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# THE FIRST FLUSH ANALYSIS OF STORMWATER RUNOFF IN A HUMID CLIMATE

Reza MASTOURI[1], Hassan POURFALLAH KOUSHALI[2*], Mohammad Reza KHALEDIAN[3]

[1, 2]*Department of Civil Engineering, Arak Branch, Islamic Azad University, Arak, Iran*
[3]*Department of Water Engineering, Faculty of Agricultural Sciences, University of Guilan, Rasht, Iran*

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**Highlights**

- The TSS and COD concentrations are higher than those of other pollutants such as nitrogen and phosphorus.
- The average ranking of the first flush strength between the pollutants was COD > $NO_3$-N > TP > Pb > TSS.
- On average, the first 38% of runoff volume was capable of transporting 50% of the pollutant masses.
- In all events, $NO_3$-N and COD demonstrated the first flush effect.
- First flush strength for metal concentrations do not have a relationship with rainfall intensity.

**Abstract.** This study focuses on the pollutants from urban runoff to Zarjoob River, which is one of the rivers leading to Anzali International Wetland, which was listed in the Montreux Record in 1993 as a site in need of priority conservation. Storm water runoff from a residential area in Rasht (the largest city on Iran's Caspian Sea coast) was monitored in this study during thirteen rainfall events, with a total of 58 storm runoff samples collected from 2018 to 2019. In most rainfall events, the mean concentration of total suspended solids (TSS) and chemical oxygen demand (COD) were higher than the other pollutants. The event mean concentrations (EMC) of TSS loads ranged from 57.3 mg/L to 682.5 mg/L and from 46.7 mg/L to 590.4 mg/L for COD. The site mean concentrations (SMC) for TSS, COD, total phosphorus (Total P), nitrate-nitrogen ($NO_3$-N), and total lead (Pb) were 219, 205, 1.91, 20.63, and 0.25 mg/L, respectively. The first flush coefficient (b) was used to evaluate the first flushing of various events. The results of the study confirmed that the first flush occurred in all events, and the average ranking of first flush strength among the pollutants was COD > $NO_3$-N > TP > Pb > TSS. Controlling one-third of the initial runoff volume appeared to be critical for managing the quality of urban rivers in humid regions. The findings of this study can be applied to urban runoff management strategies in cities with similar climatic conditions.

**Keywords:** event mean concentrations, stormwater, monitoring, pollutants, first flush.

## Introduction

The "first flush" is a phenomenon that occurs as a result of the belief that the first part of a storm event's runoff is the most polluted (Stenstrom & Kayhanian, 2005). The first flush of storm pollutants has been studied in several locations, including Australia (McCarthy, 2009), the United States (Kang et al., 2008), and Japan (Lee et al., 2005). The critical runoff range and the volume required for treatment, on the other hand, are not precisely defined. Several researchers have warned that direct stormwater runoff in urban, impermeable areas, as well as wastewater discharge that is not connected to a wastewater treatment plant (WWTP), pose a serious threat to aquatic ecosystems (Brion et al., 2015; Gotkowska-Płachta et al., 2016; Kaushal & Belt, 2012). According to Kim et al. (2012), because most cities in South Korea lack separate sanitation and urban runoff collection systems, large amounts of pollution are washed off the streets and transferred to the sewage treatment plant during heavy rainfall.

Many studies on urban runoff pollution have also been conducted, which have numerous sources of air pollution and the possibility of pollutant wash off in impermeable areas (Gunawardena et al., 2013; Petrucci et al., 2014; Dorchin & Shanas, 2010). Other researchers have confirmed that transferring a high concentration of contaminants during the first stages of a rainfall event indicates

*Corresponding author. E-mail: *hpoorfallah@yahoo.com*

the first flush effect (Sansalone & Cristina, 2004). Pollutants flushed out by storm runoff can be a significant contributor to receiving waters in urban areas (Behera et al., 2006). Cleaning urban areas prior to rains can help to keep runoff from becoming contaminated by elements (for example: Al, Mn, and Fe). Many researchers have concluded that development activities such as road construction, asphalting, and canal lining exacerbate the negative effects of urban runoff on water quality (Goonetilleke & Thomas, 2004; Lundy et al., 2012; Thorpe & Harrison, 2008).

The event mean concentration (EMC) is frequently used to estimate pollutant loads in storm water (Charbeneau & Barrett, 1998; Yi et al., 2015). Furthermore, Grum et al. (1997) investigated the underlying structure of systematic variations in the EMCs of pollutants in combined sewers during rainfall events.

Understanding the first flush and classifying it is critical in flood management. According to Batroney et al. (2010), focusing on the first flush of a qualitative sampling strategy is required to evaluate Best Management Practices (BMPs). Zeng et al. (2019) investigated first flush on three different levels of roofs, roads, and green environments. They discovered that metal roofs had the greatest influence on the production of the first flush, and that ammonia nitrogen, and phosphorus were the primary pollutants in the first flush.

However, many studies have been carried out on storm water quality and pollutants transported to rivers (Zushi & Masunaga, 2009; Björklund et al., 2011; Zgheib et al., 2012; Markiewicz et al., 2017; Müller et al., 2019; Bressy et al., 2011; Gasperi et al., 2014; Markiewicz et al., 2017). Most studies have been conducted in developed countries with temperate climates, and there is still a scarcity of data for coastal and humid catchments in developing countries with poor non-point source pollution control. This study focuses on the pollutants from urban runoff to Zarjoob River, which is one of the rivers leading to Anzali International Wetland.

Anzali Wetland Located on the southern coast of the Caspian Sea in northern Iran; this Wetland covers an area of 193 square kilometers, and includes lagoons and extensive reed beds. It is known as a major breeding and wintering site for water birds around the world. The wetland is also an important spawning and nursery area for fish in the Caspian Sea, supporting fertile fishing grounds with vibrant activity in this industry. It was listed in the Montreux Record in 1993 as a site in need of priority conservation due to recent water quality deterioration caused by urbanization, agricultural drainage, sediment influx and other problems.

Therefore, the critical volume of runoff and the dimensions of storm water reservoirs were estimated simultaneously. This is important because the amounts of rainfall and runoff in humid coastal areas are different from those of temperate areas, and the discharge of primary runoff into the river without proper treatment can be dangerous for aquatic animals. Therefore, this study has the following objectives that set it apart from others:

a – Investigating the behavior of the first flush, which causes increased runoff in a humid coastal climate.

b – Determining the volume of primary runoff pollution in order to reduce the cost of land supply as well as the construction and maintenance of a treatment plant or storm tank near a river that flows to the Anzali International Coastal Wetland, which is known as a migratory bird habitat. This valuable swampy area is a Ramsar Convention-registered wetland.

This study focused on the first flush analysis in Iran's humid region, using data from 13 storm events and 58 storm runoff samples. We attempted to select a representative from each of the quality parameter categories, including physical parameters, nutrients, and heavy metals, due to the costly and time-consuming measurement and analysis of all water quality parameters. TSS (total suspended solids), COD (chemical oxygen demand), total P (total phosphorus), $NO_3$-N (Nitrate-nitrogen), and Pb (Lead) were the water quality parameters studied.

## 1. Material and methods

### 1.1. An overview of the sites used in this study

The studied catchment is in Rasht, Guilan Province, Iran, and is in a residential area. Rasht has an average annual rainfall of 1,300 to 1,500 mm (climatemps, n.d.), which is typical of Iran's humid regions. The catchment area is 8.50 ha, with impervious surface covering more than 80% of the basin, reflecting the large volume of runoff produced by each rainfall. Furthermore, more than 85% of the basin has a moderate slope (1–10 degrees), which increases pollution and discharges it into the Zarjoob River (Figure 1b shows the digital elevation model (DEM-GIS) of Zarjoob River basin).

Figure 1a depicts the Zarjoob River basin and sampling station. Homes, restaurants, and asphalt roads make up the impervious zone, while grass and agricultural land dominate the pervious zone. The catchment area, which has recently grown in size due to increased urban development, has a separate (from the sewer line) underground storm water pipe.

### 1.2. Flow measurement and sampling strategies

The depth of the runoff was measured at each step of the sampling process and calculated at each instant using the Manning equation. In this method, the parameters of flow cross section, wet perimeter, and hydraulic radius were obtained first by considering the depth of runoff in each sample, and then instantaneous flow was calculated using the Manning equation. This method required data on canal dimensions and water depth, which were determined and recorded manually with a large ruler at each stage of sampling. Furthermore, the storm collection canal at the outfall has a bottom width of 90 cm and a height of 100 cm.

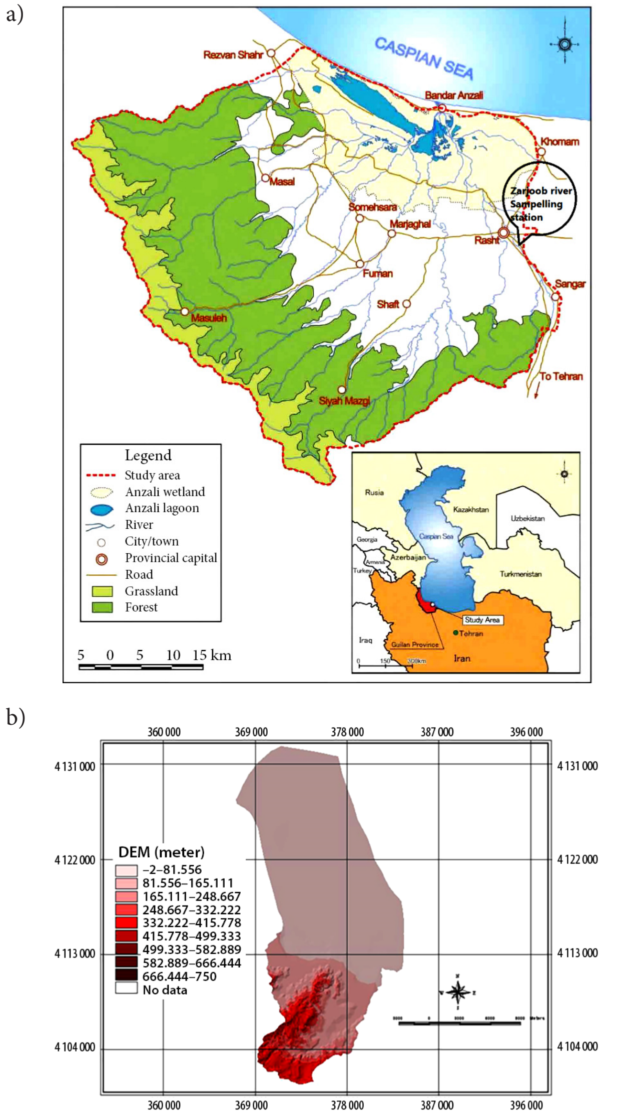


Figure 1. a) Location map of Anzali Lagoon and Zarjoob River with stormwater station; b) Digital elevation model (DEM-GIS) of Zarjoob River basin

Table 1 illustrates rainfall depth, rainfall duration period, mean intensity, and runoff discharge data collected from the Rasht Meteorological Station for rainfall events.

From February 2018 to March 2019, storm water runoff samples were collected from thirteen observed rainfall events. Each rainfall event was sampled in order to investigate changes in contamination. It should be noted that this method was costly because several samples had to be prepared for each rainfall event and the concentration of contaminants associated with each sample had to be measured. Thirteen rainfall events were sampled for this study. Water samples were collected manually every 15 to 30 minutes during the runoff and after the outflow began at the basin's outlet during rainfalls. In addition, open-mouth plastic containers with a capacity of 2 liters were used for sampling. Each sampling used three different bottles. Since the properties of COD, $NO_3$-N, and TP change over time, concentrated sulfuric acid was added to the samples immediately after collection to prevent these indicators from changing. The S1 and S2 bottles were used to determine Pb and TSS, respectively, and the S3 bottles were used to determine COD, $NO_3$-N, and TP; thus, concentrated sulfuric acid was added to the S3 bottles and Nitric acid was added to the S2 bottles.

Water samples were promptly transferred to the Water Organization Laboratory after each event to measure chemical constituents for urban water quality, such as TSS (2540D), COD (5220B), Pb (3500-Pb LEAD), $NO_3$-N (4500-$NO_3$-N B), and TP (4500-P B). All analytical procedures in this laboratory were carried out in accordance with standard methods for water and wastewater tests (U.S. Environmental Protection Agency [EPA], 1998).

Table 1. Stormwater runoff monitoring for rainfall events in 2018–2019

| Runoff discharge (lit/s) | Mean intensity (mm/hr.) | Duration (min) | Rainfall (mm) | Event |
|---|---|---|---|---|
| 50 | 5.6 | 195 | 18.2 | 2018 February 10 |
| 335 | 17.7 | 135 | 39.8 | 2018 March 10 |
| 20 | 4.6 | 300 | 22.8 | 2018 April 21 |
| 26 | 3 | 300 | 14.8 | 2018 May 23 |
| 92 | 4 | 240 | 16 | 2018 June 26 |
| 22 | 3.4 | 540 | 30.8 | 2018 July 28 |
| 74 | 1.8 | 250 | 7.6 | 2018 August 25 |
| 47 | 3.4 | 210 | 12 | 2018 October 24 |
| 28 | 4 | 150 | 10 | 2018 November 24 |
| 74 | 1.5 | 480 | 11.6 | 2018 December 24 |
| 12 | 1.8 | 120 | 3.6 | 2019 January 19 |
| 31 | 6.5 | 90 | 9.8 | 2019 February 20 |
| 23 | 4 | 100 | 6.6 | 2019 March 16 |

### 1.3. First flush analysis theory

During a storm event, the majority of the pollution load is transported in the first part of the discharge volume, resulting in a first flush phenomenon (Taebi & Droste, 2004). The effects of the first flush can be measured using one of three methods (Alias, 2013): mass-based first flush (MBFF), concentration-based first flush (CBFF), and empirically based first flush.

The first flush was evaluated using Equation (1):

$$MFF = \frac{\dfrac{\int_0^t C(t)Q(t)dt}{M}}{\dfrac{\int_0^t Q(t)dt}{V}}, \qquad (1)$$

where *MFF* is the mass first flush ratio, and *M* and *V* are the total load and total volume, $C(t)$ and $Q(t)$ are the pollutant concentration and runoff volume at time $t$.

### 1.4. Computation of Event Mean Concentrations (EMCs)

The qualitative parameters of each storm event vary greatly, and estimating the qualitative status of receiving waters based on total load yield a better result than concentration changes in any given event (Novotny & Olem, 1994). EMCs are defined mathematically as the total pollutant mass discharged during an event divided by the total flow volume (Huber, 1993):

$$EMC = \overline{C} = \frac{M}{V} = \frac{\int C(t)Q(t)\cdot dt}{\int Q(t)\cdot dt}. \quad (2)$$

In Equation (2), $C(t)$ is concentration over time $t$ (mg/L), $Q(t)$ is flow over time $t$ (mg/L), $M$ is pollutant mass (kg), $V$ is runoff volume (m$^3$) and $t$ is the total duration of runoff (s).

Previous research has typically used mass versus volume (M-V) curves to characterize the first flush phenomenon. For instance, Bertrand-Karjewiski et al. (1998) classified the M-V curve into six zones based on the value of the coefficient b (Figure 2). Zones 1, 2, and 3 above the bisector line (45° line) indicate the first flush) 1 = strong($0 \le b < 0.185$), 2 = moderate ($0 \le b < 0.862$) and 3($0.862 \le b < 1$) = weak), but regions 4, 5, and 6 below bisector line suggest no first flush effect ($1 \le b < \infty$) (Taebi & Droste, 2004).

Following the determination of the (M-V) curves, the b value in Equation (3) indicates there is a first flush.

$$M(t) = V(t)^b. \quad (3)$$

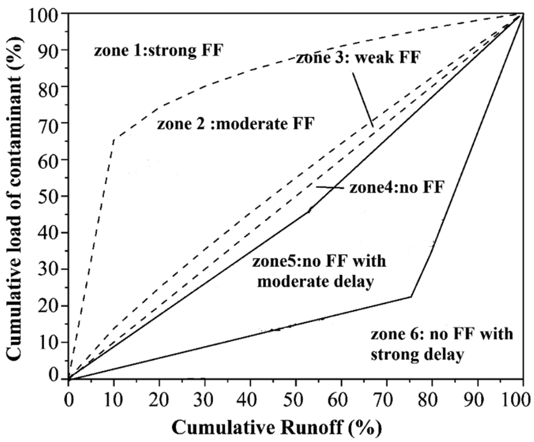


Figure 2. The M-V curve Zones depending of the value of the coefficient b adapted from Bertrand-Karjewiski (1998) and Tabei and Droste (2004)

## 2. Results and discussion

### 2.1. Rainfall and monitored events

During the course of the study, thirteen storms were monitored. The rainfall events occurred between February 2018 and March 2019, yielding 58 runoff samples in total. The maximum rainfall depth was 39.8 mm in March 2018, and the lowest rainfall depth was 3.6 mm in January 2019. Table 1 summarizes the monitored storm events.

### 2.2. First flush analysis and M(V) curve

MATLAB was used to calculate the b coefficient after drawing mass-volume (M(V)) curves for each rainfall event as shown in Figure 3. The normalized curve's position in relation to the 45° straight line is critical. Pollutant mass transfer occurs primarily in the early stages of a runoff event if the curve is above the 45°-line (Gupta & Saul, 1996). This runoff pattern could indicate the first flush. The volume of water that can be controlled to remove a specific mass of pollutant can be calculated using the normalized curve.

During rainfall events, the variation and dispersion of the normalized curves are highly dependent on the sampling location. Extending a normalized curve to several basins frequently results in incorrect results because normalized curves under geographical conditions of the sampling location vary greatly from place to place (Deletic, 1998). Table 2 shows that TSS first flush occurred in 76% of the events, with coefficient b values ranging from 0.49 to 1.11. Figure 4 shows that half of the events with first flush are in the moderate class. For example, in the February 2018 event, controlling 35% of the runoff volume allowed for the removal of 70% of the suspended solids.

According to Table 2, the percentage of events with a COD first flush is 100%, and 77% and 23% of themes can be fit into the moderate and weak first flushes, respectively. Figure 4 also indicates that the first flush coefficient b values range from 0.34 to 0.92.

According to Figure 3, in the case of the March 2018 event with the lowest first flush coefficient, approximately 60% of COD could be removed from the runoff by controlling 15% of the initial volume of runoff outflow from the studied basin. In the majority of cases in this study, more than half of the COD was extracted at a volume less than 30% of the initial volume of runoff.

This is similar to nitrate, so the first has occurred in all cases, with 8%, 62%, and 30% of cases being strong, moderate, and weak, respectively. The results show that the first flush coefficient values range from 0.06 to 0.91, and a fantastic first flush was observed in October 2018, allowing for the elimination of 75% of $NO_3$-N by controlling 10% of the initial volume of runoff.

According to the findings of this analysis, the percentage of events with total phosphorus first flush was 93% with a moderate rank. A look at Table 2 indicates that the first flush coefficient values range from 0.50 to 1.00.

Taebi and Droste (2004) discovered b value ranges of 0.72–1.19, 0.89–1.10, and 0.64–1.64 for total nitrogen, lead, and zinc, respectively.

As shown in Figure 3, there was a slight initial washing for total phosphorus in the Apr 2018 event, with 30% of the initial runoff volume only controlling 40% of the pollutant's inlet volume. The high environmental nutritional value of aquatic environments like the Zarjoob River makes them

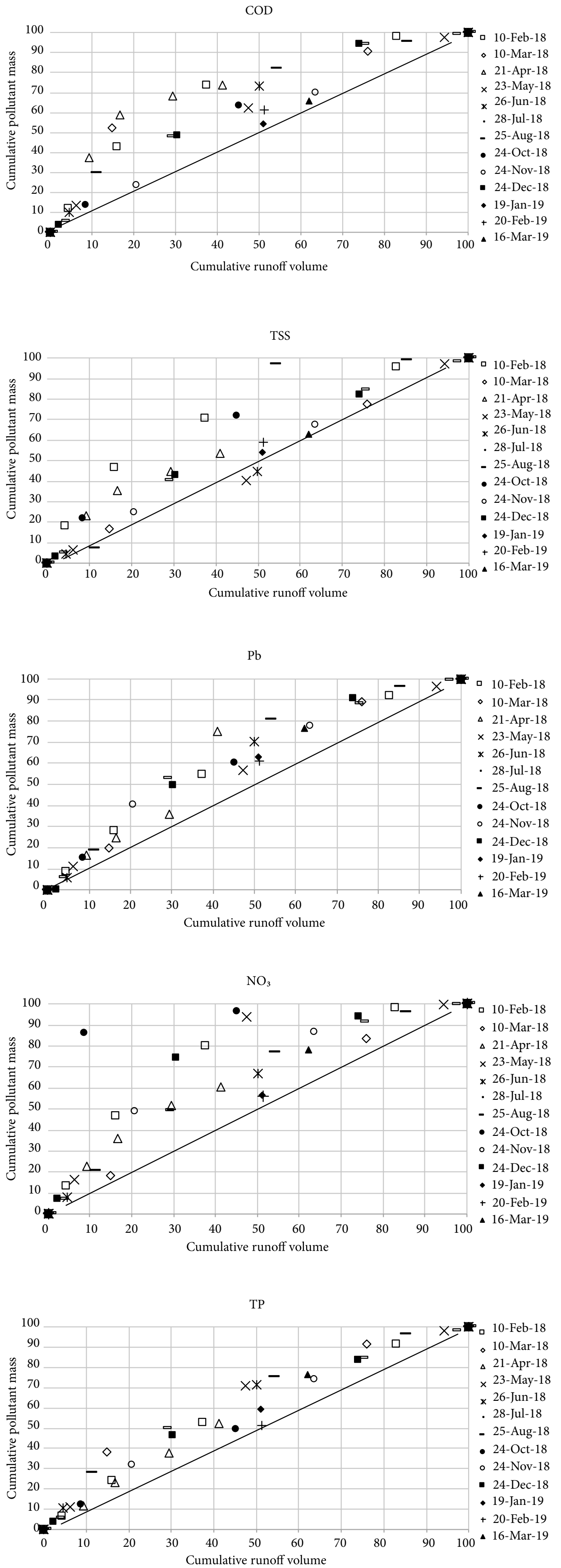


Figure 3. Mass-volume curves for each rainfall event (M(V))

vulnerable to nitrate contamination, as even a low level of phosphorus leaching is extremely harmful. It should be noted that an increase in nutrients in the Zarjoob River was identified as the most important factor influencing water quality. This has resulted in an abundance of algae growth and a disruption of the river's ecological balance.

In most events, the normalized curve for Pb pollutant is the same as the TSS curve. This is due to the fact that heavy metals are typically attached to solids and transported with them. Many other researchers, including Soller et al., found similar results in their studies. In 2005, the City of San Jose discovered that the "first flush phenomenon" did not occur consistently for total metals, dissolved metals, or anions. Table 2 shows that lead first flush occurred in 93% of the events, with 85% and 8% of them fitting into the moderate and weak first flush categories, respectively. In addition, Shamseldin et al. in Auckland (2011) explained that 54% of the total number of events can be classified as having moderate or weak first flush on Particulate Lead (Pb). According to Figure 4, first flush coefficient b values range from 0.60 to 1.12. In December 2018, the maximum value of parameter b in all events was 1.12, indicating a weak dilution effect. Chow et al. (2011) discovered stronger first flush effects for suspended solids, chemical oxygen demand and a weak first flush for $NO_3$-N. Based on Table 2, the average ranking of first flush strength among the pollutants was CO > $NO_3$-N > TP > Pb > TSS. Nutrients appeared to have a moderate first flush effect.

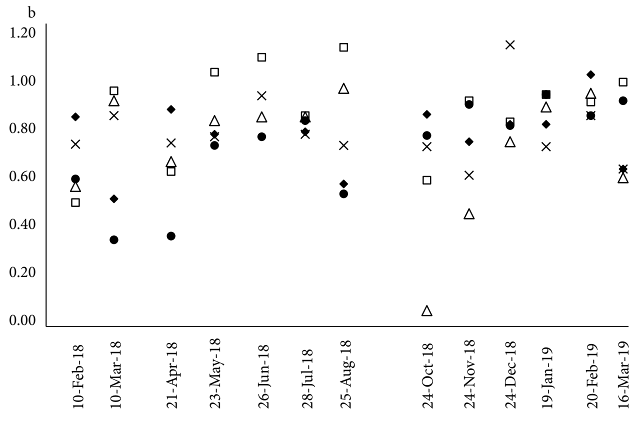


Figure 4. The calculation results of b coefficient

Table 2. The first flush coefficient values for different pollutants

| Pollutant | Range of b | Mean | Percentage of first flush Occurrence (%) |
|---|---|---|---|
| COD | 0.34–0.92 | 0.71 | 100 |
| TSS | 0.49–1.11 | 0.86 | 76 |
| $NO_3$-N | 0.06–0.94 | 0.71 | 100 |
| TP | 0.50–1.00 | 0.76 | 93 |
| Pb | 0.60–1.12 | 0.77 | 93 |

### 2.3. EMCs of water quality parameters

Figure 5 depicts the mean, median, and EMCs for the pollutants studied in this study. The maximum value for some values was startlingly high; for example, TSS had a maximum value of 682 mg/L. The range of EMCs varies greatly between storm events, particularly for TSS and COD. The average EMC for each constituent is represented by site mean concentrations (SMCs). The SMC for TSS is 219 mg/L, COD is 205 mg/L, $NO_3$-N is 20.6 mg/L, Total P is 1.12 mg/L, Pb is 0.25 mg/L and Soluble P is 1.91 mg/L. TSS and COD mean concentrations were higher than other pollutants in most rainfall events, as shown in Figure 5; hence, they were thought to be the main pollutants in the Rasht catchment's runoff. TSS and COD levels were highest in August 2018, at 682 and 590 mg/L, respectively. The high concentration of TSS in runoff increased the sediment load and turbidity of the river. According to EPA, the amount of COD, which is allowed for surface runoff is about 60 mg/L and about 40 mg/L for TSS; the point is that the amount of water dissolved in

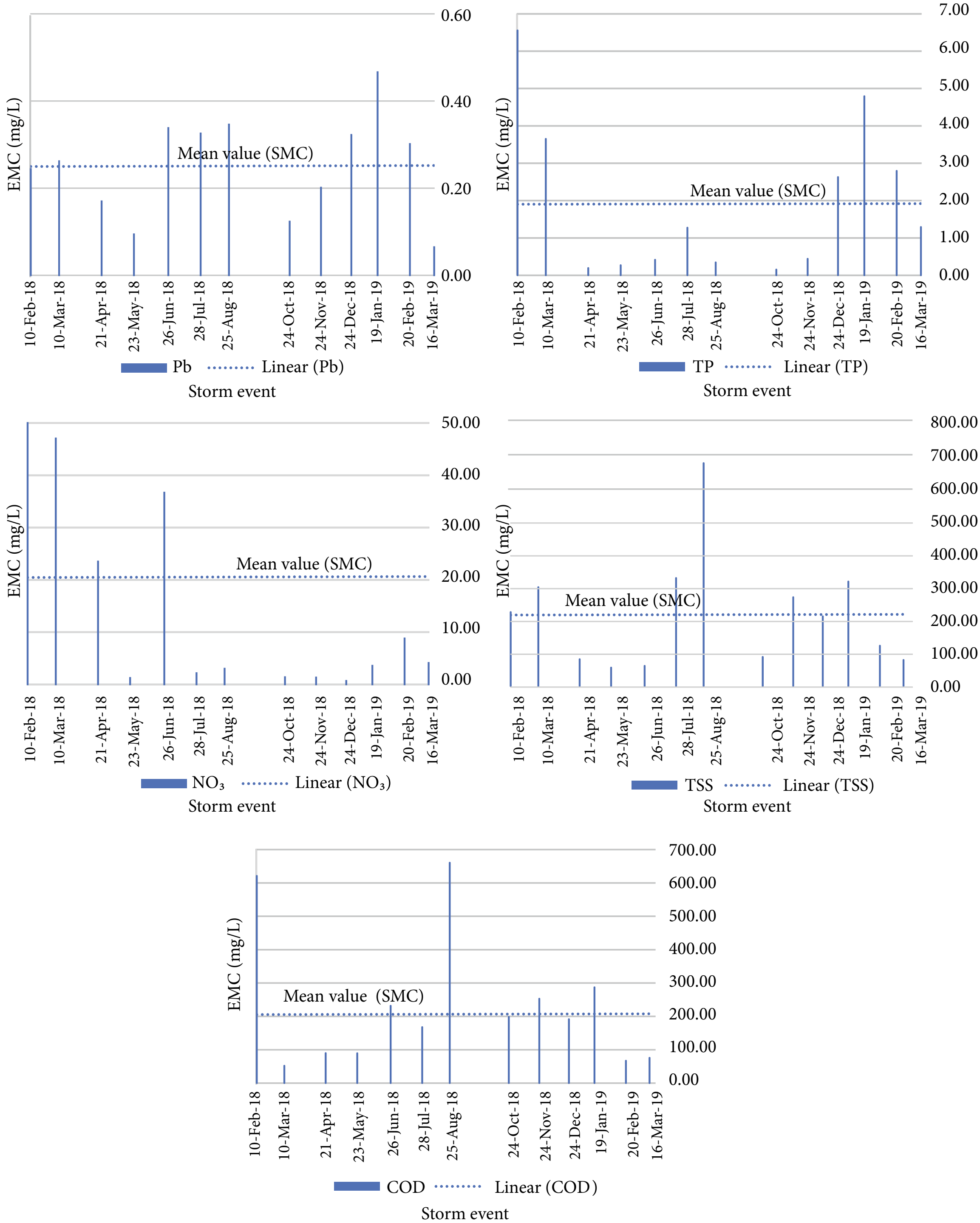


Figure 5. EMC (mg/L) of pollutants for each event

oxygen diffuses, photosynthesis decreases and the aquatic life is endangered (de Jesús-Crespo et al., 2016). Figure 5 shows that the mean COD and TSS concentrations are significantly different from their standard values in all events except May and April 2018 and March 2019. The standard amount of total phosphorus is 6 mg/L. In this study, TP levels were found to be excessively high during the February 2018 event. SMC values are higher or lower in some pollutants at the current site than in other cities (Table 3), but Malaysian researchers Chow et al. (2011) found lower SMC in all parameters except TSS; it is most likely due to higher rainfall (2–86 mm) and higher runoff than in our study, which can dilute pollutants. Brezonik and Stadelmann (2002) discovered larger EMCs in a smaller suburban residential catchment than larger ones in Minnesota, USA. He attributed this to a large basin's ability to re-sediment or a longer retention time for pollutants in depressions. Lee et al. (2002) reported the highest SMC values in Chong Joo, Korea. However, because only two events were studied, their findings may be skewed. The SMC for nitrate and lead in this study was significantly higher than in other cities in Table 3, which could be attributed to poor landfill management and a leachate leak upstream of the sampling site.

Table 3. Comparison of site mean concentrations (SMC, mg/L)

| Lead | Total P | $NO_3$-N | COD | BOD | TSS | Studies |
|---|---|---|---|---|---|---|
| – | 0.32 | 0.3 | 116 | 23 | 56 | Baird et al. (1996) Texas, USA |
| – | 0.31 | – | – | 2.6 | 37 | McConnell et al. (1999) Florida, USA |
| – | 1.92 | – | 509 | – | 275 | Lee et al. (2002) ChongJu, Korea |
| – | – | 2.8 | 487 | 135 | 195 | Nazahiyah (2005) Skudai, Malaysia |
| – | 0.45 | – | 75 | – | 210 | McLeod et al. (2006) Saskatoon, Canada |
| – | 1.12 | 1.5 | 192 | 74 | 261 | Chow et al. (2011) Skudai, Malaysia |
| 0.25 | 1.91 | 20.6 | 205 | – | 219 | This study |

### 2.4. Results of correlation analysis

Correlation analysis between the data determines the potential relationship between each of their various groups. Table 4 shows the results of the correlation test of the studied parameters with hydrological parameters (rainfall depth (Rd) and mean flow (Q mean).

Table 4 shows that the TP and TSS parameters had the highest correlation (0.628), which was significant at the 0.05 level. In other words, the changes in these two parameters are interdependent, and TP and Pb have a correlation coefficient of 0.601 at the level of 0.05. Furthermore, COD levels had a high and negative correlation with flow discharge, and as average flow discharge increased, the amount of COD decreased dramatically. However, there was no significant relationship between mean flow and TSS loading. In Alberta, He et al. (2010) demonstrated that TSS loading is primarily regulated by flow rate even in the early stages of a storm.

Table 4. Results of correlation analysis

| | TSS | COD | TP | $NO_3$-N | Pb | Qmean |
|---|---|---|---|---|---|---|
| TSS | 1.000 | | | | | |
| COD | –0.246 | 1.000 | | | | |
| TP | 0.628 | 0.337 | 1.000 | | | |
| $NO_3$-N | 0.455 | 0.119 | 0.355 | 1.000 | | |
| Pb | –0.400 | 0.483 | 0.601 | 0.303 | 1.000 | |
| Rd | 0.255 | –0.019 | 0.000 | –0.365 | –0.210 | |
| Qmean | 0.337 | –0.683 | 0.191 | 0.183 | 0.074 | 1.000 |

The Meteorological parameters used to determine the effect on first flush strength are storm duration (SDur), mean rainfall intensity (I). A multi-stage linear regression technique has been used for this purpose. Table 5 shows the summary result of the regression analysis.

The moderate negative correlation between (I) and b values indicates that a bigger (I) would result in a smaller b value or a stronger first flush. Similar results were reported, for example, by Pearson et al. (1986), Gupta and Saul (1996).

The first flush load of TSS, COD, $NO_3$-N, TP was shown in Table 5 to correlate well with rainfall intensity and storm duration, but no correlation was found between the first flush of Pb and storm variables.

Table 5. Correlation coefficients between first flush load of pollutants (b value) and storm duration (SDur), mean rainfall intensity (I)

| Meteorological variable | | |
|---|---|---|
| parameter | SDur | I |
| TSS | $-0.51^a$ | $-0.53^b$ |
| COD | $-0.65^a$ | $-0.66^a$ |
| TP | $-0.47^b$ | $-0.49^a$ |
| $NO_3$-N | $-0.55^a$ | $-0.59^b$ |
| Pb | | |

*Note:* [a] Significant at alpha 0.01. [b] Significant at alpha 0.05.

### 2.5. Determining the volume of primary runoff and dimensions of storm tank

We discovered that the first 30% of the rainwater runoff volume was capable of transporting 50% of the $NO_3$-N in this catchment (Table 6). The incidence of the first flush was highest in nitrate and COD, followed by TP, Pb, and TSS, which was consistent with the findings of Zeng et al. (2019) in Guangzhou. Table 6 shows that the average runoff volume for the transfer of 50% of pollutants ranges from 29 to 41%. To remove 50% of total nitrate and COD, approximately 30% of the first runoff volume was required in this urban catchment, lead and TP, approximately 36%, and TSS, approximately 40%. Previously, Soller et al. (2005) discovered a weak first flush for total metals and dissolved metals in the City of San Jose. For the study catchment, the initial runoff volume required to remove 50% of the pollutant mass was 35% on average. Bertrand-Krajewski et al. (1998) reached the same conclusion in their research, claiming that by controlling 38% of runoff, 50% of pollutants can be removed. The criterion of removing 80% of pollutants from storm events was also investigated in this study. In general, the amount of runoff required to transport 80% of the pollutant mass was 63% (Table 6). Chow and Yusop (2014) in Johor, Malaysia found, in order to transport 50 and 80% of the total pollutant mass, the corresponding runoff volumes required are 37 and 67 % for the tropical catchment. Therefore, it appears that in humid urban areas like Rasht, controlling one-third of the runoff volume can remove half of the pollutants, and controlling two-thirds of the runoff volume can reduce 80% of the pollutants and less runoff is required to transport the similar amount of pollutant loadings in humid urban regions. This data can be used to design runoff purification equipment. In storm events, the average cumulative volume of runoff is 1,200 cubic meters. Therefore, the design runoff volume at this site with a coefficient of 35% to control 50% of pollution (as specified in the "previous assessment") is 420 cubic meters. Researchers have previously argued that if the first flush phenomenon and influential variables are carefully defined, the costs of designing and constructing treatment systems to treat the more polluted part of the runoff will be reduced because most of the remaining runoff can be transferred to receiving waters without treatment or preliminary treatment (Bach et al., 2010; Kang et al., 2008; Lee et al., 2002). Figure 6 depicts a schematic of the storm tank (25 m long, 8 m wide, and a mean depth of 2 m) used to treat the first flush runoff.

Table 6. Volume of runoff for transporting 50 and 80% of the total mass of contaminant

| Pollutant | 50% | 80% |
|---|---|---|
| COD | 32.58 | 56.25 |
| TSS | 40.50 | 69.84 |
| $NO_3$-N | 29.3 | 53.61 |
| TP | 37.92 | 68.69 |
| Pb | 36.69 | 66.15 |

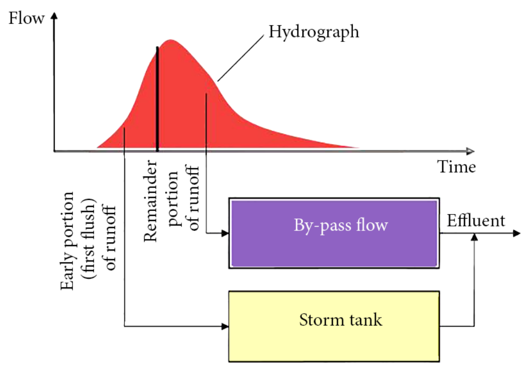


Figure 6. Schematic illustration of storm tank

## Conclusions and summary

Based on the analysis of runoff quantity, the findings of this study about the first flush concept of storm phenomena allow managers and executives to make better pollution control decisions.

In general, the following conclusions can be drawn:

1. TSS and COD concentrations were highest in our study area based on the EMC at each point.
2. The first flush was observed in all pollutants, but it was more common in COD, TP, and $NO_3$-N and less frequent in Pb and TSS.
3. Accordingly, after preventing environmental pollution in Rasht, the most important way to reduce the environmental impacts of runoff is to purify the first 30–40% of the runoff from the catchments that flow into the Zarjoob River.
4. Controlling approximately one-third of the initial runoff volume could reduce approximately half of the contaminants transferred from catchments in these humid coastal areas.
5. A suitable solution for pollution control is the construction of a canal along the river to collect and transport the critical portion of runoff to the treatment plant or storm tank.
6. The b values ratios (except for Pb) shows an inverse relationship against the storm variables.

## Conflict of interest

The authors declare no conflict of interest.

## Data availability statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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## Notations

*Abbreviations*

EMC – event meant concentration;
SMC – site meant concentration.