Research on Rainwater Runoff Pollution in Different Blocks in Xi'an

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Abstract: By monitoring the changes of SS/COD/TP/TN in rainwater runoff in residential, industrial, commercial and traffic areas of Xi’an with the rainfall duration, the characteristics of rainwater runoff pollution in different areas of the city are explored. The results show that the concentration of pollutants in different regions from high to low is: traffic area> industrial area> residential area> commercial area. The concentration of pollutants in rainwater runoff in various regions reached a peak at the beginning of rainfall (within 30 minutes), and then gradually decreased and stabilized. The concentration of main pollutants in rainwater runoff in traffic areas is significantly higher than that in other areas. It can be seen that transportation may be the main factor affecting urban rainwater runoff pollution.

1. Introduction
In recent years, the urbanization process has led to the gradual intensification of urban pollution, especially the pollutants carried by rainfall runoff. These pollutants enter the water environment through surface runoff, causing aggravation of water environment problems [1,2]. Therefore, the collection of rainwater and the reduction and control of pollutant are of great significance to the protection of the water environment. The distribution characteristics of pollutants carried by rainwater are directly related to the design and operation of low impact development technology in sponge city. Some studies on the characteristics of rainwater were carried out, mainly focusing on the underlying surface of residential areas and the characteristics of runoff rainwater in typical cities [3,4]. These studies found that the control of early rainwater is essential. Sansalone [5] found that the pollution concentration of road rainwater runoff in the early stage of rainfall was significantly higher than that in the later stage of rainfall, that is, the initial scouring effect, but the initial scouring effect is not widespread. At present, the research on the pollution characteristics of rainfall process is still not comprehensive. Previous studies have carried out runoff water quality monitoring and analysis in roof, pavement, grassland, vegetable market and other areas [6]. However, there are few studies on the pollution characteristics of rainfall rivers in urban traffic areas, residential areas, industrial areas and commercial areas.

This paper takes the traffic area, industrial area, residential area and commercial area of Xi’an as the research object. By collecting the rainfall duration data of five monitoring points from 2017 to 2019, the concentration variation of various pollutants in rainwater during rainfall in different functional areas is analysed, and the concentration distribution of main pollutants in different years is compared. The pollution characteristics of four functional areas of the city are clarified, which provides basic data...
support for the design and construction of sponge cities.

2. Research area overview and analysis method

2.1. Research area overview and layout of sampling points
This paper took the typical area of Xi'an in Shaanxi Province as the research object, and selected the urban residential area, industrial area, commercial area and traffic area as the typical area to represent the regional characteristics of the city. A total of 9 monitoring sampling points, including 3 sampling points in residential and traffic areas, 2 sampling points in industrial and commercial areas. These sampling points are located in the vicinity of Xi'an east Second Ring Road. The characteristics of each area can be integrated to reflect the characteristics of the city of Xi'an. Therefore, the sampling points are representative.

2.2. The collection of samples
No sooner had the rainfall formed surface runoff, than the samples were collected by autosampler. The collected samples were stored in glass bottles, and at the same time they were labelled and marked. Take the erosion effect of the initial rainfall into account, sample every 10 min within 0-30 min during rainfall runoff; sample every 15 min within 30-60 min; sample every 20 min within 60-120 min; after 120 min, sample every 30 minutes until the end of the rain. The sampling interval may also be adjusted according to actual rainfall conditions. Generally, there were no less than six rainfall samples in each sampling point, and the total amount of the sample was 500ml. After sampling, they were taken back to the laboratory for testing. A total of 5 rainfall samples were collected between 2017 and 2019, as shown Table 1.

| Rainfall date | Duration of rainfall/h | Rainfall/mm | Rainfall scale |
|---------------|------------------------|-------------|----------------|
| June 28, 2017 | 3.5                    | 11.0        | Heavy rain     |
| July 02, 2018 | 5.2                    | 4.5         | Moderate rain  |
| Aug. 09, 2018 | 3.0                    | 10.2        | Light rain     |
| April 02, 2019| 6.2                    | 4.1         | Light rain     |
| June 06, 2019 | 4.3                    | 2.5         | Light rain     |

2.3. Analysis method
Chemical oxygen demand (COD), total suspended solids (SS), ammonia nitrogen (NH₄⁺-N) and nitrate nitrogen (NO₃⁻-N) analysis methods refer to Water and wastewater monitoring and analysis method (the fourth edition). Total nitrogen (TN) was analyzed by the National standard of the People’s Republic of China—Water quality-Determination of total nitrogen-Alkaline potassium persulfate digestion UV spectrophotometric method (HJ 636-2012). Total phosphorus (TP) was analyzed by the National standard of the People’s Republic of China—Water Quality-Determination of Orthophosphate and Total Phosphorus-Dontinuous Flow Analysis (CFA) and Ammonium Molybdate Spectrophotometry (HJ670-2013). The correlation analysis was calculated by Person analysis method in SPSS22.0 software.

3. Result and Discussion

3.1. Analysis on Pollution Characteristics of Rainwater Runoff in Different Regions

3.1.1. SS in rainwater runoff of different blocks. Figure 1 shows the distribution of SS during rainfall-runoff time in urban residential area, industrial area, commercial area and traffic area (Changleqiao, Xianning Middle Road and Huojv Road) in 2019, where the SS in residential area, industrial area and commercial area are the average concentration of sampling points in each region. In 2019, the concentration of SS carried by rainfall runoff in urban traffic area was significantly higher than that in residential area, industrial area and commercial area, and the concentration of SS decreased with the
increase of rainfall duration. SS concentration reached the top (968 mg / L) during rainfall runoff on Xianning Middle Road in traffic area, which appeared 20 min after the beginning of rainfall, and the SS in the runoff process gradually decreased after 20 min. The concentration of SS carried by Changleqiao rainfall runoff process was second only to Xianning Middle Road, the concentration of SS reached the highest in the early rainfall (10min). The concentration of SS in the runoff of three sampling points in the traffic area showed a trend: Xianning Road > Changle Bridge > Torch Road.

The SS carried by the rainfall-runoff process in residential area, industrial area and commercial area was significantly lower than that in the traffic area, and the highest concentration was 195 mg/L. In addition, it can be found from the figure that no matter which area the concentration of SS is relatively high at the beginning of the rainfall, with the extension of the rainfall time, the concentration of SS gradually decreases. This distribution shows that the initial rain effect is not universal, which is basically consistent with the previous research conclusions [7].

Figure 1. Distribution of SS in rainwater runoff (June 6, 2019).

3.1.2. COD in rainwater runoff of different blocks. Figure 2 shows the concentration distribution by rainfall-runoff process in four typical regions of Xi’an. The COD concentration in rainwater runoff from different regions of the city showed the following characteristics: traffic area > industrial area > commercial area > residential area. The COD concentration of Huojv Road and Xianning Middle Road in the traffic area were significantly higher than those in other areas. This is mainly related to the fact that Xianning Middle Road and Torch Road are the main roads with large traffic flow [7,8]. The COD concentration in the initial rainwater of Huojv Road is 8.9 times that of V-type water in surface water. The COD concentration in rainwater of residential area, industrial area and commercial area is 3.3 times, 4.4 times and 3.5 times that of V-type water, respectively. The higher COD concentration in industrial area than that in other two areas may be related to the environmental conditions of industrial area.
Figure 2. Distribution of COD in rainwater runoff (June 6, 2019).

3.1.3. Nitrogen in rainwater runoff of different blocks. The urban rainfall runoff process inevitably carries nitrogenous pollutants. The concentration distribution results of nitrogenous pollutants in different regions on June 6, 2019 are shown in Figure 3. The concentration of nitrogenous pollutants in the runoff of various regions in Xi’an from high to low is: Huojv Road>Xianning Middle Road>Industrial District>Residential District>Business District>Changle Bridge.

During the entire rainfall process, the concentration of TN was higher than Grade V according to Environmental quality standards for surface water (GB 3838-2002) (2mg/L) of the surface water environmental quality standard, and the highest concentration in June 2019 could reach 12.81 mg/L. This result shows that TN in the pollutants carried by rainfall seriously exceeds the standard. The concentration of TN in Huojv Road is the highest among the monitoring points, and the result is consistent with the highest concentration of COD. It shows that the rainfall on Huojv Road carries a high concentration of pollutants, which is closely related to human activities and traffic in the area. The concentration of TN on the Xianning middle Road was second only to the sampling point on Huojv Road at the beginning of the rainfall. The pollution concentration carried by the rainfall decreased significantly after 30 minutes of rainfall, which was lower than other monitoring points. As this section was mainly traffic-oriented, it carried higher levels in the early stage of rainfall. Pollutants, and as the rainfall duration increases, its concentration decreases. Analysing the categories of nitrogen-containing pollutants, it can be found that the content of organic nitrogen carried by rainfall is significantly higher (more than 50%). The result is mainly related to human activities and atmospheric deposition. Combining the data of COD and nitrogen-containing pollutants, it can be found that the pollution concentration of Changle Bridge monitoring site with less human interference is significantly lower, and the pollutant concentration carried by rainfall in the four regions from high to low is traffic area> industrial area> residential area >Business district.
3.1.4 Phosphorus in rainwater runoff of different blocks. Figure 4 is the distribution of TP concentration in different functional areas of Xi'an on June 6, 2019. In the whole rainfall process TP concentration from high to low monitoring points were: Huojv Road > industrial area > commercial area > Xianning Middle Road > residential area > Changleqiao. With the increase of rainfall duration (when rainfall exceeds 30 min), TP concentration in different blocks of the city basically shows a decreasing trend. The high TP concentration in the monitoring points of Huojv Road and industrial area is mainly related to human activities and production of roads. With the increase of rainfall duration (when rainfall exceeds 30 min), TP concentration in each typical functional area of the city basically shows a decreasing trend. TP concentration in rainwater runoff of Huojv Road and industrial area is higher than that in other monitoring points due to the influence of transportation and industrial production.

3.2 Inter-annual variation of rainwater runoff pollution
According to the result of 3.1, it can be found that the pollution of rainwater runoff in Huojv Road in traffic area is more serious. COD and TN are the main pollutants of rainwater runoff in different functional areas. Through the analysis of COD and TN in rainwater runoff of Huojv Road monitoring points from 2017 to 2019, the results are shown in Figure 5. TN had an initial effect during the five rainfall durations, and the concentration of TN decreased slightly after 60 min (Lower decline) after 60
min. This result is consistent with previous research conclusions [10]. On June 28, 2017 and August 9, 2018, TN concentration in Huojv Road monitoring points was significantly higher than that in other monitoring periods. TN concentration was positively correlated with rainfall (R=0.893, p=0.0003). The results showed that higher rainfall scouring intensity had higher carrying capacity for pollution. The distribution of COD was significantly correlated with rainfall (R=0.231, p=0.435). COD and TN in runoff formed by three rainfalls (28 June 2017, 6 June 2019 and 9 August 2018) showed initial rainfall effects and remained stable (low concentration) in late 60 minutes. The concentration of COD in rainwater runoff formed by two rainfalls (July 2, 2018 and April 2, 2019) was quiet different from the other three monitoring results. The concentration of COD in rainwater runoff was still high (500 mg/L) at the final stage of rainfall, which may be due to the small rainfall intensity and the weak carrying capacity of rainwater runoff to pollutants, so that higher COD concentration was still contained in runoff at the final stage of rainfall.

Figure 5. Distribution of COD and TN during five rainfall events from 2017 to 2019 at Huojv Road (traffic area).

4. Conclusions
By monitoring the variation of pollutant concentration in rainfall runoff in different blocks of Xi’an, the results show that:

1. There are significant differences in the concentration of pollutants in rainwater during rainfall in different blocks of Xi’an. Rainfall pollution concentration in the four main urban functional areas showed a basic pattern from high to low: traffic area> The industrial> Residential> Business district.

2. The concentrations of COD and TN in each monitoring point obviously exceed Grade V according to Environmental quality standards for surface water (GB 3838-2002). Therefore, the pollution of rainwater runoff should be paid attention to urban water environment protection.

3. The concentration of pollutants in rainwater runoff is affected by the initial rainfall intensity. The higher the rainfall intensity, the higher the pollution concentration carried in the initial rainwater and quickly reached the peak, and the pollutant concentration in the runoff in the final period of rainfall will be lower.

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