discharges sullage and storm runoff through the same drainage network, hourly flow pattern and contaminant concentrations were determined both for sullage and storm runoff. Basic statistical analysis was conducted to determine the mean, standard deviation and event mean concentration values for the study area, for which such data was not available. It was observed that the runoff generated from the area is polluted due to high total suspended solids (TSS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The runoff contained more total organic carbon (TOC) than total inorganic carbon (TIC). The EMC values of BOD, COD, TSS, TOC, total Kjeldhal nitrogen, ammoniacal nitrogen and orthophosphate were 35, 168, 177, 11, 0.32, 0.54, 0.16 mg/L, respectively. The presence of heavy metals in the runoff was low. The EMC values of lead, zinc, nickel, cadmium, chromium and copper were 0.061, 0.358, 0.002, 0.002, 0.025 and 0.022 mg/L, respectively. Due to the high quantity of rainfall, a significant amount of annual contamination loading is generated from the nonpoint sources of the residential area.

Keywords: event mean concentration (EMC); non-point source contamination; contamination loading; residential area; tropical area; urban runoff quality

ARTICLE INFO

Received: 9 June 2023
Accepted: 28 August 2023
Available online: 4 January 2024

1. Introduction

The water resources are contaminated by the point and nonpoint (diffuse) sources of urban land use. Point sources of contamination are usually noticeable, confined, and the estimation of the contamination load into the waterbodies is comparatively easy. On the contrary, nonpoint sources are unconfined and it is difficult to estimate and capture the pollutants to reduce water contamination problems. The main driving force of diffuse contamination is storm runoff. For the same land use and housekeeping practices, more runoff means more contamination load. Due to frequent storm events and high annual rainfall, tropical regions have a higher susceptibility to diffuse contamination.

There is not much information available on diffuse pollutant loads due to storm runoff in tropical urban areas nonpoint contamination in urban areas is quite complex in nature and has been classified as land cover-related (buildings and infrastructure), activity-related (e.g., transport emissions), behaviour-related (e.g., pesticide and fertiliser use), plus atmospheric deposition[1]. It has been observed that in urban areas, even with good housekeeping practices, a significant amount of contamination is generated from the road surfaces and is a constant threat to the declining water quality of receiving water bodies[2–5].

Besides the increased runoff, urbanisation produces inferior quality stormwater with higher amounts of pollutants such as sediments, debris, tire dust and petroleum-based fluids (vehicle-based pollutants) resulting from runoff over paved surfaces like roofs of buildings, driveways, parking lots, sidewalks and streets[6,7]. Pollutant concentration in stormwater is very site-specific and largely dependent upon several factors such as rainfall intensities[8], cleanliness and other anthropogenic activities within the catchment[9]. In a detailed literature review regarding the composition of urban runoff, Loehr[10] highlighted a wide variation in pollutant concentration. For instance, mean and maximum BOD values ranged between 12–160 mg/L and 18–7700 mg/L respectively.

Studies on storm runoff composition in the USA indicated that stormwater is alarmingly more hazardous than treated sewage[11]. The reason is that improved technologies are applied for industrial waste and sewage treatment but the contamination arising from storm runoff is not seriously being taken care of, even in most of the urban areas. Generally, priorities were given to the minimisation of flood problems rather than the control of diffuse contamination.

Malaysia is one of the fastest-growing developing countries in the world. Since it is located in the tropics, Malaysia receives an annual average rainfall between 1700 and 4000 mm[12]. The resulting runoff carries a wide range of pollutants from various land uses. Depending on the land uses, almost 60% of the total pollutants may be entering the rivers as a runoff[13]. Progress in stormwater management practices for controlling nonpoint source contamination (NPS) is still in the initial stage in Malaysia. Even the event mean concentration (EMC) values or the pollutant export equations, which are the basic requirement for stormwater quality assessment and control, are not available for the Malaysian climate. The studies reported to be conducted in Malaysia were related to runoff quality from roofs[14,15]. The Drainage and Irrigation Department (DID) and local authorities have begun to control the runoff rate and the associated diffused pollutants. Unfortunately supporting data and research works from the local institutions are very scarce.

All relevant studies demonstrate that receiving water bodies are polluted due to urban storm runoff significantly. After the Nationwide Urban Runoff Program (NURP) in 1983, the United States Environmental Protection Agency (USEPA) identified that industrial areas are more polluted than residential areas. Being a fast-developing country, a similar situation may exist in Malaysia, but this is not revealed yet. Residential areas cover the majority portion of the total urban land use. As such, this study was conducted to collect data through scientifically sound methods to characterise the runoff quality from an urban residential area, where the annual average rainfall is about 2500 mm/year.

2. Methodology

2.1. Study area

The catchment area for the storm runoff contamination study consists of 6.14 ha of urban area with a mixture of green space, which is close to the University Putra Malaysia (UPM) located in the State of Selangor. The study area was developed in 1981 for 283 units of single-story terrace houses where the calculated population was 1415 residents. A network of open concrete drains carries stormwater and sullage (grey wastewater) all the way to a small tributary of Kuyoh River. The samples for sullage and storm runoff were collected from the drainage outlet of the catchment area as shown in **Figure 1**. The catchment was found to be ideal to conduct such a contamination study, which is neither too small nor too big.

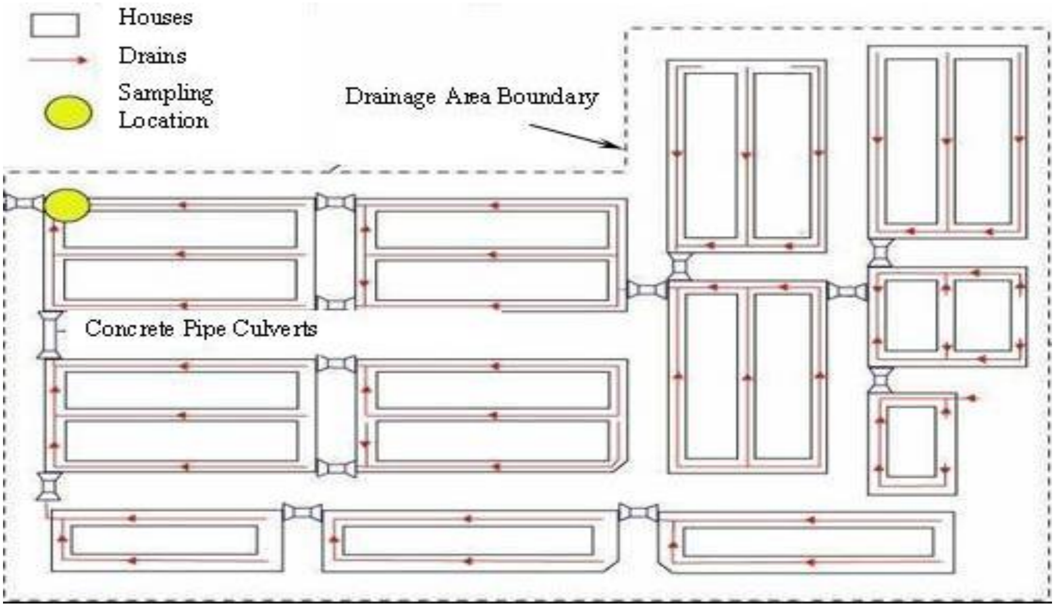

Figure 1. The layout of the drainage system (not to scale).

2.2. Field visits and laboratory work

The drainage pattern with layouts and the boundary of the catchment area were determined, as shown in **Figure 1**. The study area was also thoroughly investigated to make sure that discharge from adjacent commercial plots does not enter the selected catchment area. A level survey was carried out to determine the slope of the outlet culvert and the discharge was computed using Manning's formula. The measured discharges and depths of water of the outlet culvert (Diameter 1.23 m) were used to calibrate Manning roughness "n". The depth of the water level was recorded every minute by the water level recorder attached to the ISCO water sampler.

As the combined sewer system also conveys domestic sullage, samples were collected in four aliquots of 250 mL at an interval of 15 minutes to prepare hourly composite sullage. The samplings were done for one working day and weekends (Saturday and Sunday) to characterise the quantity and quality of sullage to determine the flow and pollutant patterns to be used as the base data. Although naturally and in reality, the flow and concentration data will not be the same every day and every moment; it is acceptable to assume that the observed data will represent the usual characteristics of the sullage data in that area. Seventy-two samples were collected in three days from the catchment outlet (**Figure 1**) and analysis for sullage quality was performed in the laboratory at Universiti Putra Malaysia (UPM). The sullage concentration was deducted from the combined quality of wastewater during storm events to compute the surface runoff quality.

Three storm events of various rainfall amounts (9.7, 47.1 and 54.8 mm) were sampled to study pollutographs during rainy days. For each storm event, 24 samples were collected from the drainage outlet. Non-uniform sampling intervals were chosen to cover the whole runoff hydrograph. During rainy days, the first 10 samples were collected at 1-minute intervals, the next 9 samples at 3-minute and the rest 5 samples at 5-minute intervals. Ice was placed inside the autosampler in order to minimise the degradation of sample properties. Twenty common pollutants (Appendix A) were tested in this study, using the standard methods[16], calibrated sensors, probes or instruments. However, the results on the runoff flow rate, TSS, BOD, COD, Pb, Zn and Cu are presented in this work.

2.3. Analytical method

Basic statistical analysis was conducted to determine certain values, as generally required for such studies. The event mean concentration (*EMC*) was calculated by dividing the total pollutant mass from the storm runoff by the total runoff volume. As the samples during the rainy day were a mixture of sullage and stormwater, *EMC* in storm runoff (EMC_{sw}) was calculated using Equation (1).

$$EMC_{sw} = \frac{\Sigma Q_{rd}.C_{rd} - \Sigma Q_{dd}.C_{dd}}{\Sigma Q_{rd} - \Sigma Q_{rd}} \tag{1}$$

where, the subscripts "*rd*" and "*dd*" denote the rainy day (combined sullage & stormwater) and dry day (sullage only) flows (*Q*) and concentrations (*C*), respectively. The sullage flow and concentration were measured during dry weather assuming only minor variation whereas the total flow and concentration were measured during the rain event.

3. Results and discussion

The data collected in the dry period indicated that during the working days, there are three peaks in sullage flow (**Figure 2**). Two mild peaks were observed during the working days, one in the morning and the other in the evening. The high peak occurred at noon every day. It was observed that both the pollutant concentrations and loading were high during the peak hours of the days (**Figures 3–5**). The daily contamination loading generated due to sullage was calculated and compared to the contamination generated from storm events (diffuse sources).

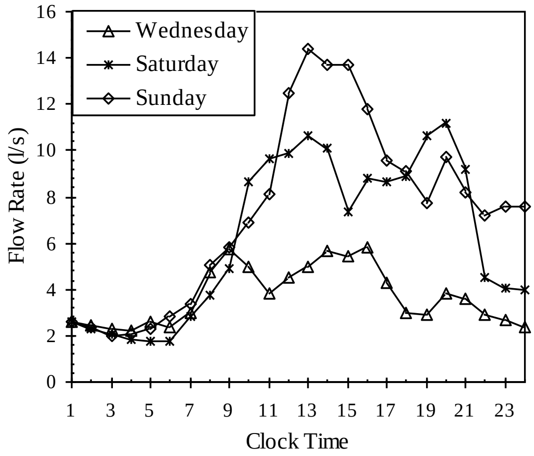

Figure 2. Variation of sullage flow with the day.

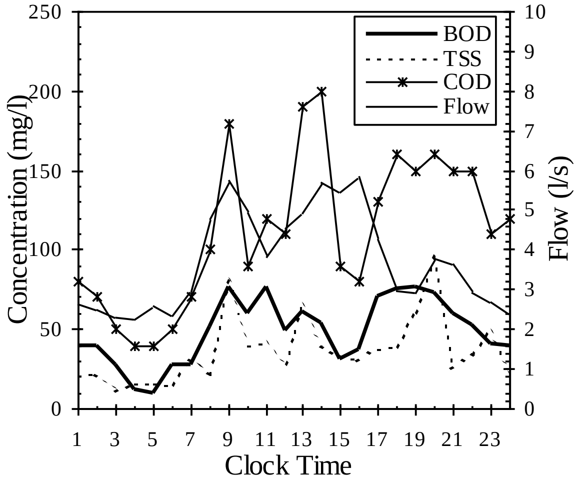

Figure 3. Variation of common pollutants in sullage (during the working day).

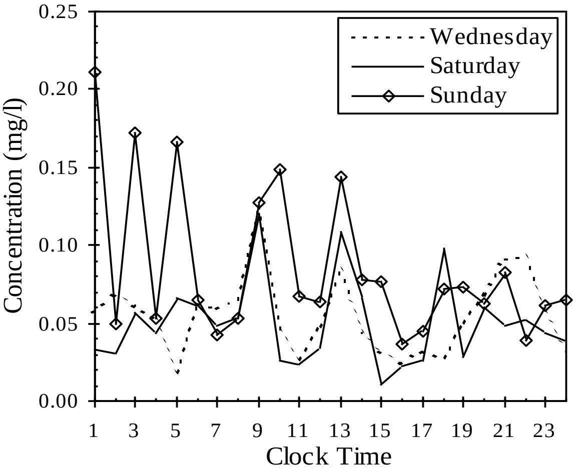

Figure 4. Variation of zinc in sullage with day.

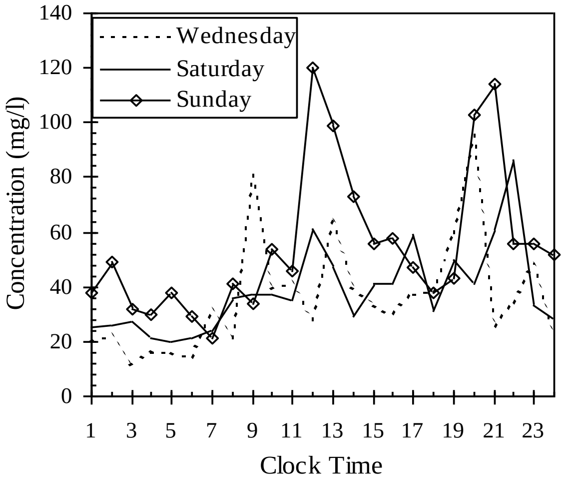

Figure 5. Variation of TSS in sullage with day.

Pollutographs were also developed to study the contamination pattern during rain events. Three storm events of various rainfall intensities were studied (**Figure 6**). Except for a few instances it was observed that the pollutant concentrations decreased with the increased runoff due to the dilution effect. However, in the case of TSS, higher concentrations were observed before the peak runoff (**Figure 7**) as pollutant wash-off is a function of the build-up of particles[17]. Therefore, TSS is the major contributor to pollutant load for the variation of water quality in different land uses.

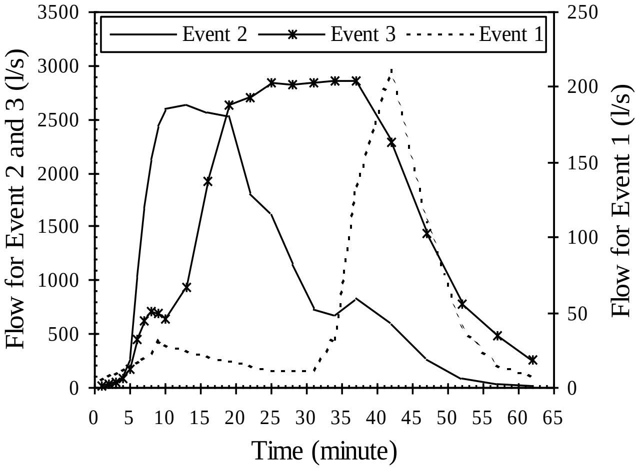

Figure 6. Runoff hydrographs of the storm events.

Wide variations in concentrations were observed within the same storm event, as shown in the case of COD (**Figure 8**). Higher concentrations of zinc, lead and copper were detected in the runoff as shown in **Figure 9**. The presence of dissolved organic matter (DOM) in stormwater runoff due to various land uses initiated the release and movement of heavy metals (Cd, Cu, Ni and Pb) for their binding affinities for heavy metals[18]. Loading rates for all pollutants were high during the hydrograph peaks due to the high amount of runoff rate.

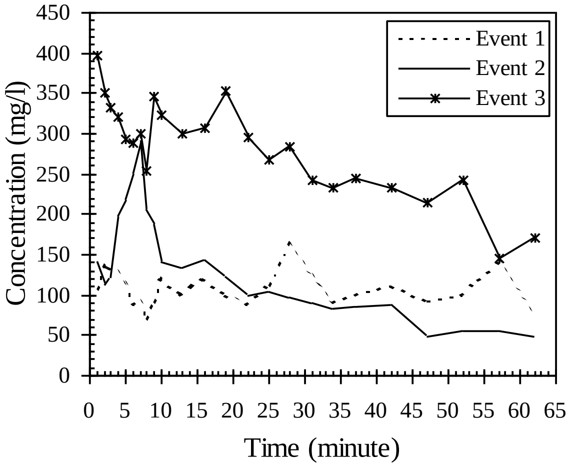

Figure 7. Pollutographs of TSS for storm events.

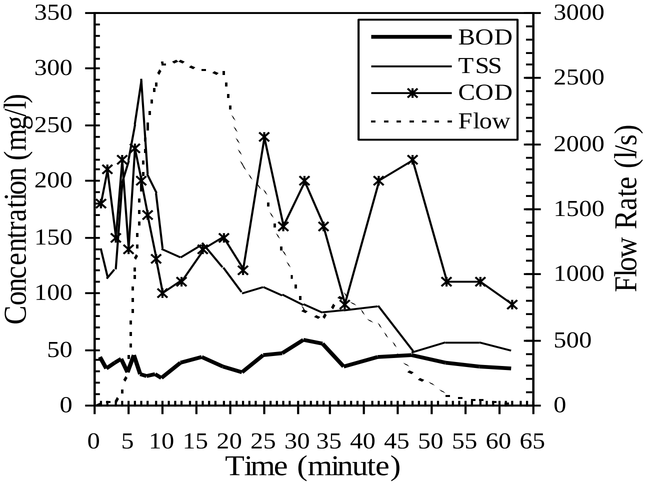

Figure 8. Pollutograph of BOD, COD and TSS (for Event 2).

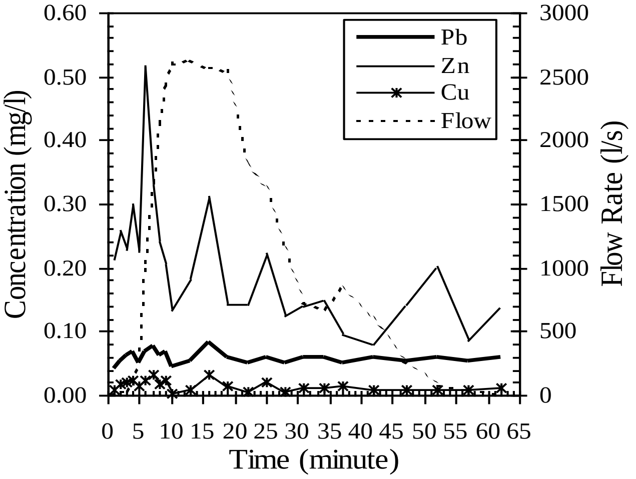

Figure 9. Pollutograph of Pb, Zn and Cu (for Event 2).

The statistical data of all samples on the sullage (dry day) and the runoff (rainy day) quality of the studied parameters are given in **Table 1**. It was observed that except for TSS, VSS, DO, turbidity, COD and heavy metals, the mean concentrations of other parameters were low during the storm event (as shown in **Table 1**). The event mean concentration (EMC) values indicated that the runoff from the study area was polluted, mainly, due to BOD, COD and TSS.

Table 1. Statistical analysis of water quality during the dry and rainy days (72 samples).

Item	**Flow**	**Turbidity**	**pH**	**TDS**	**TSS**	**VSS**	**O&G**	**DO**	**BOD**	**COD**	**AN**	**TKN**
	(L/s)	**(NTU)**	**-**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Dry Day												
Min	1.8	11	6.20	140	11	1	4	1.20	9	40	1.80	0.40
Max	14.4	67	6.95	347	120	32	23	2.40	78	200	9.20	4.50
Mean	5.8	35	6.67	228	43	8	14	1.55	50	116	4.90	2.08
SD	3.4	15	0.18	40	23	6	5	0.32	14	47	1.65	1.01
Rainy Day												
Min	5.5	19	5.44	15	48	4	3	1.80	21	90	0.29	0.02
Max	2865.3	98	6.54	140	397	234	13	5.93	59	310	2.18	1.86
Mean	803.5	46	6.13	56	173	94	8	3.64	38	173	0.75	0.51
SD	1019.2	19	0.24	26	93	62	3	1.03	10	49	0.39	0.43
Item		**Flow**	**OP**	**TC**	**TIC**	**TOC**	**Zn**	**Pb**	**Cr**	**Cu**	**Ni**	**Cd**
		(L/s)	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Dry Day												
Min		1.8	0.34	14.7	0.29	7.6	0.011	ND	ND	ND	ND	ND
Max		14.4	4.13	85.0	12.25	79.9	0.211	ND	ND	0.022	ND	0.012
Mean		5.8	2.05	41.6	6.55	35.0	0.064	ND	ND	0.009	ND	0.002
SD		3.4	0.93	13.5	3.53	14.9	0.038	ND	ND	0.006	ND	0.002
Rain Day												
Min		5.5	0.02	1.6	0.03	1.1	0.081	0.015	0.006	0.004	0.001	0.001
Max		2865.3	1.18	75.3	11.18	66.1	0.736	0.099	0.051	0.051	0.013	0.005
Mean		803.5	0.29	16.9	3.73	13.2	0.306	0.057	0.022	0.021	0.003	0.002
SD		1019.2	0.29	15.8	3.66	13.2	0.152	0.018	0.009	0.011	0.003	0.001

Note: ND—Not Detected.

The EMC values of this study were comparable with the site median EMC values for urban areas in the USA and other urban places, as given in **Table 2**[19–26]. The EMC values for TSS, BOD and COD are close to the EMC values obtained from the study conducted by Yusop et al.[26]. EMC values for BOD and COD varies significantly as compared to studies done in Europe and the USA because of the dissimilarities with respect to climatic, topographic and land use condition.

Table 2. Comparison of mean/median EMC values (mg/L) with other studies.

Pollutant	ASEAN country	Asian country[21]	The USA	EU country[20]	Malaysia[26]	This study
TSS	31.9[19]	367.19	190[25]	27	184	177
BOD	72[24]	-	9[22]	9	39	35
COD	325[24]	302.81	413[22]	65	131.9	168
Zn	0.06[19]	0.229	0.13[25]	0.16	0.18	0.358
Pb	0.01[19]	0.003	-	0.144	0.01	0.061
Cu	0.01 [19]	0.024	0.023 [23]	0.034	0.13	0.022

The study on the Rouge River basin[27] indicated that, compared to the point sources, the annual loading of heavy metals resulting from direct runoff governed the river loadings with lead at 84.3% and zinc at 68.6%. The total suspended solids (TSS), BOD, total nitrogen and total phosphorus from stormwater were (relatively less) 34.5, 43.8, 41.7 and 37.7%, respectively. TSS and COD vary significantly[21] when compared with the present study due to the urban setup and colder climate that exists in the study area of China.

The rainfall data was collected from the weather station operated by the University Putra Malaysia (UPM). The mean annual rainfall was calculated at 2387 mm. Annual contamination loadings from point and nonpoint sources were calculated, respectively, based on the sullage quantity and quality and the annual rainfall and EMC values. The annual sullage and runoff quantity, for the residential area, were calculated at 91,454 m^3[28] and 124,578 m^3, respectively. From the analysis of annual loading, it was found that TSS (77%), VSS (90%), COD (52%) and heavy metals (81%) were contributed more from the diffuse sources (due to storm runoff). Whereas other pollutants monitored in this study were contributed more from sullage (point contamination sources). The annual contamination loading rate (in kg/ha/yr) for the residential area was calculated and shown in **Figure 10**.

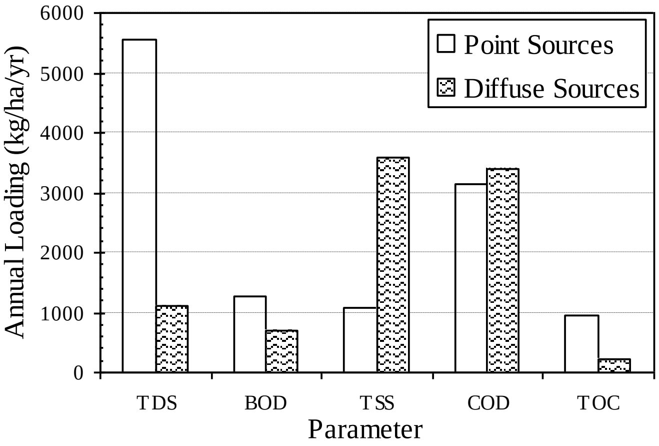

Figure 10. Water quality parameter for point and diffuse sources (importantly pollutants only).

4. Conclusions

A 6.14-ha urban residential area was studied to characterise the runoff quality from the diffuse contamination sources. Based on the findings, it is concluded that the pollutant concentrations in the sullage (grey water) of the study area are generally higher than those in the storm runoff. However, being in the tropical region where the annual rainfall is high (2387 mm in the study area), the annual contamination loadings from the diffuse sources for TSS, VSS, COD and heavy metals are found to be higher than the annual contribution from the sullage. The event mean concentration (EMC) values of BOD, COD, TSS, TOC, total Kjeldhal nitrogen (TKN), ammoniacal nitrogen and orthophosphate were 35, 168, 177, 11, 0.32, 0.54, 0.16

mg/L respectively. The concentration of heavy metals in the runoff was low. The EMC values of lead, zinc, nickel, cadmium, chromium and copper were 0.061, 0.358, 0.002, 0.002, 0.025 and 0.022 mg/L, respectively. The other pollutants monitored in this study were contributed more from the point contamination sources. The pollutant concentration and loading of heavy metals from the study area are not significant. Due to high pollutant concentration, the sullage and runoff both need to be treated before being discharged into the water bodies.

Author contributions

Conceptualization, AAM and AI; methodology, AAM; formal analysis, AAM and AI; investigation, AAM and SS; resources, AI and SS; data curation, AAM and WNAS; original draft preparation, AAM; review and editing, SS; supervision, AI; project administration, AAM. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

The authors are grateful to the staff of IIUM and UPM for supporting the expensive field and laboratory work required to conduct this study.

Conflict of interest

The authors declare no conflict of interest.

References

1. Todeschini S, Papiri S, Ciaponi C. Placement strategies and cumulative effects of wet-weather control practices for intermunicipal sewerage systems. Water Resources Management 2018; 32: 2885–2900. doi: 10.1007/s11269-018-1964-y
2. Müller A, Österlund H, Marsalek J, Viklander M. The pollution conveyed by urban runoff: A review of sources. Science of Total Environment 2020; 709: 136125. doi: 10.1016/j.scitotenv.2019.136125
3. Guo Z, Metali HMKBH, Shams S, et al. Build-up and wash-off dynamics of organic pollutants, nutrients and coliforms on impervious surfaces: An experiment. International Journal of Smart Grid and Clean Energy 2019; 8(5): 529–538. doi: 10.12720/sgce.8.5.529-538
4. Todeschini S. Hydrologic and environmental impacts of imperviousness in an industrial catchment of Northern Italy. Journal of Hydrologic Engineering 2016; 21(7): 5016013. doi: 10.1061/(ASCE)HE.1943-5584.0001348
5. Huang J, Tu Z, Du P, et al. Analysis of rainfall run of characteristics from a subtropical urban lawn catchment in South-east China. Frontiers of Environmental Science and Engineering 2012; 6(4): 531–539. doi: 10.1007/s11783-010-0287-x
6. Pilon BS, Tyner JS, Yoder DC, Buchanan JR. The effect of pervious concrete on water quality parameters: A case study. Water 2019; 11(2): 263. doi: 10.3390/w11020263
7. Yuan Q, Guerra HB, Kim Y. An investigation of the relationships between rainfall conditions and pollutant wash-off from the paved road. Water 2017; 9(4): 232. doi: 10.3390/w9040232
8. Charters FJ, Cochrane TA, O'Sullivan AD. Untreated runoff quality from roof and road surfaces in a low intensity rainfall climate. Science of Total Environment 2016; 550: 265–272. doi: 10.1016/j.scitotenv.2016.01.093
9. Wilson CO. Land use/land cover water quality nexus: Quantifying anthropogenic influences on surface water quality. Environmental Monitoring and Assessment 2015; 187(7): 424. doi: 10.1007/s10661-015-4666-4
10. Loehr RC. Non-point contamination sources and control. In: Water pollution control in low density areas. Proceedings of a rural environmental engineering conference. 1975. pp. 269-299. Available online: https://www.semanticscholar.org/paper/Water-pollution-control-in-low-density-areas-Jewell-Swan/cd0f3a2b72a7cdf323fb08693ba9731cb735bab0 (accessed on 9 June 2023).
11. Spahr S, Teixidó M, Sedlak DL, Luthy RG. Hydrophilic trace organic contaminants in urban stormwater: Occurrence, toxicological relevance, and the need to enhance green stormwater infrastructure. Environmental Science: Water Research and Technology 2020; 6(1): 15–44. doi: 10.1039/C9EW00674E
12. Department of Irrigation and Drainage (DID). Urban Stormwater Management Manual for Malaysia. Ministry of Agriculture; 2000.
13. Huang J, Zhan J, Yan H, et al. Evaluation of the impacts of land use on water quality: A case study in the Chaohu Lake basin. The Scientific World Journal 2013; 2013: 329187. doi: 10.1155/2013/329187

14. Ghazali SN, Sulaiman FR. Water quality of roof runoff in sub-urban Malaysia. Asian Journal of Agriculture and Biology 2018; 6: 125–128.
15. Gromaire MC, Lamprea-Bretaudeau K, Mirande-Bret C, et al. Organic micropollutants in roof runoff—A study of the emission/retention potential of green roofs. In: 13th International Conference on Urban Drainage; 7–12 September 2014; Kuching, Malaysia. pp. 2516832.
16. Eaton AD, Clesceri LS, Rice EW, et al. Standard Methods for the Examination of Water and Wastewater, 21th ed. Amer Public Health Assn; 2005. p. 21.
17. Wijesiri B, Egodawatta P, McGree J, et al. Influence of pollutant build-up on variability in wash-off from urban road surfaces. Science of Total Environment 2015; 527–528: 344–350. doi: 10.1016/j.scitotenv.2015.04.093
18. Zhao C, Gao SJ, Zhou L, et al. Dissolved organic matter in urban forestland soil and its interactions with typical heavy metals: A case of Daxing District, Beijing. Environmental Science and Pollution Research 2019; 26: 2960–2973. doi: 10.1007/s11356-018-3860-7
19. Song H, Qin T, Wang J, Wong THF. Characteristics of stormwater quality in Singapore catchments in 9 different types of land use. Water 2019; 11(5): 1089. doi: 10.3390/w11051089
20. Rădulescu D, Racovițeanu G, Swamikannu X. Comparison of urban residential storm water runoff quality in Bucharest, Romania with international data. E3S Web of Conferences 2019; 85: 07019. doi: 10.1051/e3sconf/20198507019
21. Zhang C, Zhang C, Gao Z, Wu Z. Pollution feature analysis on heavy metals in rainfall runoff of Qingdao residential area. In: Proceedings of the 2015 International Forum on Energy, Environment Science and Materials (IFEESM 2015); 25–26 September 2015; Shenzhen, China. pp. 1244–1250.
22. Pribak M, Siegrist J. A simplified approach to pollutant load modeling. Journal of Water Management and Modeling 2015; C387. doi: 10.14796/JWMM.C387
23. Cabezas M, Manning JP. Watershed model update and plan development contract 08-5122, PO 4500106318 Element 1, Task 3: Surface Water Pollutant Loads. Technical Memorandum, 2011. Available online: https://www.colliercountyfl.gov/home/showpublisheddocument?id=35321 (accessed on 9 June 2023).
24. Nazahiyah R, Yusop Z, Abustan I. Stormwater quality and pollution loading from an urban residential catchment in Johor, Malaysia. Water Science and Technology 2007; 56(7): 1–9. doi: 10.2166/wst.2007.692
25. Behera PK, Adams BJ, Li JY. Runoff quality analysis of urban catchments with analytical probabilistic models. Journal of Water Resources Planning and Management 2006; 132(1): 4–14. doi: 10.1061/(ASCE)0733-9496(2006)132:1(4)
26. Yusop Z, Tan LW, Ujang Z, et al. Runoff quality and contamination loadings from a tropical urban catchment. Water Science and Technology 2005; 52(9): 125–132. doi: 10.2166/wst.2005.0302
27. Murray JE, Cave KA. Rouge River national wet weather demonstration project, Wayne County, Michigan, the USA, 1997. Available online: https://www.semanticscholar.org/paper/Rouge-River-National-Wet-Weather-Demonstration-County/3c6e6cd2e96e64d741ddd748738a7a0a63e8d441 (accessed on 9 June 2023).
28. Idris A, Wan Azmin WN, Soom MAM, Abdullah-Al-Mamun. The importance of sullage (grey-water) treatment in the restoration and conservation of urban streams. International Journal of River Basin Management 2005; 3(3): 223–227. doi: 10.1080/15715124.2005.9635262

Appendix A: List of pollutants monitored in this study

1) pH
2) Dissolved Oxygen (DO)
3) Turbidity
4) Total Dissolved Solids (TDS)
5) Biochemical Oxygen Demand (BOD)
6) Chemical Oxygen Demand (COD)
7) Total Suspended Solids (TSS)
8) Volatile Suspended Solids (VSS)
9) Total Organic Carbon (TOC)
10) Total Inorganic Carbon (TIC)
11) Total Carbon (TC)
12) Total Kjeldhal Nitrogen (TKN)
13) Ammoniacal Nitrogen (AN)
14) Ortho Phosphate (OP)
15) Total Lead (Pb)
16) Total Zinc (Zn)
17) Total Copper (Cu)
18) Total Nickel (Ni)
19) Total Cadmium (Cd)
20) Total Chromium (Cr)