STUDY ON TEMPORAL AND SPATIAL DISTRIBUTION CHARACTERISTICS OF URBAN NON-POINT SOURCE POLLUTION IN HOHHOT

by

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The non-point source pollution is not easy to be controlled, and it is one of the important environmental problems facing the world. Taking Hohhot, a typical city in the arid semi-arid region in China, as an example, four monitoring sites in the city were selected, water samples from six rainfall events were collected, and pollutants such as heavy metals, ammonia, nitrate nitrogen, phosphorus and suspended matter were examined, and the water quality of the rain runoff was comprehensively evaluated by the principal component analysis and the correlation analysis. The results showed that the total phosphorus contents of monitoring points in the street were the largest and those of monitoring points in gas stations were the smallest in rainfall runoff. Arsenic, cobalt, and chromium were less than the Class I standard for environmental quality standards for surface water according to Chinese standard (GB 3838-2002). Concentrations of cadmium, copper, and iron were greatest in street monitoring sites, while nickel, lead, and zinc were greatest in roof monitoring sites, and manganese was greatest in car park monitoring sites. There was minimal contamination at gas station monitoring sites and the greatest contamination at street monitoring sites. Heavy metals and phosphorus were the main contributing factors to pollution at street monitoring sites, while the main contributing factors at gas station monitoring sites were total suspended substances.

Key words: *environmental engineering, non-point source pollution, heavy metals, water quality analysis, city rainwater runoff, principal component analysis*

Introduction

With the continuous improvement of urban infrastructure and the expansion of urban area, the change of land use types brought about by rapid urbanization has become one of the key factors affecting urban water ecosystem [1], and the urban non-point source pollution has gradually become an important source of water pollution [2]. The non-point source contamination is difficult because its control is random, uncertain, extensive, and lagging. The non-point source pollution in a complex urban environment has become a growing problem [3]. The water

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resources and environmental problems caused by the urban non-point source pollution reduce the utilization value of urban water resources, and seriously damage the normal development and utilization of urban water sources [4]. At the same time, rainwater runoff carries a large number of pollutants into the urban water system and flows into the receiving water body through the urban underground drainage system, becoming an important pollution source leading to water pollution in lakes, ponds, reservoirs, rivers, and estuaries [5, 6]. The concentration of pollutants in the runoff formed by the initial rainfall is high. Because most of the pollutants are usually contained in the early runoff, this part of rainwater is called the initial rainwater [7-10]. Taking Hohhot, a typical city in arid and semi-arid areas, as an example, according to the principal component analysis [11], this paper makes a single factor analysis and comprehensive evaluation on the urban rainwater runoff quality of Hohhot, and provides a theoretical basis for non-point source pollution control, rainwater and flood utilization and groundwater recharge.

Study area and study methods

In this study, roofs, roadsides, gas stations, and parking lots were selected as monitoring points. The four sampling points represented the main urban environment of Hohhot. Six forms of surface runoff precipitation, total phosphorus, ammonia nitrogen, nitrate nitrogen, heavy metals, and suspended pollutants were collected, and the rainwater runoff quality was comprehensively evaluated.

Hohhot city locates in the central Inner Mongolia Autonomous Region. The average annual precipitation in the urban area is only 350 mm. The selected areas included impermeable area (roadside, concrete sidewalk, roof, gas stations) and water permeable area (green belt, permeable brick sidewalk, and parking lot). The experimental area of the road is characterized by large traffic flow, complex personnel activities, more restaurants and more shops, the gas station test area has large traffic flow and obvious ground oil stains, the roof test area is single than other places, less personnel activities and no vehicles and other machines, the parking area has less activity, more traffic flow and longer vehicle stay time than the gas station, but the vehicle circulation rate is less than the gas station. Therefore, the surface runoff of the selected area has a better representative role and can be studied as a typical area.

The research selected rainy days when precipitation can form runoff, within 0.5×0.5 m on the road, the roof, the parking lot, and the gas station, and collected the initial rainwater from runoff formation to 10 minutes, a total of six samples were taken, and the sunny days before each sampling were 18, 10, 4, 3, 6, and 1 days, respectively.

Results and discussion

Pollutant concentration distribution of rainwater runoff

The mass concentration distribution of the main pollutants of rainwater runoff formed by six rains in the four typical urban areas of Hohhot, including the parking lot, the roadside, the roof and the gas station, is shown in fig. 1. The results show that the total phenolics (TP) content of average rainfall runoff concentration in Hohhot monitoring points is 0.614 mg/L, 31 times above 0.02 mg/L of surface water Class I. The ammonia nitrogen content is 0.008 mg/L to 0.0.70088 mg/L, the gas station is 0.7088 mg/L, and the roof ammonia nitrogen content is 0.0137 mg/L, slightly lower than the limit range. There is no heavy metal Hg, both Co and Cd are less than the standard values. The Cd, Cu, and Fe are the largest and abundant in road monitoring sites, In the surface water Class I standard, Cd is 0.01 mg/L, Cu 0.01 mg/L, and Fe 0.3 mg/L, more exceeded 3 times, 110 times and 1.15 times, respectively. The content of Ni, Pb, and Zn in the roof monitoring sites, the surface water Class I standard for Pb is 0.01 mg/L and Zn is 0.05 mg/L, more than 2.7 times and 3.36 times of the standard, respectively. The largest Mn content in the parking lot monitoring point, the value is 0.683 mg/L, total suspended solids (TSS) from 6.8~853.334 mg/L of each monitoring point, The gas station has the highest total suspended matter, and the lowest content of suspended matter on the roof.

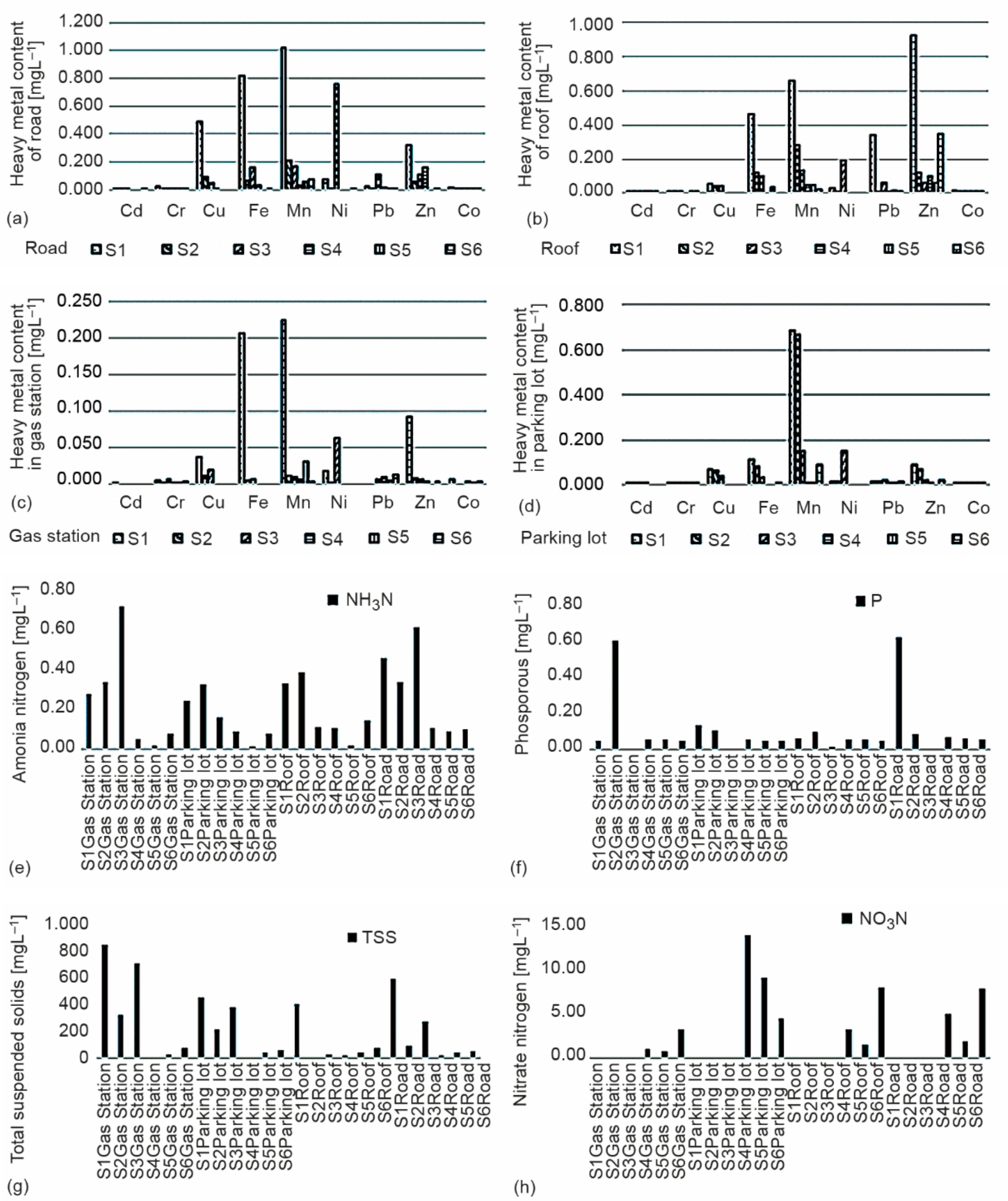

Figure 1. Pollutant concentration

Average concentration of rainwater runoff

The average concentration is used to characterize the rainwater runoff pollution characteristics, and the pollutants are applied to the calculation model of the rainwater runoff pollution load. For comparison purposes, this study conducted a statistical analysis on the concentration of main pollutants in rainwater runoff in four typical cities, including Hohhot gas stations, roofs, roadside, and parking lots. The results are shown in fig. 1.

The average concentration of TSS of rainwater runoff in different sub-cushion surfaces of Hohhot is between 94.93 mg/L and 330.91 mg/L, gas station, depot. The average concentration of rainwater runoff on the road surface is relatively high, while the roof is relatively low, the highest average concentration of manganese in heavy metals was 1.022 mg/L, minimum cobalt and zinc is 0 mg/L, the average concentration of P in the highest is 0.147 mg/L, the minimum level is the roof, 0.0508 mg/L, the highest average concentration of ammonia nitrogen was 0.2804 mg/L, minimum parking lot is 0.1471 mg/L, the highest average concentration of nitrate and nitrogen was 9.0466 mg/L, the minimum gas station is 1.6442 mg/L.

The water quality of rainwater runoff in Hohhot was analyzed. In each cushion surface, the TP content in rainwater runoff was between 0.000~0.614 mg/L, while TP was 0.02 mg/L in Class I Standard of Surface Water Environmental Quality Standard. In the experiment, the TP of rainwater runoff exceeded the Surface Water Environmental Quality Standard (GB 3838-2002), and the TP content of road surface runoff exceeded 31 times.

Based on several precipitation, the maximum phosphorus concentration in the experimental area of the road and the gas station is the smallest. This may be due to the improper fertilization of the green belt on both sides of the road, which makes the phosphorus fertilizer washed into the runoff. The ground of the gas station is well hardened and there is no green belt around. In addition, there is a large amount of iron oxide in the soil, which is an important reservoir of dissolved phosphate through chemical reaction and physical and chemical reaction. With the shortening of rainfall time interval, the concentration of phosphorus in each monitoring point is gradually reduced after repeated rain erosion.

As measured by the experimental analysis, the content of ammonia nitrogen in the four monitoring points in Hohhot ranged from 0.0080-0.7088 mg/L. China's current relevant environmental standards involving ammonia nitrogen wastewater discharge indicators are Surface Water Environmental Quality Standard, Groundwater Environmental Quality Standard, Comprehensive Sewage Discharge Standard in line with the national standard, the maximum value of ammonia nitrogen concentration in gas stations is 0.7088 mg/L, because the oil is high in organic matter, many kinds, and the gas station pavement is asphalt road, the content of organic matter in asphalt road should be greater than that in cement road, therefore, the gas station ammonia nitrogen concentration is the largest. The roof has few living creatures alive, there was no nitrogen-fixation effect, therefore, the lowest ammonia nitrogen content is 0.0137 mg/L. The average ammonia nitrogen concentration on the road is the highest because the plants have nitrogen fixation on the roadside, and the feces and the average concentration of ammonia nitrogen in the parking lot is the lowest because the car exhaust affects the survival of surrounding organisms, and the cars will drive away the surrounding animals and insects. With the increase of rainfall number, the overall ammonia nitrogen content of each monitoring point becomes a decreasing trend, which shows that ammonia nitrogen is easier to attach to the road, gas stations and other places where vehicles travel more. The high content of nitrate nitrogen in the parking lot is because there are plants in the parking lot and the nitrification bacteria in the soil form nitrous acid-containing organic matter through nitrification, resulting in the high nitrate nitrogen content in the parking lot. And in the gas station because there are staff cleaning so, its content is low.

As shown in fig. 1, the total suspension concentration is highest at gas stations. Due to the strong spring monsoons blow off part of the roof suspension, which has the lowest concentration. There will be spills on the road surface, and low levels of suspensions result from the presence of spills on the road surface and manual cleaning. With increasing time, the precipitation was frequent during the rainy season, after the third collection, and the total suspension content was greatly reduced and little different in each experimental region.

Analysis of the sources of heavy metals found in rainwater runoff

After testing the contents of nine heavy metals in rainfall rain runoff of four experimental areas by experimental analysis, the contents of each metal in surface runoff were subjected to data analysis, Cu and CO in each experimental area were below the *environmental quality standards* for surface water and Class I standard, while the concentrations of CD, Zn, Cr, Ni, Pb, Fe, and Mn were all over the Class I standard, among which, the concentrations of Mn, Ni, Pb, and Fe in street water samples were the largest and exceeded the standards by 10 times, 3 times, respectively, 20 times, 2 times. The concentrations of Ni, Pb, and Zn in water samples on the roof were the largest, exceeding the standard by a factor of 9, 33, and 2.4 times, respectively. The concentrations of CD, Mn, Pb, and Zn in water samples from the car park were the largest, which exceeded the standards by 4 times, 6.83 times, 7.5 times, 1.9 times, 1.8 times, respectively. The highest scores were obtained at the first and second principal component factors, both of which are mainly controlled by heavy metal factors, whose main sources were vehicle exhaust, the vehicle itself and the wear of the road surface by the vehicles, the corrosion of the vehicle components, and the resuspension of soil with surface dust particles. The amount of heavy metals in rain runoff is also determined by the complex source of heavy metals in atmospheric particulate matter, even in areas with relatively good environmental hygiene where there is still poor rainfall and long pre sunny days until the end of rainfall, indicating that rainfall above 10 mm still fails to wash the surface from areas with severe surface pollution. In addition to atmospheric dust reduction and wind migration, parking dust sources include particulates formed by mechanical friction of the ground by the vehicle plus deceleration tire and brakes. The canopy runoff and road surface runoff were the main components of the urban runoff. Urban hoods produce different non-point source pollutants due to their different materials, building times, slopes, exposure, and locations. Typical contaminants of the roof runoff were heavy metals such as Zn, Cu, Pb, and CD, which were mainly formed by corrosion, flushing from metal outlets on the roof and from drop pipes.

Source and correlation analysis of rainwater runoff non-metallic pollutants

In order to study the properties of various pollutants in the rainwater runoff of different lower cushion surfaces, the total phosphorus and ammonia nitrogen, nitrogen and suspended matter, comprehensive analysis of rainwater water runoff by SPSS software. The number of linear correlations between ammonia nitrogen, nitrate nitrogen, total phosphorus, and total suspended solids indicators in the four sampling sites are shown in tab. 1.

From tab. 1, the good correlation between ammonia nitrogen and nitrate nitrogen is –0.88, because they are homology and can be interconverted. No significant correlation was shown between the other pollutants. There is a good correlation between TSS and nitrate and

Table 1. Pearson correlation coefficient

		Total suspended matter	Total phosphorus	Ammonia nitrogen	Nitrate nitrogen
Grand average	Total suspended matter	1	0.452	0.755	–0.753
	Total phosphorus	0.452	1	0.414	–0.52
	Ammonia nitrogen	0.755	0.414	1	–0880*
	Nitrate nitrogen	–0.753	–0.52	–0.880*	1
Parking lot		Total suspended matter	Total phosphorus	Ammonia nitrogen	Nitrate nitrogen
	Total suspended matter	1	0.304	0.654	–0.996
	Total phosphorus	0.304	1	0.619	0.992
	Ammonia nitrogen	0.654	0.619	1	0.162
	Nitrate nitrogen	–0.996	0.992	0.162	1
Roof		Total suspended matter	Total phosphorus	Nitrate nitrogen	Ammonia nitrogen
	Total suspended matter	1	0.055	0.445	0.785
	Total phosphorus	0.055	1	0.642	–0.85
	Ammonia nitrogen	0.445	0.642	1	0.891
	Nitrate nitrogen	0.785	–0.85	0.891	1
Road		Total suspended matter	Total phosphorus	Nitrate nitrogen	Ammonia nitrogen
	Total suspended matter	1	0.867*	0.721	0.199
	Total phosphorus	0.867*	1	0.321	–0.542
	Ammonia nitrogen	0.721	0.321	1	0.683
	Nitrate nitrogen	0.199	–0.542	0.683	1
Gas station		Total suspended matter	Total phosphorus	Nitrate nitrogen	Ammonia nitrogen
	Total suspended matter	1	-0.065	0.758	0.962
	Total phosphorus	–0.065	1	0.083	–1.000**
	Ammonia nitrogen	0.758	0.083	1	0.869
	Nitrate nitrogen	0.962	–1.000**	0.869	1

*At the 0.05 level (double-tail), the correlation was significant.

ammonia nitrogen in the gas station runoff, and the correlation coefficient reaches –0.996 and 0.654. The rainwater runoff in the parking lot also has a good correlation between the TSS and the nitrate and ammonia nitrogen. The sources of pollutants in the gas station and

the parking lot are similar. These pollutants are mainly caused by vehicle tire and ground wear and engine exhaust emissions. In the roof runoff, TP and nitrate nitrogen, ammonia nitrogen, TSS, and nitrate nitrogen have a good correlation with their Pearson coefficients of 0.624,
–0.85, and 0.785, and these pollutants are mainly affected by the sedimentation of atmospheric particles. For the correlation coefficient of TSS, phosphorus and ammonia nitrogen in road runoff, the correlation coefficient of pollutants is 0.867 and 0.721, respectively, and the correlation coefficient of other indicators is slightly low, indicating that TSS and TP have good homology, and are also affected by the particle sedimentation of atmospheric pollutants.

The monitoring components in rainwater should be related to three aspects:

– Traffic factors: road, gas station, parking lot traffic is larger, convolved dust containing nitrogen is plant biological transformation into nitrate nitrogen, ammonia nitrogen, nitrogen, therefore, the three test points of nitrate nitrogen, ammonia nitrogen has a good correlation, TSS because of traffic disturbance, lead to the three areas of TSS and nitrate nitrogen have a good correlation.
– Air pollution degree: the waste gas discharged by factory enterprises contains a large amount of soot and other elements, which are mixed with the nitrogen in the air, bringing it to the surface runoff, resulting in non-point source pollution.
– Floor factors: the road, gas station pavement is mainly asphalt road, rainwater is not easy to seep, so the two monitoring points have high pollutant correlation. The roof is mainly asbestos and red brick, parking lot is mainly constructed with hole brick and soil, rainwater seeping fast, it is difficult to form large runoff, so pollutant correlation is poor.

Main component analysis method to evaluate the water quality distribution characteristics of rainwater runoff

According to the monitoring results, 13 indexes of TSS, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Co, P, ammonia nitrogen, and nitrate nitrogen were selected, and comprehensively evaluated by principal component analysis. Using statistical software, the 13 water quality indicators of the above 24 water samples were analyzed and evaluated. The contribution rate of each principal component, tab. 2, and the component score coefficient matrix were obtained.

From the calculation results, the first four principal component cumulative contribution rate is 85.52%, and in the principal component analysis, the cumulative contribution rate is more than or equal to 85%, that the principal component factors can represent most of the information of the original data, we can use the comprehensive evaluation of the original urban rainwater runoff water quality, and from the original 13 water quality index to 4, to a large extent, simplify the analysis process. The contribution rate of the first principal component obtained in tab. 2 was 49.435%, accounting for 49.435% of the total cumulative contribution rate, which was far greater than the second, third and fourth components, 13.739% and 6.946% of 15.400%. Therefore, Hohhot city rainwater runoff water quality is mainly by the first main component, namely controlled by TSS, ammonia nitrogen, nitrate nitrogen, Zn, TSS, and ammonia nitrogen, nitrate nitrogen is the main influence factors of water pollution of Hohhot rainwater runoff, then controlled in the runoff water of zinc, nickel, copper, and other heavy metals is also affect the factors of runoff water quality.

Table 2. Eigenvalues and the principal component contribution rate and the cumulative contribution rate

	Ranking	Percentage contribution	Cumulative percentage	Score
TSS	1	49.435	49.435	15.209
NO_3^--N	2	15.4	64.835	–1.411
NH_3-N	3	13.739	78.574	–1.41
Zn	4	6.946	85.52	–1.404
Ni	5	4.847	90.367	–1.392
Cu	6	3.725	94.093	–1.365
Pb	7	2.08	96.172	–1.402
Co	8	1.508	97.68	–1.405
Fe	9	1.147	98.827	–1.377
P	10	0.56	99.388	–1.41
Mn	11	0.386	99.773	–1.379
Cr	12	0.179	99.952	–1.341
Cd	13	0.048	100	0.085

Conclusion

The average concentration of secondary rainfall runoff at each monitoring point in Hohhot is between 0 and 0.614 mg/L, with the largest TP content, and the TP content of the road monitoring point exceeds 31 times than that of the standard. The ammonia nitrogen content range is 0.008-0.7088 mg/L, the highest ammonia nitrogen content in the gas station is 0.7088 mg/L, and the lowest roof ammonia nitrogen content is 0.0137 mg/L, slightly lower than the standard value. The monitoring points do not contain heavy metal Hg, As, Co, and Cd are less than the standard values. But Mn, Cd, Cu, and Fe exceed the standard values, exceeding 10 times, 3 times, 110 times, and 1.15 times, respectively. The Ni, Pb, and Zn in the roof monitoring points exceeding 3.8 times, 2.7 times, and 3.36 times above the standard values, respectively. Nanofibers membranes [12-15] provide an effective tool to absorption of heavy metals. The TSS concentration of each monitoring point is 6.8~853.334 mg/L, and the total suspended matter of the gas station is the highest. The leading factors leading to rainwater runoff pollution in Hohhot are TSS, NH_3-N, NO_3^--N, and Zn. The road monitoring point is the most polluted. The main pollution factors are heavy metals and total phosphorus. The main pollution factor is TSS. The degree of pollution at other monitoring points except the parking lot decreases with the decrease of days between rainfall.

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