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Physicochemical Properties of Highway Stormwater Runoff, Sulaymaniyah-Iraq

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Abstract Urban stormwater runoff contributes to contamination of downstream water bodies, through washing away accumulated pollutants from streets. Studies are necessary to develop methods for managing urban runoff towards building a sustainable urban drainage system. Rainfall runoff samples were collected from Tasluja highway of Sulaymaniyah City, KRG, in fall of 2024 and tested for water quality parameters. Runoff samples were tested for temperature (T), turbidity, pH, total dissolved solids (TDS), total suspended solids (TSS), electrical conductivity (EC), zinc (Zn), cadmium (Cd), chromium (Cr), cobalt (Co), cupper (Cu), nickel (Ni), iron (Fe), lead (Pb), magnesium (Mg), and manganese (Mn) parameters. After long dry seasons, first and second rainfalls runoff samples showed significant concentrations of pollutants. Results of the study from the first flush showed the following average concentration of heavy metals in (mg/L) in descending order Mg (22.191), Fe (0.994), Mn (0.611), Zn (0.220), Cu (0.214), Ni (0.084), Cr (0.030) and Co (0.012). First rainfall test results showed higher heavy metals concentration compared to the second rainfall. Furthermore, to regulate the degree of pollution from different samples, water quality index (WQI) calculated for both rainfalls. The results demonstrated variations in stormwater WQI values ranging from 64 to 411. Results of this study suggest onsite stormwater treatment to protect nearby receiving water bodies from contamination.

Keywords Urban, Stormwater, Pollution, Sulaymaniyah

1. Introduction

Urban area rainfall runoff is one of the environmental challenges resulting from rapid urbanization in the world [1]. Naturally, precipitation can easily percolate through the soil land cover to recharge groundwater. Conversely, urbanization tends to convert natural land cover into impervious land cover such as driveways, parking lots, roads, and roofs which reduces runoff infiltration and raises surface runoff [2,3]. Stormwater runoff gathers contaminants when it passes over impermeable surfaces and releases them into nearby receiving water bodies, often degrading the quality of the water and endangering aquatic and perhaps human life. Urban stormwater runoff contributes significantly to non-point source pollution since these pollutants come from both natural and artificial activities within the urban watershed [4].

Stormwater has been regarded as a significant alternative water resource for the purpose of addressing water scarcity challenges on a global scale [5]. However, the runoff from urban streets and highways is considered to be a significant diffuse source of pollution in the urban environment because it includes high amounts of contaminants, including heavy metals, nutrients, and trace organics [6]. Highway stormwater runoff is contaminated by a number of factors, such as dust from the surrounding areas, pavement wear, maintenance activities, and traffic deposits such as tire wear, car brake coatings, and oil and lubricant leaks [7]. The typical contaminants detected in roadway runoff as dissolved and particulate matter are TSS and heavy metals, including Cu, Pb, Zn, Ni, Cr, Fe, and Cd [8].

Suspended solids can carry contaminants like heavy metals and hydrocarbons and contribute significantly to the total pollution potential [9].

Heavy metals, which are abundant, toxic, and non-degradable, are among the hazardous elements that play a significant ecological role. Heavy metals are affixed to dispersed particulates that are transported with the runoff and may accumulate in the bottom sediments of receptacles. Zinc, Cr, Ni, and Cd are frequent heavy metals originating from vehicle parts wearing motor oil, tire wear, and brake wear [10].

First flush is defined as the first half inch of rainfall after a considerable dry period which carries more than 80% of accumulated pollutants [11]. According to the 30/80 rule, which was developed by Krajewski et al. [12], a first flush occurs when 80% of the contaminants are released during the first 30% of runoff. Proper urban runoff management requires a detailed knowledge of watershed environmental processes, specifically the significance of first flush in pollution loading during rainfall events [13]. The quality of receiving water bodies in industrialized area is more vulnerable due to synergy of heavy metal loads from both roads and wastewater effluent [14]. Sustainable road drainage system can improve the quality of rainfall runoff to protect downstream water resources [15].

Evaluation of water quality involves various physicochemical and biological data, and the analysis becomes more difficult as the number of variables expands. To address this issue, quantitative techniques as WQI are necessary for improving decision-making and effective ecological assessment [16]. Gabr [17] examined the influences of heavy traffic on stormwater quality in highways and parking zones. The findings revealed that the ranges of WQI were between 426 and 929, the stormwater was polluted and needed prior treatments. Sustainable drainage systems are widely acknowledged as the most effective method for achieving comprehensive stormwater management on a global scale [18]. Low impact development designs (LIDs) are structural and procedural controls that mitigate surface runoff and enhance water quality via infiltration, filtration, adsorption, bioaccumulation, and percolation. Instances of LIDs components include swales, infiltration trenches, ponds and wetlands [19].

Objective of this research was to find key pollutants in the highways runoff of Sulaymaniyah city. First flush stormwater runoff samples were collected and tested for the expected contaminants from urban areas. In order to complete the task, WQI was utilized to identify the degree of pollution in stormwater runoff. Finally, suitable stormwater management system can be suggested based on the study results.

2. Materials and Methods

2.1. Study Area

Sulaymaniyah City is one of the largest cities in the Kurdistan region of Iraq, located at an average elevation of around 850 over the sea level [20]. The city falls within an arid and semi-arid zone, characterized by dry and hot in summer, while cold and wet in winter. The precipitation begins in October and persists until May. The typical yearly precipitation ranges from 848 mm in rainy years to 328 mm in dry years [21,22].

Tasluja road is a section of main road which links Kirkuk City with Sulaymaniyah City, as one of the city's main roadways with heavy traffic flow [23]. More specifically, the study area starts from Sarchnar roundabout at (Latitude = 35.565194°, Longitude = 45.390388°) and proceeds to the Tasluja checkpoint at (Latitude = 35.588819°, Longitude = 45.197818°), which is about 18 kilometers long (Figure 1).

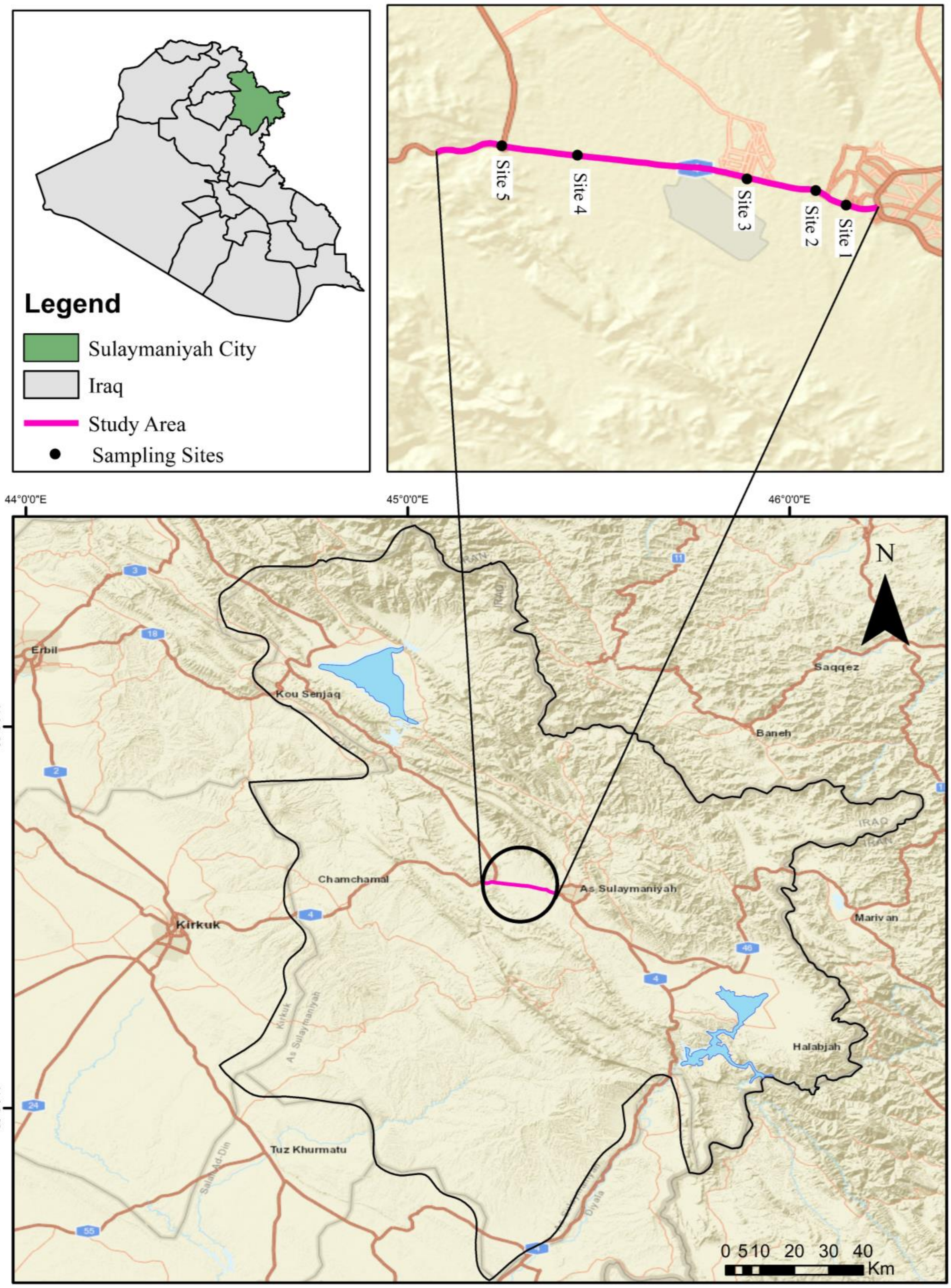


Figure 1. Study area, Tasluja road with sampling locations

2.2. Sampling and Testing Procedures

Stormwater runoff samples were collected along Tasluja- road from five locations, referred to as 1 to 5 locations (Figure 1). Based on the road profile sample locations were chosen, especially sag points where runoff from the road surface is accumulated [24]. Stormwater runoff samples were gathered from the five selected locations (1 to 5) during two rainfall events in September, and November of 2024, after dry months. Samples were collected from the road curbside at the same location and immediately at beginning of the runoff flowing, for both rainfalls. Table 1 provides overview of the rainfall patterns during the sample events.

Runoff samples were collected in one-liter open-mouth high-density polyethylene (HDPE) bottles using grab-sampling method. The collected stormwater runoff samples were labeled and preserved at 4℃ in a cooler until test and the analysis were accomplished.

Physiochemical parameters such as temperature and turbidity were analyzed by using thermometer and Turbidimeter (Lovibond). Multiparameter device (milwaukee MW803 MAX) was utilized for measuring pH, TDS, and Ec. Samples were tested for detecting possibility of the following heavy metals Zn, Pb, Fe, Cu, Co, Cd, Cr, Ni, Mg and Mn, using ICP optical emission spectrometer.

2.3. Water Quality Indices

The WQI index is an effective tool for summarizing and conveying information on water quality to stakeholders and decision-makers. When many variables are employed, it might be confusing to compare measured water quality variables with international guidelines.

WQI is a method for evaluating the combined impact of many water quality measures on the general condition of water [25].

The WQI values for the physicochemical parameters were determined through the following formulas from [26]:

$$WAWQI = (\sum WiQi)/Wi \quad (1)$$

Qi is the quality rating for each parameter, and it is computed using the formula below:

$$Qi = 100*(Vi-V0)/(Si-V0) \quad (2)$$

Where:

Vi: is the concentration of the ith parameter in water sample, V0: represents the optimal value of ith parameter in clean water, which equals to zero for all parameters except pH=7, Si: indicates the allowable value for ith parameter.

Each parameter's weight (Wi) is determined using the formula below:

$$Wi = K/Si \quad (3)$$

Where K is constant, and can be found using this expression:

$$K = 1/(\sum(1/Si)) \quad (4)$$

WQI typically has a scale that ranges from 0 to 100. The best and excellent water quality is represented by 0, while worst and unusable quality is 100 and more. The classification of water quality according to weighted arithmetic water quality (WAWQI) is presented in Table 2, as reported in [27].

Table 1. Rainfall events characteristics

Event No.	Date	Rainfall depth(mm)	Number of antecedent dry days
First Rain	22/9/2024	4.3	119
Second Rain	21/11/2024	25.6	43

Table 2. Water quality index (WQI) value, statue, grading, and use cases

WQI Value	Water Quality State	Grading	Potential Application
0-25	Excellent	A	Drinking, industrial, and irrigation
26-50	Good	B	Drinking, industrial, and irrigation
51-75	Poor	C	Industrial, and irrigation
76-100	Very Poor	D	Irrigation
Above 100	Unusable	E	Treatment is required for any type of water usage.

3. Results and Discussion

3.1. Physiochemical Test Results

Rainfall runoff samples were tested for different physiochemical parameters. Results of the test were compared to water quality limits that are given in Table 3. The pH test results from all the five sampling locations along Tasluja roadway ranged between 6.1 and 6.76 for the first rainfall, with average pH value of 6.48 for all locations. The pH test results indicate that the rain is slightly acidic. Conversely, the pH test results of the second rain ranged from 6.89 to 7.69, with an average of 7.45, which is above neutral value of 7 for pH. The reasons for lower pH values in the first rainfall may be due to longer dry period before the first flush which was 119 days, where possibility of accumulating more pollutants was higher compared to the second rainfall dry period which was 43 days. Figure 2A shows variations of pH values for all five sample location for both first and second rainfalls. Average values of pH for both rainfalls are located in the allowable range given in Table 3.

Figure 2B shows results of EC tests for all locations. There is notable fluctuation in EC values from a minimum of 436 µS/cm at site 1 to a maximum of 2406 µS/cm at site 3 during the first rainfall event. The subsequent event recorded a minimum conductivity of 308 µS/cm at site 4 and a high of 1324 µS/cm at site 1. The amount of EC for all sampling sites meets allowable limitation in Table 3, except site 4, which is over the limit. The preceding dry weather period has a direct impact on the quality of the rainfall runoff, especially the first rainfall after long dry period. Dump of different inorganic ions affects electrical conductivity of water samples. Phosphate, nitrate, sulphate, and chloride are considered as main source of roadway contaminants which have direct effect on the EC values.

While TDS test results obey EC test values, typically about half of the EC values. Consequently, TDS vales take same patterns of the EC variations for all locations with TDS values in mg/L units about half of EC in µS/cm units (Fig. 2C).

Turbidity is mainly caused by nonfiltered extremely fine solid particles in water using regular techniques. For the first rainfall, lowest value of turbidity was 410 Nephelometric turbidity unit (NTU) at location 2, while highest value of turbidity was 850 NTU for sample location 1. The average value of turbidity for all the 5 sample locations was 609.7 NTU. For the second rainfall, the lowest turbidity values of 1200 at sample location 1 and the extreme value of 2480 NTU at location 4 were obtained, with an average of 1845 NTU (Fig. 2D). In both cases, the measured turbidity results were much higher than the acceptable limit in Table 3.

The most prevalent contaminant in urban stormwater runoff is suspended solids which are acknowledged as a key determinant of stormwater quality [28]. Therefore, the concentration of suspended particles was determined to be the primary stormwater quality metric for the chosen storm events. Significant variations in the concentration of suspended particulates are indicated by the two rainfall events. The first event had an average TSS value of 2012 mg/L, with values ranging from 1020 to 3850 mg/L. On the other hand, TSS levels were higher during the second event, ranging from 2,020 mg/L to 9,850 mg/L, with an average TSS of 5718 mg/L (Fig. 2E).

Table 3. Maximum and allowable ranges for each parameter

No.	Parameters and Unit	Allowable ranges	Sources
1	Temperature (℃)	30	[27]
2	pH	6.5-8.5	[29]
3	EC (µs/cm)	2250	[30]
4	TDS (mg/l)	< 2500	[30]
5	TSS (mg/l)	< 60	[30]
6	Turbidity (NTU)	< 50	[31]
7	Fe (mg/l)	0.3	[29]
8	Zn (mg/l)	0.5	[29]
9	Cu (mg/l)	0.05	[29]
10	Co (mg/l)	0.05	[29]
11	Cr (mg/l)	0.05	[29]
12	Cd (mg/l)	0.005	[26]
13	Pb (mg/l)	0.05	[26]
14	Ni (mg/l)	0.1	[26]
15	Mn (mg/l)	0.1	[26]
16	Mg (mg/l)	50	[26]

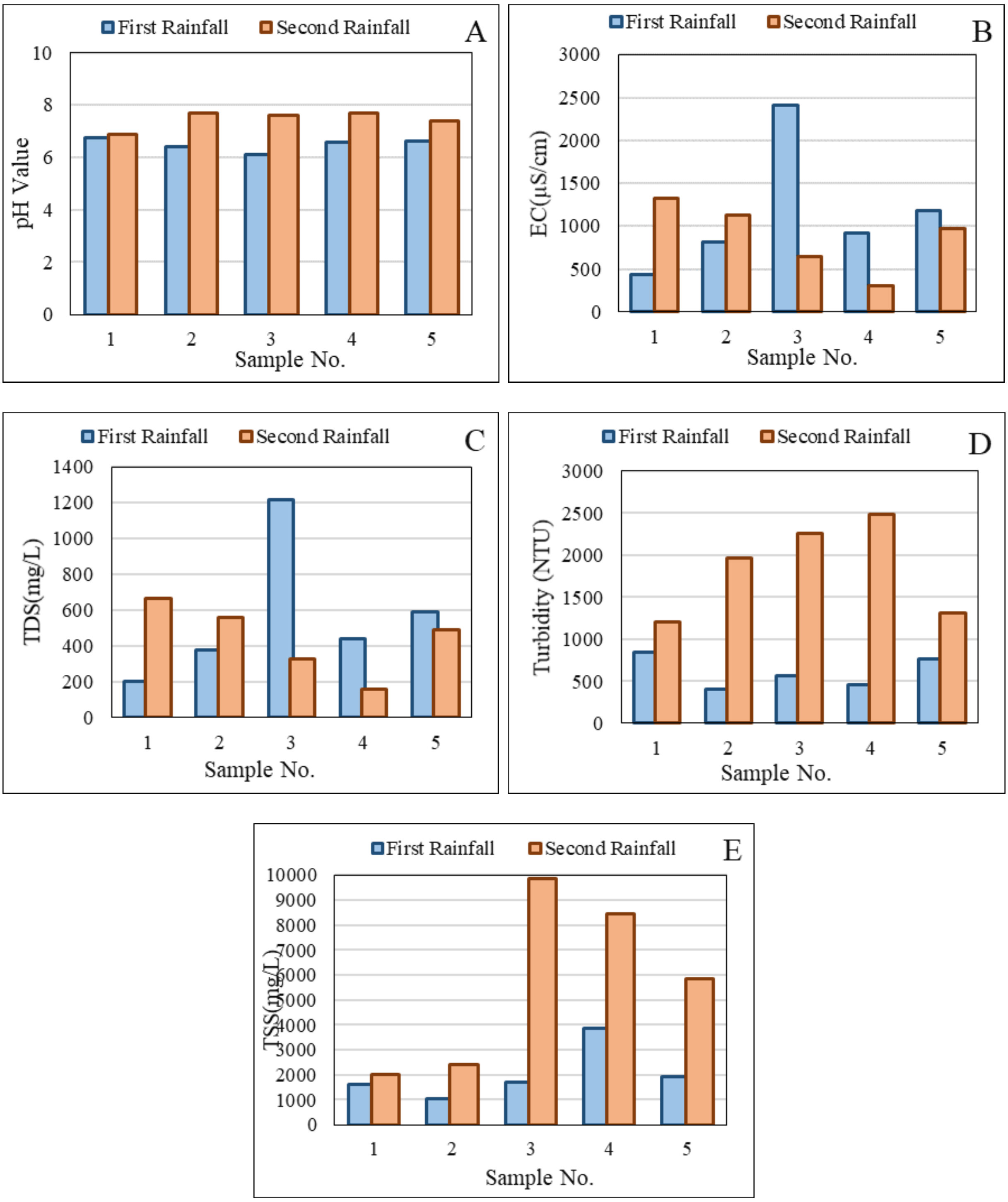


Figure 2. Values of pH, EC, TDS, turbidity, TSS for the two rainfall events

Higher values of TSS for the second rainfall were expected due to higher value of rainfall depth which was 25.4 mm compared to the first rainfall of 4.3 mm. Higher amount of rainfall means higher volume of runoff, consequently higher land erosion around the roadway, and finally higher value of TSS. Values of TSS for all sampling points are greater than the allowable limit in Table 3. Typically, TSS correlates to higher pollutant transfer especially heavy metals which are attached to soil suspended particles that is the major component of TSS in the stormwater runoff.

3.2. Heavy Metal Test Results

Rainfall runoff samples from all five locations are tested for heavy metals pollutants for both first and second rainfall events after significant dry period. The results of the study show that the average concentration of heavy metals varies with antecedent dry day number. Therefor the highest peaks of pollutants are expected to be found after the first fall rainfall event. The antecedent dry day of the first flush was 119 days that can cause accumulation of higher amount of pollutant which would be washed away by runoff flowing. This is consistent with the first flush theory, which states that a higher concentration of pollutants accumulates on highways through dry period spills which are released during the first flush rainfall [32]. Significant amounts of toxic elements from anthropogenic activities accumulate in soil and waterways through urban runoff. Heavy metals are deposited on the highway soils and vegetation including copper, lead, and zinc which originate from wearing of car parts, gasoline additives and lubricating oils leaks [33].

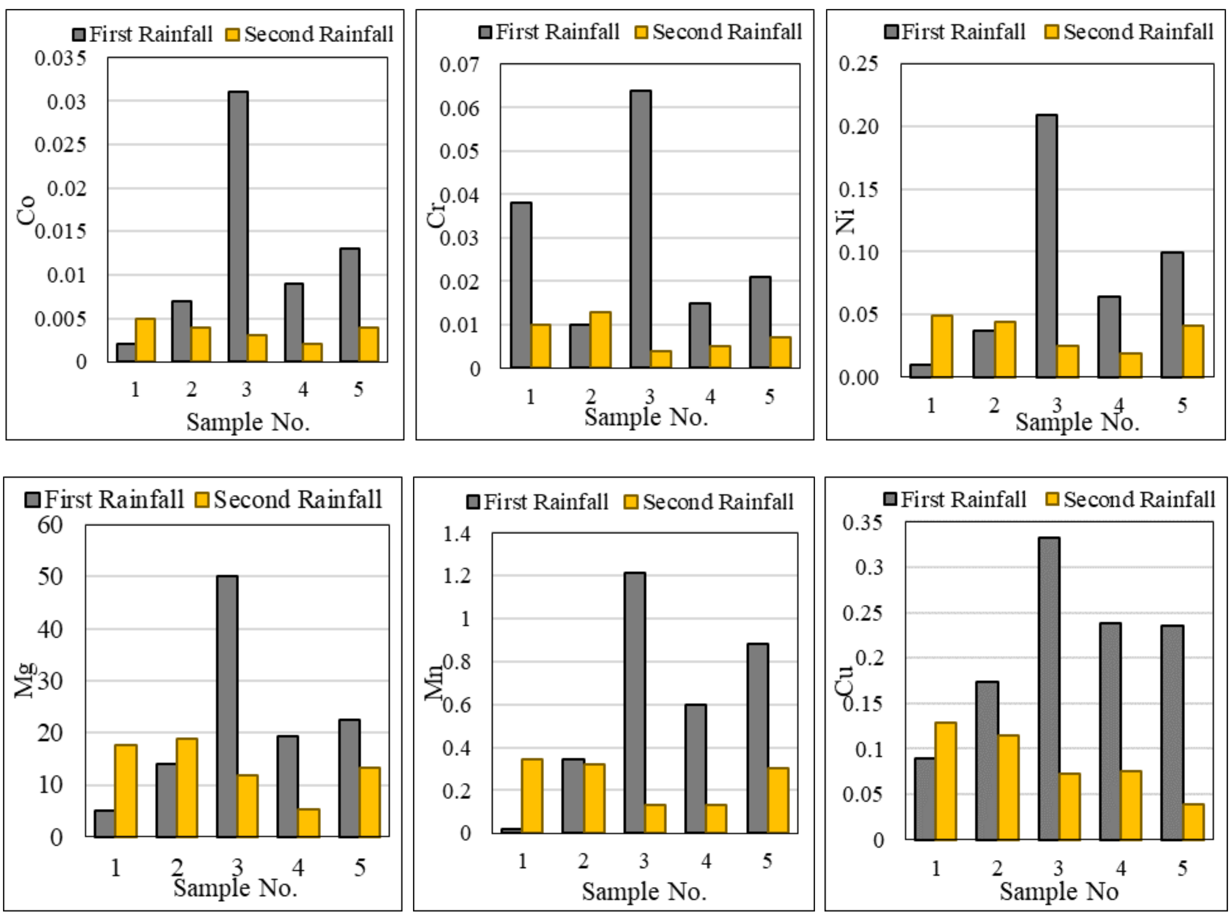
Road runoff had the greatest values of Cr during the first flush at site 3 and above the safe limit, with ranging from 0.004 to 0.064 mg/L. The safe limits of Cr and Ni are 0.05 mg/L and 0.01 mg/L, respectively, Table 3. This research found that Ni concentrations varied from 0.010 to 0.209 mg/L during the first rain, which exceeded the standard at all sampling sites except site (1). Nickel content ranged from 0.019 to 0.049 mg/L after the second rain. Rate of Cr and Ni in the second rainfall samples was found to be below the standards.

The most common aquatic hazardous metal found in storm water is Cu that accumulates rapidly in living organism. Copper originates from wearing of vehicle parts (e.g. brake pads. Similar to most heavy metals, Cu levels tend to increase with higher traffic flow rate [34]. The lowest value of Cu was 0.089 mg/L at site 1, while the highest recorded test value was 0.333 mg/L at site 3 for the first rainfall. Cu in the second rain recorded a low concentration of 0.039 mg/L at spot 5, while the maximum concentration of 0.128 mg/L at site 1 was recorded. During two sampling periods, the concentration of Cu exceeded the regulatory standards of 0.05 mg/L.

The Fe and Mn content fell within the range of (0.14 to 3.162 mg/L), and (0.002 to 0.031 mg/L) respectively, whereas for all sampling sites surpass the permissible limit as per Table 3 except site 1 in the first sampling time. The measured concentration of Co across all sampling points varied between 0.002 and 0.031 mg/L, which is within the guidelines of 0.05 mg/L (Table 3).

In the first rain, the detected Zn concentrations varied from 0.021 PPM at site 1 to a high of 0.550 mg/L at site 3. Additionally, the second rain recorded a high of 0.092 PPM at site 1 and a low of 0.048 PPM at site 3. Considerable amount of Zn can be sourced from car parts wearing and lubricant leakage and engine emissions [35].

The allowable limit of Mg is 50 mg/L provided in Table 3 and the concentration of Mg was observed between 5.006 and 50.06 mg/L. At all measured location, Mg level was within the acceptable limit except site 3 in the first rainfall. Figure 3 shows concentration of metals during first and second rain.



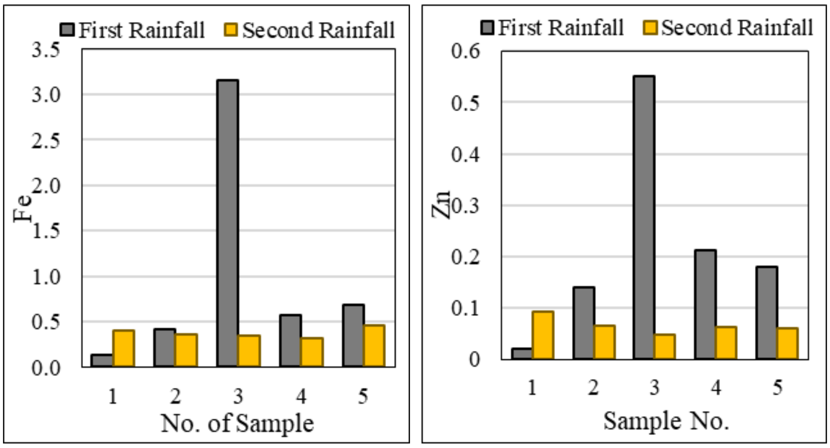


Figure 3. Concentration of metals during First and second rain

Lead heavy metal (Pb) was found only at station 1 during the second events at a low concentration of 0.001 mg/L. Lead concentrations gradually decreased over the last several decades, as a result of the global switch to unleaded petrol [36], although Pb is still being deposited on roadway surfaces through air deposition and paints applied to right-of-ways [37]. Also, Cd was not detected in any sample location.

While rainfall is a continuous process and keeps washing out pollutants from road surfaces to downstream areas, even if the concentration of certain pollutants is relatively low and does not exceed the limitation. Continuous washout of pollutants leads to buildup of the pollutants downstream of the area and results in accumulation of pollutants in downstream receiving waters.

3.3. WQI

Water quality index (WQI) is the numerical expression of water quality which accumulates several water quality parameters into a single straightforward number. WQI can be easily understood and used by stakeholders to make water resources management and treatment decisions. In this study stormwater quality was found using weighted arithmetic water quality index(WAWQI), because it is broadly used for classifying surface water and ground water quality based on the level of pollution, and serves as a valuable tool for conveying comprehensive water quality information to stakeholders, and policymakers [38]. The index was calculated through the equations specified previously using fourteen parameters, as presented in Table 4. At site 3, the lowest WQI value of 64 was found during the second rainfall and the highest WQI value of 411 was calculated in the first rainfall event, indicating poor to unsuitable status. Moreover, the first rainfall WQI values for stations 1, 2, 4, and 5 were 66, 141, 210, and 252 respectively. Table 4 represents the results of WQI for two rainfall events. It is found that the WQI values for the second rainfall are lower than the first rainfall samples except station 1. During the first rainfall, all sampling locations show unusable water quality except site 1, which has poor water quality as outlined in Table 5. On the other hand, the second rainfall results exposed unsafe WQI for sites 1, and 2, while the other sampling location exhibit poor to very poor WQI (Table 5).

Table 4. Calculated water quality index for two rainfall events

Sampling Site	WQI Values	
	First Rainfall	Second Rainfall
1	66	120
2	141	111
3	411	64
4	210	66
5	252	97

Table 5. Classification of water quality based on WQI values

Sampling Site	WQI Classifications	
	First Rainfall	Second Rainfall
1	Class C, Poor	Class E, Unusable
2	Class E, Unusable	Class E, Unusable
3	Class E, Unusable	Class C, Poor
4	Class E, Unusable	Class C, Poor
5	Class E, Unusable	Class D, Very Poor

4. Conclusions

Heavy metals have diverse impacts on human and environmental well-being. Roadways and traffic loads are one of the primary contributors to environmental pollution sources. Runoff from roads can transfer these pollutants to nearby soils and waterways. In this study, highway stormwater runoff was analyzed for primary pollutants including TSS, TDS, turbidity, EC, pH, Cr, Fe, Pb, Mn, Mg, Ni, Co, Cd, Cu, and Zn, during the first flush and second rainfall events. The results showed that the average concentration of these parameters in the first rainfall samples was greater than in the second one except TSS and turbidity. Moreover, Cd was not detected in any sample from both rainfall events, nevertheless Pb was detected once at site (1) in the second rainfall. Results of the study revealed the following average values of heavy metals from both rainfalls: Mg (17.82 mg/L), Fe (0.685 mg/L), Mn (0.428 mg/L), Cu (0.150 mg/L), Zn (0.143 mg/L), Ni (0.06 mg/L), Cr (0.019 mg/L), and Co (0.008 mg/L). Findings revealed that TSS and Turbidity were significantly high and above standards. This is caused by accumulation of particulates from road surfaces erosion, tire abrasion, construction activities, and vehicle exhaust deposition. Elevated quantities of these stormwater contaminants present an issue to both human and aquatic life. It can be concluded that stormwater quality from most sampling stations within the class E, which is unsuitable for use and requires treatment for all types of usage.

Low impact development (LID) techniques or best management practices (BMP) can be recommended as a treatment at the pollution site to remove all these pollutants from the rainfall runoff before their washout downstream to the receiving water sources. Bioswales which include vegetation are one of the good solution for treatment in moderate relatively wet climate areas, while and dry swales without vegetation can be a good option in dry weather areas. Where secondary treatment process desired, bioretention basin is recommended to raise the level of pollutant removal which receives overflow from bioswales as the next stage of the treatment.

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