An Investigation of Stormwater Quality Variation within an Industry Sector Using the Self-Reported Data Collected under the Stormwater Monitoring Program

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Abstract: Storm runoff pollutants are among the major sources of surface water impairments, globally. Despite several monitoring programs and guidance on stormwater management practices, there are many streams still impaired by urban runoff. This study evaluates an industry sector’s pollutant discharge characteristics using the self-reported data collected under Tennessee Multi Sector Permit program. The stormwater pollutant discharge characteristics were analyzed from 2014 to 2018 for an industry sector involving twelve facilities in West Tennessee, USA. The data analysis revealed the presence of both organic and inorganic contaminants in stormwater samples collected at all twelve industrial facilities, with the most common metals being magnesium, copper, and aluminum. The principal component analysis (PCA) was applied to better understand the correlation between water quality parameters, their origins, and seasonal variations. Furthermore, the water quality indexes (WQIs) were calculated to evaluate the stormwater quality variations among studied facilities and seasons. The results demonstrated slight variations in stormwater WQIs among the studied facilities ranging from “Bad” to “Medium” quality. The lowest seasonal average WQI was found for spring compared to the other seasons. Certain limitations associated with the self-reported nature of data were identified to inform the decision makers regarding the required future changes.

Keywords: stormwater; industrial facilities; BMPs; water quality; runoff; self-reported data

1. Introduction

Storm runoff pollutants are among the major sources of surface water impairments, globally [1–3]. However, there are several types of guidance on stormwater best management practices (BMPs) and pollution prevention plans (SWPPPs), but there are many streams still impaired by runoff contaminants [4–6]. Storm runoff from urban areas, roads, agricultural and constructional sites, atmospheric depositions, and acid drainage from abandoned mines are considered as the major sources of pollution threatening the surface water quality [6]. Deteriorated stormwater quality is linked to the human health due to the acute and chronic illnesses from exposure through drinking water, seafood, and contact recreation [7–9]. To protect and enhance the quality of ground and surface water resources as a top priority for both public and governments, it is essential to understand the pollutant discharge by different sources. Stormwater pollutants originate from a variety of sources in the urban environment including residential and commercial landscapes, construction sites, roads and highways, parking lots, and industrial sites [10,11].

The proportion of pollutants in urban stormwater that originated from industrial activities has been reported to be significant compared to the other sources [12]. Manufacturing, shipping,
and storage operations that are exposed to the rain release several pollutants such as heavy metals, nitrate, and organic materials into the stormwater. Despite the extensive research in stormwater quality at urban areas like roads, residential or construction sites [8–10], industrial facilities’ runoff constituents, pollutants loading, and their impacts on receiving waters are less understood. Few studies conducted in this area reported the large numbers of organic and inorganic constituents’ presence in the industrial facilities’ stormwater [13,14]. Concentration of certain pollutants like heavy metals in industrial facilities’ storm runoff has been found to be significantly greater than that from other land uses. Additionally, human health risks associated with stormwater from the industrial area is considerably greater than a residential or commercial area [15].

Several federal and state stormwater monitoring programs are implemented to encourage or enforce many types of industrial facilities taking steps toward protecting their stormwater quality [16,17]. These monitoring programs mainly aimed to identify the high risk dischargers and eventually reduce the stormwater pollution. However, due to the requirement and design of these monitoring programs, the precise data were not generated generally to satisfy the decision-making needs [18]. As demonstrated by Clean Water Act 303(d) section, numerous streams and surface waters in Tennessee have been listed as impaired by runoff contaminants [19]. As a part of the Tennessee Multi Sector Permit (TMSP), qualified industrial facilities located in Tennessee are required to develop the site-specific Stormwater Pollution Prevention Plan (SWPPP) to maintain the stormwater quality. The expected stormwater pollution sources are identified in SWPPP and the planned strategies to minimize the pollutant release to stormwater are described. As a part of the National Pollutant Discharge Elimination System (NPDES), TN Multi-Sector Stormwater Permit (TMSP), each facility is required to collect the stormwater run-off samples, conduct the laboratory analysis to quantify the certain constituents in stormwater, and report the analytical results to the Tennessee Department of Environment and Conservation (TDEC), annually. Table 1 demonstrates the benchmark’s stormwater quality levels listed in TMSP, in addition to the associated USEPA drinking water and acute aquatic life limits for both fresh and saltwater. The purpose of this annual monitoring is both to assist the regulatory agency in understanding the effectiveness of management practices and evaluate aggregate pollutant loading by an individual facility to the watershed, and to help the facility operators understand their BMPs’ effectiveness. However, limited collected data along with a lack of understanding of the long-term stormwater quality variations obscure the understanding of the BMPs’ performance. Evaluation of regulations that impact thousands of industries would not be possible without understanding industrial facilities’ stormwater pollutants’ loadings to the watersheds. This study aimed to better understand an industry sector’s pollutant discharge characteristics using the self-reported data collected under TMSP program. Specific objectives were to (1) investigate the stormwater quality characteristics in twelve industrial facilities within an industry sector, (2) examine the seasonal and temporal variations of stormwater quality within this industry sector, and (3) identify the limitations associated with the self-reported nature of stormwater quality to inform the decision makers and monitoring agencies regarding the required future changes.

### Table 1. Tennessee Department of Environment and Conservation (TDEC) Tennessee Multi Sector Permit (TMSP) stormwater quality benchmark levels in 2018 and USEPA limits for drinking water and aquatic life (1 SMCL: Secondary Maximum Contaminant Level; 2 NL: No Limit; 3 USEPA Action Limit, 4 NO$_2^-$ as N; 5 NO$_3^-$ as N).

| Parameter | TDEC | Drinking Water | Aquatic (Acute Levels) |
|-----------|------|----------------|-----------------------|
|           |      |                | Fresh | Salt |
| Al (µg/L) | 750  | 50 to 500$^1$  | NL$^2$ | NL   |
| Cd (µg/L) | 16   | 5$^3$          | 2     | 33   |
| Cyanide   | 64   | 200$^3$        | 22    | 1    |
| Cu (µg/L) | 18   | 1000$^1$       | NL    | 5    |
| Pb (µg/L) | 150  | 15$^3$         | 82    | 140  |
| Ag (µg/L) | 32   | 100$^1$        | 3     | 2    |
2. Methods

2.1. Data Sources

The industrial facilities under TMSP permit are required to collect stormwater samples and conduct laboratory analysis to quantify certain constituents in stormwater, and report to the monitoring agency, annually. In this study, the self-reported stormwater quality for 12 industrial facilities within an industry sector with active coverage under TMSP during the period of 2014–2018 was analyzed. This industry sector’s activities mainly consist of storage of utility related equipment as summarized in Table 2. The stormwater quality for this industrial sector was selected to be monitored quarterly instead of the usual annual monitoring requirement. The stormwater management team at the targeted industrial facilities collected the grab stormwater samples at designated outfalls at different drainage areas through the facilities. Further information regarding the location of outfall and potential pollution sources in each drainage area is described in the facilities’ SWPPPs. The TMSP requires collection of the grab samples within the first 30 min of discharge at the outfall. Additionally, if more than one sample is collected and analyzed, the average concentration of that parameter should be reported. The water samples were mostly examined for pH, aluminum (Al), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg) and zinc (Zn), chemical oxygen demand (COD), and biochemical oxygen demand (BOD₅) concentrations, ammonia (NH₄⁺), total suspended solids (TSS), nitrate and nitrite nitrogen (NO₂⁻ + NO₃⁻), and oil and grease concentrations. Additional information about these industrial sites was sought through other compliance documents such as Notices of Intent (NOI), Inspection Reports, SWPPPs, and through TDEC-Division of Water Resources, Memphis Environmental Field Office. Occasionally some stormwater quality data were not reported to the regulatory agency due to the dry seasons and lack of enough rain to collect the stormwater samples. The list of available self-reported data for the studied industrial facilities is shown in the supplementary materials (Table S1). Accounting for all 12 facilities, in total, 9363 data were analyzed in this study, but in total, no data were reported for 34% of quarters from 2014 to 2018. The greatest number of missing data belonged to 2015. Calculating the number of outfalls per industrial area revealed the lowest number of outfalls in facilities A9 (1 outfall/100,000 m²), and the greatest number of outfalls was present in facility A8 and A10 (51 outfall/100,000 m²). It should be noted that the reported area is only the area of property associated with the industrial activities and does not include the recreation area, office buildings, landscaping, employee parking, etc. This industry sector has been regulated under sector AD of the
TMSP, that requires monitoring for pH, BOD$_5$, COD, TSS, oil and grease, and ammonia concentrations in stormwater.

**Table 2.** The list of studied industrial facilities, their industrial area, and activities exposed to stormwater.

| Site Label | Area (m$^2$) | Activity                        |
|------------|--------------|---------------------------------|
| A1         | 8903         | Storage/Distribution Vehicle Storage Outside Waste Disposal |
| A2         | 2833         | Storage/Distribution Outside Waste Disposal |
| A3         | 2428         | Storage/Distribution Outside Waste Disposal |
| A4         | 70,415       | Storage/Distribution Outside Waste Disposal |
| A5         | 118,978      | Storage/Distribution Outside Waste Disposal |
| A6         | 6475         | Storage/Distribution Vehicle Storage |
| A7         | 101,576      | Outside Waste Disposal |
| A8         | 9712         | Outside Waste Disposal |
| A9         | 441,512      | Outside Waste Disposal |
| A10        | 9712         | Outside Waste Disposal |
| A11        | 214,888      | Vehicle Maintenance |
| A12        | 47,348       | Vehicle Maintenance |

2.2. Statistical Analysis

The statistical analysis was conducted using IBM SPSS version 26 software. The Normal distribution of stormwater quality data has been evaluated using Kolmogorov–Smirnov test [20]. Due to non-normal distribution, the non-parametric test of Mood’s Median was applied to examine the significant variations of stormwater quality data [20,21]. The non-parametric Kruskal Wallis test with multiple comparisons was followed if only a significant difference between the median of tested variables was assessed using the Mood’s Median test [22]. The difference was considered significant if $p$-value < 0.05.

The principal component analysis (PCA) was implemented to identify the stormwater pollution sources and correlation between stormwater quality parameters. Furthermore, PCA was used to assess seasonal correlations of stormwater quality parameters. For this purpose, the data were divided into four different temporal databases of winter (quarter 1), spring (quarter 2), summer (quarter 3), and fall (quarter 4). Due to a large number of missing water quality parameters at facilities A1, A2, A3, A6, and A9, these facilities were not considered for the PCA analysis. The PCA was only conducted for facilities A4, A5, A7, A8, A10, A11, and A12. The water quality parameters including Al, NH$_4^+$, Cu, Fe, Pb, Zn, COD, BOD$_5$, TSS, pH, NO$_2^-$ + NO$_3^-$, oil and grease concentrations were utilized for the PCA analysis. As data were not normally distributed ($p$-value < 0.05), the lognormal transformation was applied to normalize the data prior to the PCA analysis. This transformation advantageously scaled the data to the range of 0 to 1. In PCA, the number of extracted components is equal to the number of input variables. There were 13 water quality characteristics, so 13 components were extracted, however, only the components with large total variance were considered as the most significant. Kaiser’s criteria was used to identify the number of significant principal components [23].

2.3. Water Quality Index (WQI) Calculation

The water quality index (WQI) was utilized to account for a large number of water quality parameters into the simplest form in terms of water quality classification [24,25]. The WQI that was defined by Pesce and Wunderlin (2000), Reference [26] and calculated using Equation (1) was used in this study. The $C_i$ is the value assigned to the parameter $i$ after normalization, $n$ is the number of water quality parameters, and $P_i$ is the relative weight associated with $i$th water quality parameter. The relative weight ($P_i$) varies from 1 to 4, where the most impactful water quality parameter has the relative weight of 4. The relative weight of water quality parameters was adapted from the
literature [26]. The water quality index was graded as excellent (91–100), good (71–90), medium (51–70), bad (26–50), and very bad (0–25) [24]. The average WQIs were calculated across different facilities and during different seasons using Equation (1).

\[
WQI_{obj} = \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i}
\]

(1)

3. Results and Discussion

3.1. The Industry Sector’s Stormwater Quality Evaluation

Analyzing the self-reported data revealed that both organic and inorganic contaminants were released to the stormwater at studied industrial facilities. The percentage of collected data exceeded the state regulatory agency benchmark levels is shown in Table 3. The variation of the median concentrations of BOD$_5$, COD, NH$_4^+$, NO$_2^-$ + NO$_3^-$, oil and grease and TSS across 12 different facilities within the studied industry sector is shown in Figure 1. These data revealed that oil and grease concentrations were mostly below the benchmark level (15 mg/L), despite the fact that some of these facilities were utilized for the vehicle storage and maintenance activities (Table 2). The median pH value at studied industrial facilities varied between 7.8 and 8.2. The individual stormwater samples’ pH levels were generally within the USEPA recommended pH values of 6.5 to 9.0 for fresh water, except for some elevated pHs (>9.0) at facilities A4, A5, and A8. The median TSS concentration showed a very wide range of variations from 40 to 334 mg/L. The unvegetated and unpaved areas are known as the main sources contributing to the TSS in stormwater [27]. Furthermore, reviewing the recent inspection reports at facility A4 revealed the contribution of fill material storage sites to silt/sand release to the stormwater. The median NH$_4^+$ concentration varied between 0.2 and 0.6 mg/L, which might be released to the stormwater by decaying the nitrogen-containing organic matters. The median NO$_3^-$ + NO$_2^-$ concentration varied from 0.4 to 1.3 mg/L as N. The excessive NO$_3^-$ + NO$_2^-$ presence in freshwater could negatively impact the aquatic organisms [28]. The organic contaminant loadings in stormwater at studied industrial facilities were evaluated through COD and BOD$_5$ concentrations. The median BOD$_5$ concentrations varied between 8.0 and 20.0 mg/L, and median COD concentration varied between 55.0 and 199.0 mg/L. As demonstrated in Table 3, a greater number of stormwater samples exceeded the COD concentration benchmark level (120 mg/L) compared to the BOD$_5$ concentrations benchmark level (30 mg/L). The strong significant correlation ($r = 0.83$) between median COD and BOD$_5$ concentrations indicates that the major part of organic components was biodegradable. The correlation matrix for stormwater quality parameters is shown in Supplementary materials (Table S2).

Table 3. Percentage of data that exceeded the TDEC benchmark stormwater quality levels (NR: not reported).

| Water Quality | Facilities | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | A12 |
|---------------|-----------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| Metals        | Al        | NR | NR | NR | 81 | 87 | 64 | 64 | 55 | 86 | 86  | 93  |     |
|               | Cu        | NR | 46 | NR | 70 | 52 | NR | 40 | 61 | NR | 7   | 77  | 90  |
|               | Fe        | NR | NR | 27 | 50 | NR | 26 | 0  | NR | 45 | 44  | NR  |     |
|               | Pb        | NR | NR | 5  | 6  | NR | NR | NR | NR | 9  | NR  | NR  |     |
|               | Zn        | NR | 25 | 25 | 23 | NR | NR | 49 | NR | 30 | 33  |     |     |
| Magnesium     | Mg        | 100| 100| 100| 100| 100| 100| 100| 100| 100| 100 | 100 | 100 |
| Organics      | COD       | 31 | 46 | 33 | 65 | 48 | 45 | 41 | 24 | 26 | 36  | 63  | 57  |
|               | BOD$_5$   | 0  | 38 | 8  | 32 | 28 | 9  | 18 | 7  | 6  | 10  | 34  | 31  |
|               | Oil and   | 0  | 8  | 0  | 4  | 5  | 0  | 2  | 4  | 2  | 2   | 3   | 6   |
|               | Grease    |     |    |    |    |    |    |    |    |    |     |     |     |
| Others        | TSS       | 31 | 31 | 33 | 64 | 59 | 45 | 40 | 28 | 36 | 60  | 72  | 62  |
|               | pH        | 8  | 8  | 8  | 15 | 19 | 9  | 2  | 14 | 7  | 10  | 11  | 7   |
|               | NH$_4^+$  | 0  | 0  | 0  | 0  | 0  | 0  | 2  | 0  | 0  | 0   | 0   | 0   |
The variation of metals concentration within the studied industrial facilities is shown in Table 4. The total Mg, Al, and Cu mostly exceeded the benchmark levels (64 µg/L, 750 µg/L, 18 µg/L). The greater levels of Mg and Al in stormwater samples might be associated with their higher abundance in the silty soils which is common in this region [29,30]. Figure 2C shows the erosion around the facility (A3) fence, which may have contributed to the TSS presence in stormwater samples. A low percentage of stormwater samples collected at facilities A4, A5, A10 exceeded the benchmark Pb level (150 µg/L) although, Pb was not monitored at the other facilities. The equipment related to metallic utility like transformers (Figure 2A), pipes (Figure 2B), and rusted metal scrape (Figure 2D) may also contributed to the metal release to stormwater. This finding is in agreement with the literature that reported metals as the major contaminant released by industrial sources to the storm runoff [18]. The self-reported nature of data may result in insufficient quality controls which makes identification of the meaningful trends challenging [12]. Our analysis suggested that TSS should be considered as the priority in developing future stormwater pollution prevention plans for this industry sector, as it mostly exceeded the recommended benchmark levels. Furthermore, the metals such as Al and Mg which are associated with silt/sand presence in stormwater frequently exceeded the benchmark levels.
Table 4. The statistical description of metals concentration in stormwater samples collected at studied industrial facilities (STD: standard deviation, NR: not reported).

| Facility | Conc. (mg/L) | Median | STD | 95tile |
|----------|--------------|--------|-----|--------|
| A1       | Mg           | 1.66   | 2.24| 5.06   |
| A2       | 1.35         | 4.10   | 11.88| 22.00  |
| A3       | 1.09         | 9.53   | 20.00| 37.5   |
| A4       | 4.80         | 18.9   | 35.50| 79.4   |
| A5       | 4.87         | 29.77  | 50.50| 73.40  |
| A6       | 1.44         | 7.05   | 13.06| 19.75  |
| A7       | 2.31         | 4.39   | 7.34 | 10.59  |
| A8       | 0.80         | 3.10   | 1.17 | 2.20   |
| A9       | 2.45         | 40.78  | 51.20| 49.64  |
| A10      | 6.93         | 19.75  | 49.64| 25.98  |
| A11      | 3.44         | 10.59  | 49.64| 25.98  |
| A12      | 1.67         | 2.20   | 4.05 |        |

| Facilit | Median | 95tile |
|---------|--------|--------|
| A1      | NR     | NR     |
| A2      | NR     | NR     |
| A3      | NR     | 3.22   |
| A4      | NR     | 11.11  |
| A5      | NR     | 2.19   |
| A6      | NR     | 4.30   |
| A7      | NR     | 1.51   |
| A8      | NR     | 7.34   |
| A9      | NR     | 13.06  |
| A10     | NR     | 3.89   |
| A11     | NR     | 51.20  |
| A12     | NR     | 49.64  |

| Parameter (mg/L) | n | Mean | STD | CV% | Median |
|------------------|---|------|-----|-----|--------|
| Al               | 646| 4.7  | 8.0 | 168 | 2.4    |
| Cu               | 585| 0.1  | 0.3 | 463 | 0.03   |
| Fe               | 427| 6.8  | 10.8| 158 | 3.2    |
| Zn               | 134| 0.21 | 0.23| 0.18| 0.39   |
| Pb               | 136| 0.15 | 0.16| 0.47| 0.53   |
| Fe               | 138| 1.95 | 1.25| 1.25| 1.70   |
| Fe               | 134| 2.71 | 4.96| 2.18| 0.10   |
| Fe               | 136| 4.82 | 18.36| 6.38 | 0.04   |

The statistical description of self-reported stormwater quality data for the studied industry sector is shown in Table 5. A comparison has been made between the stormwater quality at the studied industry sector and the data reported in the literature for several other industrial facilities.
commercial and residential sites (supplementary materials Table S3). No record was found describing the stormwater quality for residential or commercial areas in the studied region thus, we compared our data with the other published literature. As demonstrated in Table S3, the Al, Pb, TSS, and NO$_3^-$ + NO$_2^-$ concentrations were greater in the studied industry sector than values reported by Lau et al. (2001) for residential and commercial sites [31]. The stormwater quality investigation for the industrial facilities is limited in the literature and the type of industrial activities, and water sampling procedures were different which made the comparison challenging [19,32–34]. The research investigated the stormwater quality at an industrial log yard during eight run-off events that resulted in greater levels of heavy metals, TSS, and COD concentrations than our investigation [33]. However, sampling after eight events might be too small to capture the variation of pollutant release to the stormwater by sources present in the industry sector. The study conducted by Line et al. (1997), examined the first flush runoff quality at 20 industrial sites and found Zn and Cu as the most common metals found at these sites [13]. Although, our analysis revealed Mg, Cu, and Al as the most common metals present in stormwater at the 12 studied industrial facilities. It should be noted that rather than different industrial activities, their data acquisition was more controlled than self-reported data which are utilized in our study. These findings underscore the critical impacts of land uses and data acquisition practices on stormwater quality evaluations, which should be considered in the future urban planning and development of stormwater monitoring programs.

Table 5. The statistical description of stormwater quality parameters within the studied industry sector.

| Parameter (mg/L) | n  | Mean  | STDV  | CV%  | Median | 95th Percentile |
|-----------------|----|-------|-------|------|--------|-----------------|
| Al              | 646| 4.7   | 8.0   | 168  | 2.4    | 15.7            |
| Cu              | 585| 0.1   | 0.3   | 463  | 0.03   | 0.2             |
| Fe              | 427| 6.8   | 10.8  | 158  | 3.2    | 23.6            |
| Pb              | 249| 0.1   | 0.3   | 428  | 0.0    | 0.2             |
| Zn              | 446| 0.4   | 0.6   | 131  | 0.3    | 1.5             |
| Mg              | 784| 8.8   | 20.3  | 231  | 3.1    | 33.8            |
| COD             | 783| 208.8 | 332.2 | 159  | 118    | 600.0           |
| BOD$_5$         | 767| 23.2  | 34.1  | 147  | 12.0   | 60.0            |
| Oil and Grease  | 779| 5.0   | 16.9  | 338  | 1.8    | 11.6            |
| TSS             | 779| 428.2 | 969.2 | 226  | 191    | 1415            |
| pH              | 761| 7.8   | 11.1  | 14   | 8.0    | 9.2             |
| NH$_4^+$        | 788| 0.4   | 0.5   | 116  | 0.3    | 1.1             |
| NO$_2^-$ + NO$_3^-$ | 770| 1.7   | 10.0  | 576  | 0.6    | 2.5             |

The metals released to the storm runoff at the studied facilities may not only be originated from the stored scrape metals or erosion materials (Figure 2C,D), but they also could be released from building materials, as previously suggested by Davis et al. (2001) [31]. In facility A11, the drainage area included the parking lots, storage area for drums, old pipes, wooden poles, and metal spools, as well as a paved driveway and warehouse. The main contaminants at this facility were Mg and Al which possibly were released due to the silt and sand release to the stormwater. The median concentration of Mg at this facility was the greatest among all facilities and it was 111 times greater than the benchmark level (64 µg/L). The median concentration of Al at this facility (3.0 mg/L) was four and 15 times greater than the TDEC benchmark level and USEPA drinking limit, respectively. The drainage area at facility A4 included the storage area for the equipment, treated wood, drums, metal scrap, and pipes. In addition, the recent inspection report of facility A4 indicated the silt and sand release from the fill material storage area. In this facility, Mg and Al median concentrations were 75 and three times greater than TDEC benchmark levels, respectively. The statistical analysis revealed significant differences among all organic and inorganic contaminants found in stormwater at these 12 industrial sites ($p$-value < 0.05) but not the Fe (Supplementary materials Tables S4 and S5). The greatest median
Pb and Zn levels (0.04 mg/L and 0.39 mg/L) were found in facility A10, however, the greatest median Fe and Al levels (5.0 mg/L and 3.8 mg/L) were identified in facility A5. Though all water quality data were not available for all facilities, the greatest median Mg and Cu levels (7.1 mg/L and 0.05 mg/L) belonged to facility A11 and A12. The high variation of metals concentration among studied facilities prevented identifying a specific trend in stormwater quality deterioration. It was noted by the State Regulatory Agency that the main activities at each facility were stagnant, however, ancillary activities, along with their associated pollutant sources, may have been changed daily. No record was found describing the types of ancillary activities, thus, it was challenging to identify the potential sources for the identified stormwater pollutants.

The variation of stormwater quality within the industrial facilities was investigated in terms of Water Quality Index (WQI). As demonstrated in Figure 3, the water quality within this industry sector varied from “Bad” to “Medium”. The greatest water quality within this industry sector was evaluated as “Medium” and belonged to facilities A1, A3, A6, A7, A8, and A9 (50 ≤ WQI ≤ 58). The stormwater quality at the rest of the studied facilities was evaluated as “Bad” (42 ≤ WQI ≤ 49). The WQI at facility A3 was significantly greater than WQI at facilities A5, A10, and A11 (p-value < 0.05). The lowest average WQI was found for facility A11 as 42. It should be noted that as the authors followed the literature, some of the water quality parameters like metals concentration (Pb, Cu, Fe, Zn, Al) were not considered in WQI calculation, however those may impact the variation among facilities [26]. This information could be utilized by the decision makers in the industry sector developing their priority list to modify and develop their future SWPPPs. To have a complete assessment of reasons behind the variation of stormwater quality, the detailed description of the type of industrial activities conducted at each site is required. However, the SWPPPs that contain more descriptions regarding the facility characteristics and activities resulting in stormwater contamination were only accessible by authors for facilities A3, A4, and A11.

![Figure 3](image.png)

**Figure 3.** The variation of stormwater water quality index (WQI) at studied industrial facilities.

### 3.2. Implementation the Principle Component Analysis (PCA) to Identify the Stormwater Pollution Sources

As demonstrated in the scree plot of components (Supplementary materials Figure S1), only three components were retained which had the Eigenvalues greater than one. The PC loadings were categorized as “strong”, “moderate”, and “weak” according to their absolute loading values of >0.75, 0.75–0.50, and <0.5, respectively [23]. The loadings of water quality variables on principal components are shown in Table 6. With the Kaiser normalization, these components explained 74% of the total variance. The first component (PC1), accounting for 50% of the total variance and was strongly loaded by several inorganic contaminants (Al, Cu, Fe, Pb, Mg, TSS, and Zn). This factor could be attributed...
to the contaminant release by storage of utility-related equipment and fill materials at the industrial facilities. The second component (PC2), accounting for 17% of the total variance and showed a strong positive loading of nitrogenous contaminants (NH$_4^+$, NO$_2^−$ + NO$_3^−$) and moderate loading with BOD$_5$ substances. This factor might be associated with biogenic pollution sources [23]. However, the third component (PC3), accounting only for 8% of the total variance, and similar to the other seasons, was largely impacted by NH$_4^+$, NO$_2^−$ + NO$_3^−$, and pH. This slight seasonal variability of stormwater quality could be due to environmental conditions like the number, duration, and intensity of precipitation events, the time between rainfalls, and the type of ancillary activities conducted at studied facilities [24,35].

### Table 6. The loading of water quality variables on principal components.

| Variables         | Components |
|-------------------|------------|
|                   | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 |
| Al                | 0.87| −0.28| −0.06| 0.16| −0.16| −0.08| −0.13| 0.06| 0.23| −0.08| −0.02| 0.12| −0.12|
| NH$_4^+$          | 0.23| 0.79| 0.04| 0.33| 0.03| −0.34| 0.34| 0.06| 0.09| 0.00| −0.06| −0.02| 0.00|
| BOD$_5$          | 0.59| 0.64| 0.10| −0.21| −0.14| −0.20| −0.20| −0.07| 0.01| 0.23| 0.18| 0.02| 0.00|
| COD              | 0.80| 0.36| 0.08| −0.13| −0.04| −0.16| −0.21| −0.12| −0.17| −0.24| −0.16| −0.08| 0.00|
| Cu               | 0.82| 0.02| −0.15| −0.04| 0.38| −0.03| −0.08| 0.35| −0.16| 0.08| −0.03| 0.07| 0.00|
| Fe               | 0.90| −0.28| −0.14| 0.13| −0.15| −0.05| −0.05| 0.02| 0.16| −0.03| −0.01| 0.06| 0.16|
| Pb               | 0.86| −0.26| −0.12| 0.02| 0.23| 0.06| −0.01| −0.05| 0.16| 0.11| −0.01| −0.28| −0.02|
| Mg               | 0.88| −0.11| −0.08| 0.11| −0.19| 0.08| 0.18| 0.07| −0.17| −0.18| 0.24| −0.07| −0.01|
| NO$_2^−$ + NO$_3^−$| 0.14| 0.77| −0.01| 0.41| 0.06| 0.44| −0.16| −0.03| 0.03| −0.02| 0.00| 0.02| 0.01|
| Oil and Grease   | 0.54| 0.22| 0.54| −0.52| −0.01| 0.22| 0.14| 0.11| 0.15| −0.06| −0.02| 0.02| 0.01|
| pH               | 0.08| −0.41| 0.78| 0.41| 0.16| −0.10| −0.08| −0.02| −0.06| 0.02| 0.05| 0.00| 0.01|
| TSS              | 0.82| −0.19| 0.08| 0.09| −0.35| 0.14| 0.14| −0.04| −0.18| 0.24| −0.16| 0.02| −0.02|
| Zn               | 0.83| −0.09| −0.10| −0.09| 0.37| 0.03| 0.16| −0.32| −0.03| −0.01| 0.03| 0.15| −0.01|
| Eigen value      | 6.44| 2.25| 1.00| 0.85| 0.59| 0.43| 0.35| 0.27| 0.26| 0.22| 0.15| 0.14| 0.04|
| % of Variance    | 49.57| 17.3| 7.67| 6.55| 4.56| 3.33| 2.71| 2.05| 1.98| 1.73| 1.19| 1.04| 0.32|
| Cumulative %     | 49.57| 66.87| 74.54| 81.09| 85.65| 88.98| 91.69| 93.74| 95.72| 97.46| 98.64| 99.68| 100|

#### 3.3. Seasonal Variation of Stormwater Quality at the Industrial Facilities

Considering the first two principal components, a general view of seasonal variation of stormwater quality parameters at studied industrial facilities was provided, as shown in Figure 4. The winter’s first principal component described 52% of the total variance, in which all water quality parameters were positively influential. Winter’s second principal component explained 19% of the total variance, in which NH$_4^+$, NO$_2^−$ + NO$_3^−$, and pH were the most influential. Other inorganics like Fe, Zn, and Al were negatively impacted. In spring, water pH was slightly and negatively influential on the first component which explained 45% of total variance. In summer, the first component described 50% of the total variance, and was largely impacted by both organic and inorganic contaminants present in stormwater. Summer’s second principal component which described 14% of the total variance was largely influenced by NH$_4^+$, NO$_2^−$ + NO$_3^−$, and pH, however, other water quality parameters were not that influential. Fall’s first component explains 54% of the total variance and revealed a similar pattern to winter as the majority of water quality parameters were influential. Its second component accounts for 12% of the total variance, and similar to the other seasons, was largely impacted by NH$_4^+$, NO$_2^−$ + NO$_3^−$, and pH. This slight seasonal variability of stormwater quality could be due to environmental conditions like the number, duration, and intensity of precipitation events, the time between rainfalls, and the type of ancillary activities conducted at studied facilities [24,35].
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The seasonal variation of WQI was significant within this industry sector ($p$-value < 0.05). As demonstrated in Supplementary materials (Figure S2), most of the facilities experienced a slightly lower stormwater quality in spring (average WQI: 45) compared to the other seasons (average WQI: 50–51). However, it should be noted that heavy metals concentrations were not considered in calculation of WQI due to the large number of missing data, while they impacted the water quality. Analyzing the seasonal data revealed the lowest median concentrations of oil and grease, TSS, Al, Fe, Pb, Cu and Mg in stormwater samples collected during the summer ($p$-value < 0.05). The highest concentrations of NH$_4^+$, BOD$_5$ and COD concentrations were found in samples collected during spring with the median values of 0.4 mg/L, 18.0 mg/L, and 199.0 mg/L, respectively, which resulted in the lowest WQI for this season. This results are in a good agreement with the literature that reported a lower stormwater quality in spring due to the largest range of total phosphorous, dissolved phosphorus, soluble reactive phosphorous, COD, total Kjeldahl nitrogen (TKN), and total NO$_2^−$ + NO$_3^−$[36]. Few studies conducted in the Europe and U.S. reported the seasonality of stormwater pollutant loadings. The research investigated road runoff quality in Germany and highlighted a significant seasonal increase in Cu, Zn, TSS, pH, and TOC concentration during the cold seasons compared to the warm seasons [37]. The higher levels of heavy metals were also reported in urban storm runoff during spring and winter compared to summer [38]. The number of dry days before the storm event is a critical factor impacting the contaminant accumulation on the surface [39]. Investigating the temporal changes of stormwater...
quality during the study period (2014 to 2018) revealed the lowest median concentrations of oil and grease, Mg and TSS in 2015 compared to the other years. However, other stormwater quality parameters varied during the years, and no specific trend was identified. Calculation of WQIs using the data reported by this industry sector over the years revealed a better water quality in 2016 (average WQI: 48), although it was not statistically different from other years (average WQI: 44 to 45). Rather than variation of type and extent of industrial activities, the alteration of rainfall pattern during the years may influence the stormwater quality characteristics [40]. The intensity and duration of rainfall influences dislodging and transporting the pollutant to stormwater [35].

4. Limitations and Policy Implications

Our review of published literature revealed that industrial facilities’ stormwater quality characteristics are either investigated through a limited number of water samplings over a short duration of time [13], or through the large numbers of self-reported stormwater quality data collected over a longer period [12]. Conducting the systematic stormwater sampling is beneficial as it generates more reliable data source. However, collecting the limited number of water samples during the short duration of time limits the understanding of seasonal and temporal changes in contaminant loadings to the surface waters. Furthermore, limited or lack of access to the industrial facilities and inadequate financial resources mostly obscure the detailed and long-term investigation of pollutant discharge by industry sectors into the stormwater. Although a large volume of stormwater quality data are collected by industrial sectors to satisfy the regulatory agencies’ monitoring requirements, only a few investigations have been conducted to examine the contaminant loadings and temporal variations in stormwater using these self-reported data. These self-reported data have been utilized to identify high polluting facilities, assess the pollutant loads to receiving water resources, and examine the facility improvement in reducing the pollutant discharges [41]. In our study due to the lack of access to the industrial sites, only the self-reported stormwater quality data and state regulatory agency compliance documents such as recent SWPPPs, inspection reports, and notices of violations were utilized. Thus, certain uncertainties associated with the self-reported nature of data like poor sampling or analysis practices should be considered. Although 9363 data points were analyzed in this study, there was a significant number of missing data (33.75%) that made the identification of specific trends difficult. Limited information regarding the type of industrial activities was reported in the Notice of Intent documents which created significant challenges in identifying the pollution sources. Despite the presence of heavy metals in stormwater at industrial facilities, this was not considered in the calculation of water quality index (WQI) as we applied the method reported in the literature [26]. However, future research is needed to specifically develop a WQI for industrial facilities’ storm runoff, accounting for heavy metals and their appropriate relative weights in the calculations.

Decision makers’ understanding of existing stormwater monitoring programs’ effectiveness is limited due to the high variability of stormwater quality data. This variability even could rise due to the stormwater’s natural variability, variation of industrial activities, poor sampling practices, and analysis. In our study, the state regulatory agency required the collection of grab samples within the first 30 min of discharge at outfall and not later than one hour, but sampling either late or early during storm event could have a significant impact on the result. Sampling at the beginning of storm event results in a collection of the first flush stormwater sample, which generally contains a greater concentration of contaminant [18]. This is an appropriate practice if the peak concentration of contaminant is required, otherwise the samples that are collected in the middle of storm event are more representative [18]. The duration of the dry period before the storm event could influence the level of stormwater contaminant. After a long dry period, the higher concentration of contaminant could be found in stormwater [42]. The results of this study suggested that the efficiency of current industrial stormwater monitoring programs could be improved by providing more detailed stormwater sampling guidelines and more strict requirements for the water quality reports to generate a more accurate database for future decision making and policy development. This research also highlights
the importance of understanding stormwater quality data, to encourage industrial stakeholders to take serious steps toward protection of their stormwater quality. Industrial facilities’ operators are encouraged to understand their stormwater quality data, detect the pollutants of concern, potential problems in contaminating the storm runoff and implement the efficient BMPs. In addition, our findings will assist the state and federal regulatory decision makers recognize the impacts of industrial activities on local creek and streams. It will allow the regulators to assess their progress toward managing the stormwater quality at industrial sites and protecting the watersheds to lower the pollutant discharge. The data could serve as the representative of industrial stormwater quality resulting from different types of activities to assist the regional, state, and local decision makers in protecting receiving waters effectively. We expect this work to catalyze the community and regulatory agencies into understanding this increasingly important, although not yet completely understood fact. Lack of information about the pollutants’ types and their concentrations released to the stormwater by the specific type of industry, makes it difficult for the regulatory agencies to identify the specific pollutants that should be monitored. So, this research will provide background data about the type and concentrations of the pollutants we expect from a specific type of industry. In addition, the research outcomes could be used in issuing future industrial stormwater permits. Our study is aligned with the previous research that found high variability within the collected self-reported stormwater quality. The study conducted by Lee et al., (2007) evaluated several stormwater monitoring programs by investigating several data sets collected between 1991 and 2003 [18]. They found high variability in data collected by the industrial monitoring program and suggested reducing this variability from experimental error and artifacts in data collection to provide better guidance to the decision makers [18].

5. Conclusions

The pollutions originate from a variety of sources in industrial facilities are substantial contributors to surface water quality impairment. This study was conducted to better understand stormwater quality at 12 industrial facilities to evaluate the industry sector’s pollutant discharge characteristics. In this study, the quarterly self-reported stormwater quality data reported by an industry sector during 2014–2018 were analyzed to identify the variation of stormwater quality within an industrial sector and examine the seasonal changes of stormwater quality. Implementation of principle component analysis (PCA) revealed three major components that were significantly loaded—inorganic contaminant (PC1), nitrogenous contaminant (PC2), and water pH (PC3)—and demonstrated their association with the industrial activities and biogenic pollution sources. A significant variation of stormwater quality parameters was found within the studied industrial facilities. The WQI calculation showed the variation of stormwater quality ranging from “Bad” to “Medium” quality among the industrial facilities. The seasonal variation of stormwater quality was analyzed using PCA and WQI calculations. The result demonstrated a lower water quality in spring compared to the other seasons. Several limitations were identified with respect to the self-reported nature of data and information on industrial activities. This research underscores the importance of understanding stormwater quality data to encourage the industry stakeholders to improve their best management practices to maintain the storm runoff quality. It also assists the policymakers in better understanding the impact of their regulatory strategies on protecting the water resources.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/12/11/3185/s1.
Table S1: The number of outfalls with available self-reported stormwater quality data. Table S2: The stormwater quality parameters correlation factors. Table S3: A comparison of median values of stormwater quality in studied industry sector with the levels reported in the literature. Table S4: The results of Mood’s Median test. Table S5: The results of Kruskal–Wallis test and Normality test. Figure S1: The scree plot for the components. Figure S2: The seasonal variation of stormwater WQI at studied industrial facilities.

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**References**

1. Rădulescu, D.; Racovițăeanu, G.; Swamikannu, X. Comparison of urban residential storm water runoff quality in Bucharest, Romania with international data. *E3S Web Conf.* **2019**, *85*, 07019. [CrossRef]
2. Bichai, F.; Ashbolt, N. Public health and water quality management in low-exposure stormwater schemes: A critical review of regulatory frameworks and path forward. *Sustain. Cities Soc.* **2017**, *28*, 453–465. [CrossRef]
3. Jeong, H.; Choi, J.Y.; Lee, J.; Lim, J.; Ra, K. Heavy metal pollution by road-deposited sediments and its contribution to total suspended solids in rainfall runoff from intensive industrial areas. *Environ. Pollut.* **2020**, *265*, 115028. [CrossRef] [PubMed]
4. Toronto Region Conservation Authority (TRCA). *Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide Version 1.0*; Toronto. 2016. Available online: https://sustainabletechnologies.ca/app/uploads/2016/08/LID-IM-Guide-2016-1.pdf (accessed on 11 November 2020).
5. DayWater. Report 5.1. Review of the Use of Stormwater BMPs in Europe; Middlesex University: London, UK, 2003; Available online: http://daywater.enpc.fr/www.daywater.org/REPORT/DS-5-1.pdf (accessed on 11 November 2020).
6. He, J.; Valeo, C.; Chu, A.; Neumann, N.F. Characterizing Physicochemical Quality of Storm-Water Runoff from an Urban Area in Calgary, Alberta. *J. Environ. Eng.* **2010**, *136*, 1206–1217. [CrossRef]
7. Gan, H.; Zhuo, M.; Li, D.; Zhou, Y. Quality characterization and impact assessment of highway runoff in urban and rural area of Guangzhou, China. *Environ. Monit. Assess.* **2007**, *140*, 147–159. [CrossRef] [PubMed]
8. Gaffield, S.J.; Goo, R.L.; Richards, L.A.; Jackson, R.J. Public Health Effects of Inadequately Managed Stormwater Runoff. *Am. J. Public Health* **2003**, *93*, 1527–1533. [CrossRef] [PubMed]
9. Mann, A.G.; Tam, C.C.; Higgins, C.D.; Rodrigues, L.C. The association between drinking water turbidity and gastrointestinal illness: A systematic review. *BMJ Public Health* **2007**, *7*, 1–7. [CrossRef]
10. Xu, C.; Jia, M.; Xu, M.; Long, Y.; Jia, H. Progress on environmental and economic evaluation of low-impact development type of best management practices through a life cycle perspective. *J. Clean. Prod.* **2019**, *213*, 1103–1114. [CrossRef]
11. Aghilinasrollahabadi, K.; Salehi, M.; Fujiwara, T. Investigate the Influence of Microplastics Weathering on Their Heavy Metals Uptake in Stormwater. *J. Hazard. Mater.* **2020**, 124439. [CrossRef]
12. Duke, L.D.; Buffeleben, M.; Bauersachs, L.A. Pollutants in storm water runoff from metal plating facilities, Los Angeles, California. *Waste Manag.* **1998**, *18*, 25–38. [CrossRef]
13. Line, D.E.; Wu, J.; Arnold, J.A.; Jennings, G.D.; Rubin, A.R. Water quality of first flush runoff from 20 industrial sites. *Water Environ. Res.* **1997**, *69*, 305–310. [CrossRef]
14. Lee, H.; Stenstrom, M.K. Utility of Stormwater Monitoring. *Water Environ. Res.* **2005**, *77*, 219–228. [CrossRef] [PubMed]
15. Ma, Y.; Egodawatta, P.; McGree, J.; Liu, A.; Goonetilleke, A. Human health risk assessment of heavy metals in urban stormwater. *Sci. Total Environ.* **2016**, *56*, 764–772. [CrossRef] [PubMed]
16. USEPA. National Pollutant Discharge Elimination System (NPDES). Available online: https://www.epa.gov/npdes/stormwater-discharges-industrial-activities%0A%0A (accessed on 7 November 2020).
17. USEPA. Developing Your Stormwater Pollution Prevention Plan A Guide for Industrial Operators June 2015. Available online: https://www.epa.gov/sites/production/files/2015-11/documents/swppp_guide_industrial_2015.pdf (accessed on 7 November 2020).
18. Lee, H.; Swamikannu, X.; Radulescu, D.; Kim, S.-J.; Stenstrom, M.K. Design of stormwater monitoring programs. *Water Res.* **2007**, *41*, 4186–4196. [CrossRef]
19. USEPA. Final YEAR 2016 303 (d) LIST. 2017. Available online: https://www.adeq.state.ar.us/water/planning/integrated/303d/pdfs/2016/final-2016-303d-list.pdf (accessed on 7 November 2020).

20. Ullah, A.; Arshad, M.; Kächele, H.; Khan, A.; Mahmood, N.; Müller, K. Information asymmetry, input markets, adoption of innovations and agricultural land use in Khyber Pakhtunkhwa, Pakistan. Land Use Policy 2020, 90, 104261. [CrossRef]

21. Lien, L.T.Q.; Chuc, N.T.K.; Hoa, N.Q.; Lan, P.T.; Thoa, N.T.M.; Riggi, E.; Tamhankar, A.J.; Lundborg, C.S. Knowledge and self-reported practices of infection control among various occupational groups in a rural and an urban hospital in Vietnam. Sci. Rep. 2018, 8, 1–6. [CrossRef]

22. Więcław, H.; Kurnicki, B. Morphological variation of Platanthera chlorantha (Orchidaceae) in forest sites of NW Poland. Acta Biol. 2016, 23, 139–149. [CrossRef]

23. Barakat, A.; El Baghdadi, M.; Rais, J.; Aghezzaf, B.; Slassi, M. Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. Int. Soil Water Conserv. Res. 2016, 4, 284–292. [CrossRef]

24. Zeinalzadeh, K.; Rezaei, E. Determining spatial and temporal changes of surface water quality using principal component analysis. J. Hydrol. Reg. Stud. 2017, 13, 1–10. [CrossRef]

25. Mohd Hafiyyan, M.; Lee, K.E.; Mazlin, M.; Marfiah, A.W.; Goh, T.L.; Norbert, S.; Maria, M.H.; Azhar, A.H. Spatial distribution of water quality index in stormwater channel: A case study of Alur Ilmu, UKM Bangi campus. Asia Pacific Environ. Occup. Health J. 2017, 3, 33–38.

26. Pesce, S. Use of water quality indices to verify the impact of Córdoba City (Argentina) on Suquía River. Water Res. 2000, 34, 2915–2926. [CrossRef]

27. Han, Y.; Lau, S.-L.; Kayahian, M.; Stenstrom, M.K. Characteristics of highway stormwater runoff. Water Environ. Res. 2006, 78, 2377–2388. [CrossRef] [PubMed]

28. Camargo, J.A.; Alonso, A.; Salamanca, A. Nitrate toxicity to aquatic animals: A review with new data for freshwater invertebrates. Chemosphere 2005, 58, 1255–1267. [CrossRef] [PubMed]

29. Gransee, A.; Fuhrs, H. Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. Plant. Soil 2012, 368, 5–21. [CrossRef]

30. Hugh, C.R.W.; Bennett, H.; Risden, T.; Allen, L.; Davis, V. Soil Survey of Shelby County, Tennessee; U.S. Department of Agriculture: Nashville, TN, USA, 1916. Available online: https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/tennessee/shelbyTN1970/Shelby.pdf (accessed on 11 November 2020).

31. Lau, S.L.; Khan, E.; Stenstrom, M.K. Catch basin inserts to reduce pollution from stormwater. Water Sci. Technol. 2001, 44, 23–34. [CrossRef]

32. Campbell, C.G.; Mathews, S. An Approach to Industrial Stormwater Benchmarks: Establishing and Using Site-Specific Threshold Criteria at Lawrence Livermore National Laboratory. In Proceedings of the CASQA Stormwater 2006 Conference, Sacramento, CA, USA, 25–27 September 2006. UCRL-CONF-224278.

33. Kaczala, F.; Marques, M.; Vinrot, E.; Hogland, W. Stormwater run-off from an industrial log yard: Characterization, contaminant correlation and first-flush phenomenon. Environ. Technol. 2012, 33, 1615–1628. [CrossRef]

34. Davis, A.P.; Shokouhian, M.; Ni, S. Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. Chemosphere 2001, 44, 997–1009. [CrossRef]

35. Greenway, M.; Le Muth, N.; Jenkins, G. Monitoring Spatial and Temporal Changes in Stormwater Quality through a Series of Treatment Trains. A Case Study—Golden Pond, Brisbane, Australia. Glob. Solut. Urban. Drain. 2002, 44, 1–16. [CrossRef]

36. Brezonik, P.L.; Stadelmann, T.H. Analysis and predictive models of stormwater runoff volumes, loads, and pollutant concentrations from watersheds in the Twin Cities metropolitan area, Minnesota, USA. Water Res. 2002, 36, 1743–1757. [CrossRef]

37. Helmreich, B.; Hilliges, R.; Schriewer, A.; Horn, H. Runoff pollutants of a highly trafficked urban road—Correlation analysis and seasonal influences. Chemosphere 2010, 80, 991–997. [CrossRef]

38. Zhang, L.; Zhao, B.; Xu, G.; Guan, Y. Characterizing fluvial heavy metal pollutions under different rainfall conditions: Implication for aquatic environment protection. Sci. Total Environ. 2018, 635, 1495–1506. [CrossRef] [PubMed]

39. Tsihrintzis, V.A.; Hamid, R. Modeling and Management of Urban Stormwater Runoff Quality: A Review. Water Resour. Manag. 2001, 11, 137–164. [CrossRef]
40. Wijesiri, B.; Liu, A.; Goonetilleke, A. Impact of global warming on urban stormwater quality: From the perspective of an alternative water resource. *J. Clean. Prod.* 2020, 262, 121330. [CrossRef]

41. Gleaton, K.L. *Effectiveness of Environmental Regulations: Monitoring by the Regulated Community under Clean Water Act. Industrial Stormwater Runoff Requirements*; University of South Florida: Tampa, FL, USA, 2006.

42. Barbosa, A.; Fernandes, J.; David, L. Key issues for sustainable urban stormwater management. *Water Res.* 2012, 46, 6787–6798. [CrossRef] [PubMed]

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