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Influence of Site-specific Land Use Patterns on Event Mean Concentrations (EMC) of Runoff Pollutants in an Urban Setting

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Abstract

Event Mean Concentration (EMC) is a better representation of characterizing stormwater runoff quality of a particular pollutant during a rainfall event which is to estimate the total load of pollutants from a given area during a specific rainfall event. The EMC of pollutants in stormwater runoff from major land uses in Chattogram, namely residential, commercial, and industrial are significantly different in the types and amounts due to site specific variability that are not often studied in detail, and hence a complete characterization is missing. The purpose of this study was to examine the levels of pollutants in stormwater runoff from sixteen (16) different locations in Chattogram city, which were categorized into four different types of land use. Twelve different water quality parameters were analyzed in the collected samples, such as pH, TSS, DO, COD, BOD_5, TOC, NH_3-N, NO_2, SO_4, TN, TP, and Zn. The study also investigates the correlation between various runoff quality parameters and their association with specific types of land uses. The results showed that residential areas had the highest levels of pollutants, followed by industrial, commercial, and institutional areas reflecting poor waste management at a glance. The pollutants with the highest levels across all land uses were TSS, COD, BOD_5, NH_3-N, NO_2, TN, and TP, except a few pollutants (pH, TOC and Zn).

Keywords: *EMC; runoff quality; land-use pattern; correlation.*

1 Introduction

Water is a fundamental natural resource which is deemed necessary for the existence of all living species, including human, as well as food production and economic development. However, the association between different land use types and the quality of stormwater runoff indicates that different land use categories have a significant influence on the quality of stormwater runoff. Water quality and accessibility have been catalysts for the proliferation of residential, commercial, industrial, agricultural, marine, and navigational infrastructure. However, unregulated industrial expansion, urban migration, and insufficient enforcement of environmental regulations have collectively led to a decline in surface water quality in recent times (Bhuyan & Islam, 2017; Hossain et al., 2017). Unplanned urbanization also deteriorates water quality, degrades stream habitat, and causes flash floods, resulting in pollution buildup and discharge during runoff events within the watershed (Khatun et al., 2014; Song et al., 2019). Urban land use generates pollutants that are washed off by surface runoff, eventually ending up in nearby water bodies.The major pollutants in this runoff consist mainly of sediments, nutrients, organics, oil and grease and heavy metals (Lee et al., 2011; Li et al., 2015; Niazi et al., 2017). The Event Mean Concentration (EMC) plays an essential role in urban stormwater quality assessment and modeling, requiring a complete rainfall-runoff event sampling program due to its reliance on storm and site variables. EMC is used for precise estimation of pollutant loadings into receiving streams (Chaudhary et al., 2022; Lee, 2003).

Many studies found a significant correlation among pollutants concentrations and also with storm characteristics (Lee et al., 2011; Li et al., 2015; Sharma et al., 2012; Wei et al., 2013), while a few studies did not find such an association between pollutants concentrations and precipitation characteristics (Dan’azumi & Barka, 2018; C. Li et al., 2016). Peng et al. (2016) observed that combined drainage systems and residential areas showed high EMC of runoff pollutants during typical rainfall events (Peng et al., 2016). TSS and COD were the most prominent pollutants in the Gangwon-do Province of South Korea (Lee et al., 2011), whereas the Yamuna River in Delhi, India, had significant concentrations of TSS, TN, PO_4^{3-}, and BOD in the EMC (Sharma et al., 2012). Recent literature reveals substantial research has been conducted in characterizing EMC under different climatic and rainfall conditions. Nevertheless, the number of studied addresses the correlation between EMC and existing land use patterns, particularly in the context of developing urban cities are not adequate. Therefore, the objective of this study is set to analyze the EMC (Event Mean Concentration) of stormwater pollutants generated in various urban land use settings, aiming to investigate the impact of land use patterns on the EMC of stormwater runoff.

2 Methods and Materials

2.1 Study Area and Sampling Methods

The study is conducted in Chaktai-Rajakhali watershed (as seen in figure 1) in south-east region of Chattogram city, Bangladesh. It is situated within the geographic coordinates of 22°14´00´´ to 22°24´30´´N latitude and 91°46´00´´ to 91°53´00´´E longitude, in close proximity to the Bay of Bengal. The study area spans 11.45 km^2 with a slope of 15.45±17.61% and an average elevation of 10.46±6.34 m, ranging from 1 to 56 m. There exists four (04) dominant types land use in the watershed and they are residential (77.37%), commercial (16.34%), institutional (5.07%), and industrial (1.22%). Stormwater runoff samples were collected manually (see figure 1) at five (05) minute intervals, up to a maximum of thirty (30) minutes, from sixteen (16) representative outlets of four (04) land use types between June-August, 2021 using a 5L pre-cleaned bucket. The data was collected in order to catch the first flash, which usually happened within 20 minutes (Huang et al., 2012; Lee et al., 2011). Table 1 contains the information about the runoff parameter, standards, and experimental methods used in the study. The experiments were conducted at the Environmental Engineering laboratory of CUET within a 24-hour

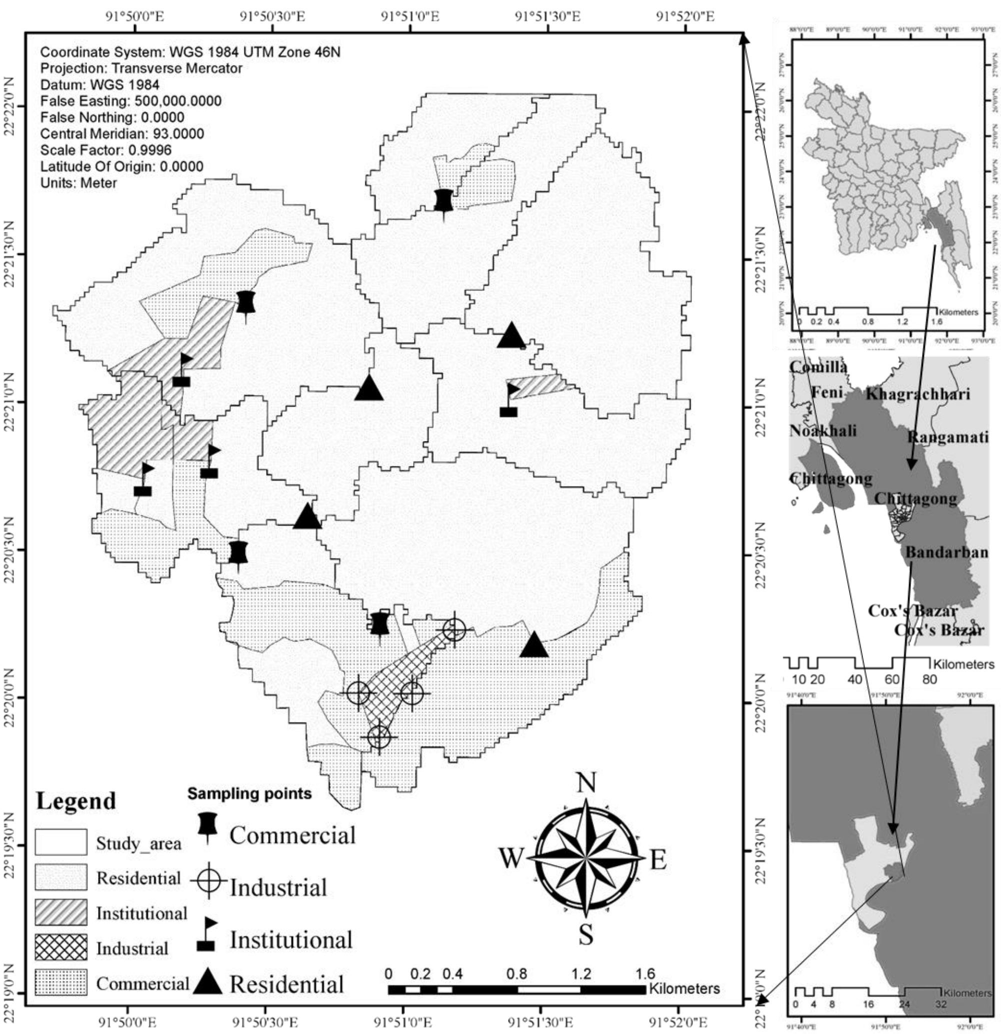

Figure 1. Geographic locations of the runoff sampling points.

Table 1. Runoff quality parameters, laboratory device specification, standards, and methodologies employed for conducting the experimental tests.

Runoff Quality Parameters	Instrument/ Methods	Range of the parameters	Accuracy of the equipment	Standards (mg/L) for runoff or surface water quality parameters	
				BDS[a]	CWP[b]
pH	Hanna (HI9814)	-2.0-16.0	± 2.0%	6-9	6.5-8.5
TSS	Standard Methods provided by APHA			100	78.4
DO	Hanna (HI98198)	0.0 to 50.0 mg/L	± 1.5%	≥ 6	≥5
BOD_5	Standard Methods provided by APHA			30	14.1
COD	Standard Methods provided by APHA			125	52.8
TOC	Hach (10173)	0.0 to 150.0 mg/L	± 0.5%	--	17
NH_3-N	Hanna (HI784)	0.0-99.0 mg/L	± 1.0%	1.2	1.2
NO_2^-	Hanna (HI3873)	0.0-50.0 mg/L	± 1.0%	50	24
SO_4^{2-}	Hanna (HI97751)	0.0-99.0 mg/L	± 1.0%	--	30
TN	Hanna (HI801)	10-150 mg/L	± 4.0%	--	2.39
TP	Hanna (HI801)	0.0 t 32.6 mg/L	± 4.0%	--	0.32
Zn	Hanna (HI801)	0.0-3.0 mg/L	± 3.0%	--	0.16

[a]BDS: Bangladesh Standards for runoff quality or surface water quality parameters (BECR, 1997)**,** [b]CWP: Center for Watershed Protection (CWP, 2003)

2.2 Estimation of Event Mean Concentration (EMC)

The Event Mean Concentration (EMC) refers to the average flow weighted concentration of pollutants during a specific rainfall-runoff event (Jung et al., 2013; Lee et al., 2011; Li et al., 2015). It is typically utilized to analyze the impacts of stormwater runoff on the water quality of nearby waterbodies and rivers. It is determined by dividing the total mass of the pollutant load by the entire volume of runoff from a specific rainfall event. The EMC for specific runoff pollutant was calculated using Eq. (1).

$$EMC = \frac{W}{V} = \frac{\int_0^t Q_t C_t dt}{\int_0^t Q_t dt} = \frac{\sum_{i=0}^{n} Q_t C_t \Delta t}{\sum_{i=0}^{n} Q_t \Delta t} \qquad (1)$$

Where, W indicates the total mass of the runoff pollutants (mg), V is the total volume of an entire event (L), t represents the considered duration (min), Q_t is the rate of flow for a specific duration (t) (L/min), Ct indicates the concentration of the pollutants for a specific duration (mg/L).

Data on water volume, duration, and concentration of runoff parameters were gathered to assess the EMC of a particular runoff pollutant for a specific rainfall event. The runoff flow rate was determined by dividing the water volume by the time duration.

2.3 Data Analysis

Descriptive statistics (mean, minimum, maximum, range, standard error (SE) of the mean, median, mode, standard deviation, coefficient of variation (CoV), skewness, kurtosis, and percentiles) were calculated using the Statistical Package for the Social Sciences (SPSS v. 26). A color map was also developed to evaluate the pollution levels of different land use types based on the considered runoff quality parameters. The concentrations of runoff parameters were also compared to standard limits. Spearman's non-parametric rank correlation method with a 95% confidence interval was employed to determine the association among stormwater runoff quality parameters and various land use patterns (Spearman, 2008). Land use types, being non-scaler values, were assigned false values with specific designations (4=Residential, 3= Industrial, 2=Commercial, 1=Institutional). The comprehensive and detailed information about the statistical methods used in this study can be found from Pal et al. (2023) and Pal and Masum (2021).

3 Results and Discussion

The descriptive statistics (as seen in table 2) of runoff sediment (TSS), physio-chemical parameters (pH, DO, COD, BOD_5, TOC), nutrient (NH_3-N, NO_2, SO_4, TN) and heavy metal (Zn) for various land use types in the

Chaktai-Rajakhali watershed. The EMC values for pH, TSS, DO, COD, BOD, TOC, NH_3-N, NO_2, SO_4, TN, TP and Zn are recorded as 7.30 ± 0.28, 705 ± 663 mg/L, 4.76 ± 1.86 mg/L, 103 ± 40 mg/L, 37 ± 14 mg/L, 8.9 ± 2.4 mg/L, 4.13 ± 3.28 mg/L, 68 ± 29 mg/L, 40 ± 53 mg/L, 4.5 ± 3.28 mg/L, 0.68 ± 0.53 mg/L, and 0.08 ± 0.10 mg/L, respectively. Furthermore, the EMC values of the runoff parameter are found substantially high as reported elsewhere around the world by different researchers (Lee et al. 2011; Jung et al. 2013; Li et al. 2015; Peng et al. 2016; Sharma et al. 2012). In table 2, it can be observed that the EMC of almost all runoff quality parameters integrated overall sites exceeded the standard limits specified in table 1, except for pH and Zn. Moreover, EMC values of sediment, nutrient, and heavy metal parameters exhibited significant fluctuations (CoV > 50%) across different land use types, whereas physio-chemical parameters showed comparatively less variability when compared to the other runoff parameters. The results indicate that urban runoff is heavy polluted influenced by urban land uses.

Table 2. Descriptive statistics of the runoff quality parameters in Chaktai-Rajakhali watershed of Chattogram city.

Statistics		**pH**	**TSS**	**DO**	**COD**	**BOD**	**TOC**	**NH_3**	**NO_2**	**SO_4**	**TN**	**TP**	**Zn**
Unit		-	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Mean		7.30	705	4.76	102.7	36.5	8.92	4.13	68.31	40.61	4.46	0.68	0.08
Minimum		6.90	54	0.22	57.3	20.7	6.42	0.50	10.00	2.68	0.65	0.08	0.00
Maximum		7.86	1864	6.62	200.6	71.3	15.61	12.10	115.00	173.68	12.59	1.95	0.36
Range		0.96	1810	6.40	143.3	50.5	9.19	11.60	105.00	171.00	11.94	1.87	0.36
SE of Mean		0.07	165.83	0.47	10.04	3.58	0.60	0.82	7.19	13.34	0.82	0.13	0.03
Median		7.31	426.50	5.35	97.24	34.3	8.56	3.05	71.50	16.00	3.41	0.51	0.04
Mode		7.40	54.00	0.22	79.84	20.7	6.42	0.50	10.00	2.68	0.65	0.08	0.00
SD		0.28	663.31	1.86	40.18	14.3	2.39	3.28	28.74	53.37	3.28	0.53	0.10
CoV (%)		3.84	94.09	39.12	39.11	39.2	26.76	79.57	42.08	131.42	73.39	77.62	126.4
Skewness		0.26	0.61	-1.27	1.22	1.19	1.69	1.51	-0.35	1.97	1.42	1.47	1.76
Kurtosis		-0.7	-1.31	0.97	1.16	1.08	3.24	1.79	-0.16	2.72	1.63	1.68	3.01
Percentiles	25%	7.05	130.5	3.72	72.16	25.7	7.28	1.85	47.25	13.38	2.10	0.31	0.01
	50%	7.31	426.5	5.35	97.24	34.3	8.56	3.05	71.50	16.00	3.41	0.51	0.04
	75%	7.50	1367	6.11	113.1	43.7	9.52	5.60	86.50	34.84	5.93	0.92	0.12

Collection points	**pH**	**TSS (ppm)**	**DO (mg/L)**	**COD (mg/L)**	**BOD5 (20ºC) mg/L**	**TOC (mg/L)**	**NH3-N (ammonia) mg/L**	**Nitrite (mg/L)**	**Sulfate (mg/l)**	**TN (mg/L)**	**TP (mg/L)**	**Zinc (Zn) mg/l**
R1		x	x	x	x		x	x		x	x	
R2		x	x	x	x		x	x		x	x	
R3			x	x	x		x	x		x	x	x
R4		x	x	x	x		x	x	x	x	x	x
I1			x	x	x		x	x	x	x	x	
I2		x		x	x		x	x		x	x	
I3		x	x	x	x		x	x	x	x	x	
I4		x		x	x		x	x				
C1		x		x	x		x	x				
C2		x		x	x		x	x	x	x	x	
C3		x		x	x		x	x	x	x	x	
C4		x		x	x			x				
Ins1		x	x	x	x		x	x		x	x	
Ins2		x		x	x		x			x	x	
Ins3		x		x	x		x	x		x	x	
Ins4		x		x	x			x				

Note: *R=Residential, I= Industrial, C=Commercial, Ins=Institutional*

Figure 2. Pollution level of runoff quality parameter at different land use patterns (the deeper color indicates the concentration of the particular pollutants is comparatively higher and 'x' mark represents the concentration exceeded the standard values)

Figure 2 depicts the pollution status across various land use types within the Chaktai-Rajakhali watershed of Chattogram city. The EMC values of pH and TOC were found to fall within permissible limits regarding the land use types. Similarly, DO and Zn EMC values were acceptable for all land use types except residential areas. However, sulfate exceeded acceptable limits in commercial and industrial areas primarily. All other runoff quality parameters exceeded permissible limits across all land use types. The order of EMC for different runoff parameters across various land use patterns was observed as follows: Residential > Industrial > Commercial > Institutional. A similar trend of pollution is reported by Peng et al. (2016) at Fozhou city, China. TSS, COD, BOD_5, NH_3-N, NO_2, TN, and TP were identified as the dominant pollutants based on their EMC values across various land use types. This observation aligns with the findings of a separate study conducted by Lee et al. (2011) in South Korea, where TSS and COD were also highlighted as the predominant pollutants.

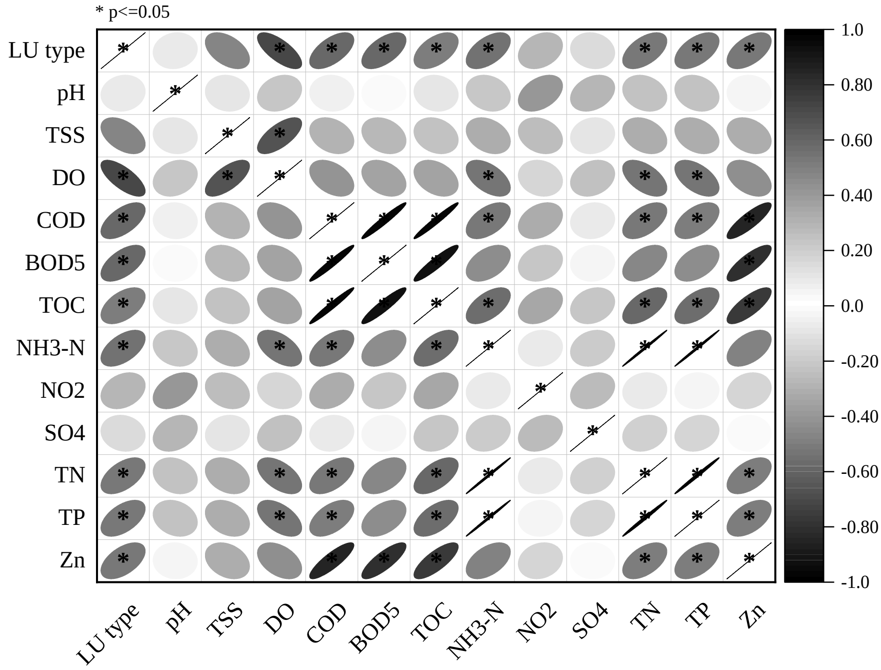

Figure 3. Correlation plot among the land use types and runoff quality variables.

Figure 3 illustrates the correlation plot depicting the associations between the EMC of runoff quality parameters and land use types. The analysis reveals notable correlations among the runoff quality parameters. Specifically, sediment (TSS) exhibits a significant connection with DO, while nutrients, particularly NH_3-N, TN, and TP, show significant correlations with both physio-chemical parameters and heavy metals. These observed relationships among the pollutant parameters align with previous research conducted by scholars around the world (Dan'azumi and Barka 2018; Li et al. 2015; Sharma et al. 2012; Lee et al. 2011; Wei et al. 2013). The study revealed that land use types have a significant influence on the EMC of runoff parameters. TSS demonstrated a moderate association with land use types, whereas DO, COD, BOD_5, TOC, NH_3-N, TN, TP, and Zn exhibited significant correlations with different land use types.

4 Conclusion

The conversion of undeveloped lands into diverse urban land uses in Chattogram city increases impervious surfaces, leading to high-pollutant urban stormwater runoff and posing environmental risks to nearby water bodies. This study mainly focused to assess the EMC of runoff parameters in different urban land use settings, and hence to understand how land use patterns influence the EMC of stormwater runoff. The study found that the EMC of considered runoff parameters were comparatively high then other countries. Residential land use had the highest EMC values, followed by Industrial, Commercial, and Institutional land uses. This indicates that residential areas contributed the most to elevated runoff pollutant concentrations to the nearby waterbodies, while institutional areas had the lowest impact on runoff pollution levels. The correlation study found a substantial relationship between land use patterns and physio-chemical parameters, nutrients, and heavy metals. This suggests that different forms of land use have a significant influence on the concentrations of these runoff quality. The findings imply that certain land use activities, such as industrial or residential constructions, may cause varied amounts of pollution in stormwater runoff, altering the abundance of physio-chemical substances, nutrients, and heavy metals in the water.

References

BECR. (1997). The Environment Conservation Rules, 1997. Bangladesh Department of Environment, Ministry of Environment and Forest, Government of the People's Republic of Bangladesh, 179–227.

Bhuyan, M. S., & Islam, M. S. (2017). Status and Impacts of Industrial Pollution on the Karnafully River in Bangladesh: A Review. International Journal of Marine Science, 7(16), 141–160. https://doi.org/10.5376/ijms.2017.07.0016

Chaudhary, S., Chua, L. H., & Kansal, A. (2022). Event mean concentration and first flush from residential catchments in different climate zones. Water Research, 219(118594), 1–9. https://doi.org/10.1016/j.watres.2022.118594

CWP. (2003). Impacts of Impervious Cover on Aquatic Systems, Watershed Protection Research. https://cwp.org/

Dan'azumi, S., & Barka, M. A. (2018). Event mean concentrations of urban stormwater runoff quality from a small catchment in Nigeria. ASM Science Journal, 11(Special Issue 2), 101–105.

Hossain, M. A., Zakir, H. M., Kumar, D., & Alam, M. S. (2017). Quality and Metallic Pollution Level in Surface Waters of an Urban Industrialized City: A Case Study of Chittagong City, Bangladesh. Journal of Industrial Safety Engineering, 4(2), 9–18. https://doi.org/10.37591/joise.v4i2.1941

Huang, J., Tu, Z., Du, P., Li, Q., & Lin, J. (2012). Analysis of rainfall runoff characteristics from a subtropical urban lawn catchment in South-east China. Frontiers of Environmental Science and Engineering in China, 6(4), 531–539. https://doi.org/10.1007/s11783-010-0287-x

Jung, J. W., Park, H. N., Yoon, K. S., Choi, D. H., & Lim, B. J. (2013). Event mean concentrations (EMCs) and first flush characteristics of runoff from a public park in Korea. Journal of the Korean Society for Applied Biological Chemistry, 56(5), 597–604. https://doi.org/10.1007/s13765-013-3128-3

Khatun, A., Bhattacharyya, K. G., & Sarma, H. P. (2014). Levels of pollutants in runoff water from different land uses in Guwahati City , Assam , India. Archives of Applied Science Research, 6(5), 96–100.

Lee, H.-K. (2003). Research Papers : Determination of Event Mean Concentrations and First Flush Criteria in Urban Runoff. In Environmental Engineering Research (Vol. 8, Issue 4, pp. 163–176). https://doi.org/10.4491/eer.2003.8.4.163

Lee, J. Y., Kim, H., Kim, Y., & Han, M. Y. (2011). Characteristics of the event mean concentration (EMC) from rainfall runoff on an urban highway. Environmental Pollution, 159(4), 884–888. https://doi.org/10.1016/j.envpol.2010.12.022

Li, C., Liu, M., Hu, Y., Gong, J., & Xu, Y. (2016). Modeling the quality and quantity of runoff in a highly urbanized catchment using storm water management model. Polish Journal of Environmental Studies, 25(4), 1573–1581. https://doi.org/10.15244/pjoes/60721

Li, D., Wan, J., Ma, Y., Wang, Y., Huang, M., & Chen, Y. (2015). Stormwater runoff pollutant loading distributions and their correlation with rainfall and catchment characteristics in a rapidly industrialized city. PLoS ONE, 10(3), 1–17. https://doi.org/10.1371/journal.pone.0118776

Niazi, M., Nietch, C., Maghrebi, M., Jackson, N., Bennett, B. R., Tryby, M., & Massoudieh, A. (2017). Storm Water Management Model: Performance Review and Gap Analysis. In Journal of Sustainable Water in the Built Environment (Vol. 3, Issue 04017002). https://doi.org/10.1061/jswbay.0000817

Pal, S. K., & Masum, M. M. H. (2021). Spatiotemporal trends of selected air quality parameters during force lockdown and its relationship to COVID-19 positive cases in Bangladesh. Urban Climate, 39(August), 100952. https://doi.org/10.1016/j.uclim.2021.100952

Pal, S. K., Masum, M. M. H., Salauddin, M., Hossen, M. A., Ruva, I. J., & Akhie, A. A. (2023). Appraisal of stormwater-induced runoff quality influenced by site-specific land use patterns in the south-eastern region of Bangladesh. Environmental Science and Pollution Research, 30(13), 36112–36126. https://doi.org/10.1007/s11356-022-24806-8

Peng, H. Q., Liu, Y., Wang, H. W., Gao, X. L., & Ma, L. M. (2016). Event mean concentration and first flush effect from different drainage systems and functional areas during storms. Environmental Science and Pollution Research, 23(6), 5390–5398. https://doi.org/10.1007/s11356-015-5657-2

Sharma, D., Gupta, R., Singh, R. K., & Kansal, A. (2012). Characteristics of the event mean concentration (EMCs) from rainfall runoff on mixed agricultural land use in the shoreline zone of the Yamuna River in Delhi, India. Applied Water Science, 2(1), 55–62. https://doi.org/10.1007/s13201-011-0022-1

Song, H., Qin, T., Wang, J., & Wong, T. H. F. (2019). Characteristics of stormwater quality in Singapore catchments in 9 different types of land use. Water (Switzerland), 11(5), 1–10. https://doi.org/10.3390/w11051089

Spearman, C. (2008). Spearman Rank Correlation Coefficient. In The Concise Encyclopedia of Statistics (pp. 502–505). Springer New York. https://doi.org/10.1007/978-0-387-32833-1_379

Wei, Z., Simin, L., & Fengbing, T. (2013). Characterization of urban runoff pollution between dissolved and particulate phases. The Scientific World Journal, 2013(964737), 1–6. https://doi.org/10.1155/2013/964737