N, P, and COD conveyed by urban runoff: a comparative research between a city and a town in the Taihu Basin

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Abstract

Stormwater runoff containing various pollutants exerts adverse effects on receiving water bodies and deteriorates the urban aquatic environment. Although numerous studies have been conducted on runoff pollution, research comparing its characteristics in cities with those in towns is rare in the literature. To close this gap, the present study was conducted. The outflow concentration and peak value of N in the town were higher than those in the city in most conditions (at 75% and 67%, respectively). The second peak value of P in the town was higher and occurred earlier than the city. EMCs of TN and DTN in the town were 20%–60% (10%–50%) higher than those in the city. DTP accounted for 76.9%–83.3% of the total P (TP) in the town, which was generally higher than the city values of 50%–87.5%. According to our results, road runoff in the town contributed more to urban aquatic pollution, thus further research should concentrate on this particular type of runoff.

Introduction

Extensive research has been conducted on the longstanding eutrophication occurring in China's Lake Taihu (Geng et al. 2019, Liu et al. 2012, Yu et al. 2020), which is attributed primarily to an oversupply of nutrients resulting in point-source and nonpoint-source pollution (Paerl et al. 2011). With the effective control and management of point-source pollution, the impacts of nonpoint-source pollution on the water quality have become increasingly prominent (Xiang et al. 2017). Urban runoff, as an inevitable nonpoint source, is the main transport mode of urban pollutant release and plays a significantly negative role in the deterioration of water bodies (Bjorklund et al. 2018).

In the process of urbanization, increasing numbers of impervious roads have been constructed. Pollutants accumulate on the impervious pavement and are then incorporated into the stormwater runoff, with final discharge into rivers. Road runoff contains various pollutants such as suspended solids (SS), chemical oxygen demand (COD), heavy metals, N and P nutrients, chlorides, oils and fats, pesticides, and *polycyclic aromatic hydrocarbons* (PAHs) (Polukarova et al. 2020, Stotz 1987) as well as emerging pollutants including phthalates, alkylphenol compounds, bisphenol-A, and insecticides (Gasperi et al. 2014, Müller et al. 2019, Zgheib et al. 2012). These pollutants cause adverse physical, chemical, and biological effects in the receiving waters to a considerable degree, threatening the health of aquatic organisms and humans (Field et al. 1998). The sources of these pollutants have been studied for the past 50 years, wherein vehicular transportation and atmospheric deposition are generally regarded as the dominant sources. However, recent research indicates that rapid advances in clean manufacturing and pollution control technologies; sources such as building and structure surfaces, gardens, parks, humans, animals; and the effects of future climate change should be considered (Muller et al. 2020). To control water pollution in urban stormwater runoff, researchers have developed numerous models for predicting and eliminating pollution (Wang et al. 2011, Yu et al. 2020). Moreover, utilization of rainwater resources has been considered to mitigate pollution (Cheng et al. 2020, Hou et al. 2020).

The Taihu Basin, a core area of China's economy, features dense population distributed in large cities and towns (Fig. 1(a)). Stormwater pollution commonly occurs in cities and in small towns, although the characteristics of runoff pollution can differ between them owing to the relatively smaller scale and population of the towns. Numerous comparative studies have been conducted on the characteristics of runoff in various functional areas and underlying surfaces in cities (Lucke et al. 2018, Peng et al. 2016, Wu et al. 2015, Zhenyao et al. 2016); however, the differences in runoff pollution between cities and towns are rarely reported in the literature. Therefore, to close this gap, the present study analyzes and compares the pollution characteristics in Changzhou, a major city located in the upper reaches of the Taihu Basin, with those in Shajiabang, a key town within the area. In total, 288 runoff samples were obtained from six sampling sites in the city and the town during four rainfall events.

The objectives of this study were to (1) compare the pollution characteristics of runoff pollutants identified in Changzhou with those recorded in Shajiabang; (2) analyze and compare the degree of pollution in rainwater runoff in the Taihu Basin with the results of similar studies; and (3) investigate the homology of N, P, and COD in the rainwater runoff. The results can help to further explain the contribution of road runoff pollution to the eutrophication problem in Taihu and elucidate the characteristics of stormwater runoff in cities and towns. Thus, the present study can be used to develop classified management practices of road rainwater runoff in cities and towns to effectively mitigate runoff pollution.

Materials And Methods

2.1 Study area

Three urban catchments located in Changzhou and three town catchments located in Shajiabang were selected to study the discharge characteristics of the road runoff; the six sampling points are presented in Fig. 1. Changzhou and Shajiabang are both located in the Taihu Basin in eastern China, where the climate type is subtropical monsoon with abundant rainfall and obvious monsoon characteristics. The annual average rainfall is more than 1000 mm in the two locations and is concentrated in the summer. We selected industrial, commercial, and residential areas in both Changzhou and Shajiabang to examine any differences in the road runoff in the city from that in the town. The underlying surfaces of all six sampling points were composed of impermeable concrete. The location characteristics and the methods used for road cleaning at the sampling points are presented in Table 1.

Table 1 Characteristics and road cleaning methods of sampling points

Sampling points	Locations	Types of urban functional areas	Abbreviations	Road cleaning methods
A	Changzhou (city)	Industrial areas	IC	Cleaning cars
B		Residential areas	RC	Manual cleaning
C		Commercial areas	CC	Cleaning cars
D	Shajiabang (town)	Industrial areas	IS	Manual cleaning
E		Residential areas	RS	Manual cleaning
F		Commercial areas	CS	Manual cleaning

2.2 Sampling procedure

Airtight plastic bottles moistened in advance with rainwater were used to collect the runoff samples at the catchments with low elevation as soon as the rainfall runoff emerged. While collecting the samples, the times of the rainfall start, runoff generation, and each sampling were recorded synchronously. Samples were taken in intervals of 5–10 min, 10–15 min, and 30–120 min during the periods of 0–30 min and 30–60 min after runoff generation and until the rainfall event ended, respectively. The sampling interval time was adjusted according to the actual rainfall intensity and rainfall duration. In particular, the sampling interval was shortened to 3 min during short rainfall or high rainfall intensity and was extended to 20–30 min under the condition of long rainfall duration or light rainfall intensity. In total, we obtained 288 runoff samples ranging in volume from 300 mL to 800 mL during four rainfall events occurring between October 2016 and June 2017. All samples were tested within 24 h before being refrigerated and preserved.

2.3 Data statistics

Variation in the event mean concentrations (EMC) recorded in the city and in the town were determined by the coefficient of variation, and the Pearson correlation coefficient was used for correlation of water quality parameters. All statistical analyses were conducted using SPSS 22.0 and Excel 2010. The methods used to determine the water quality parameters are listed in Table 2.

Table 2 Analytical methods for water quality parameters

Contaminant	Determination method	Note
Ammonia-N	Nessler's Reagent Spectrophotometry	-
Nitrate	Dual wavelength ultraviolet spectrophotometry	-
TN	Alkaline potassium persulfate digestion spectrophotometry	-
DTN	Alkaline potassium persulfate digestion spectrophotometry	Water samples were measured by 0.45 μm filter membrane
TP	Ammonium molybdate spectrophotometry	-
DTP	Ammonium molybdate spectrophotometry	Water samples were measured by 0.45 μm filter membrane
COD	Spectrophotometry of COD digester	-

Results And Discussion

3.1 Outflow law of runoff pollutants in two representative rainfall events

The characteristics of each rainfall event sampled at the six sampling points are presented in Table 3. The four rainfall events occurred during the four seasons of the year, respectively. The 24-h rainfall depths of the four events in Changzhou and Shajiabang were 7.8–103.8 mm and 9.0–218.8 mm, respectively; the antecedent dry day periods in the two regions were four to seven days and five to seven days, respectively.

Table 3 Characteristics of studied rainfall events

Locations	Rainfall events	Date	Sampling duration time(min)	Rainfall depth in 24 hours(mm)	Rainfall intensity(mm/h)	Antecedent dry days (d)
Changzhou (city)	1	07/November/2016	130	18.2	6.69	6
	2	21/December/2016	145	7.8	0.99	7
	2	16/April/2017	205	21.9	1.87	6
	4	10/June/2017	175	103.8	2.43	4
Shajiabang (town)	1	07/November/2016	175	38.2	3.09	7
	2	21/December/2016	145	16.5	1.24	6
	2	16/April/2017	155	9	2.67	6
	4	10/June/2017	170	218.8	2.4	5

The Taihu Basin receives regular and abundant rainfall, although the temporal distribution is uneven. Most of the precipitation is distributed in summer and autumn; hence, we selected one rainfall event each in summer (June 10, 2017) and autumn (November 07, 2016) as representative rainfall events for the outflow analysis.

Although the water quality of the Taihu Basin has improved recently, pollution caused by cyanobacteria remains in the summer (Xi &Yun 2019). In this section, we examine the characteristics of N and P outflow in correlation with eutrophication. All of the studied rainfall events exceeded 2 h, which is a feasible period for analyzing the law of pollutant outflow.

Aside from a few exceptions, the outflow concentrations of ammonia-N in the town were notably higher than those in the matching functional area in the city at the beginning of runoff generation, as shown in Fig. 2 (a)(b), and the contamination was stronger in the town's dry roads. In general, the ammonia-N concentrations reached peak values at the beginning of the runoff process, which was caused by the obvious initial scouring effect; this characteristic is common in previous research (Andres-Domenech et al. 2018, Barrett 1998, Bertrand-Krajewski et al. 1998, Janet et al. 2008). Occasionally, the peak value was reached during the middle of runoff process. This second peak value could have been caused by a sudden increase in rainfall intensity or the input of new pollutants from anthropogenic activities. Fig. 2(a)(b) shows that second peak values were reached in the commercial areas of both the town and city; however, strong discrepancies were noted between the two location types. The second peak values in the town were 1.2–2.1 times higher and occurred nearly half time earlier than those in the city. Similarly, as shown in Fig. 2(c)(d), the outflow concentrations of TN in the town were in most cases higher than those in the city at the beginning of the runoff formation. Overall, the N instantaneous concentrations in the town were notably higher than those in the city throughout the runoff process. As presented in Fig. 2(e)(f), the outflow difference in P amount between the city and the town was similar to that of N. In most conditions, the P instantaneous concentrations in the town were higher than those in the city during the rainfall events, and the second peak values in the town were higher and occurred earlier than those in the city.

In general, the runoff instantaneous concentrations of N and P in the town were notably higher than those in the corresponding functional areas of the city during the rainfall event. In 75% and 67% of the cases, the outflow concentrations of N at the beginning of the runoff formation in the town and the peak values were higher than those in the city, respectively. Moreover, the second peak values for P, which were reached during the middle of runoff process, were higher and occurred earlier in the town than those in the city.

3.2 Distribution of different pollutant concentrations

Fig. 3 illustrates the pollution degrees of various forms of N, which were measured by using EMC. That of N in the town showed considerably greater variation compared with the corresponding functional areas in the city. In particular, the variation coefficients of ammonia-N, nitrate, TN, and DTN in the town were 1.2–2.9, 1.2–2.1, 1.5–3.7, and 1.6–2.7 times those in the city, respectively. Moreover, the average EMC values (EMCs), expressed by the open squares in the figure, were also higher in the town. In particular, the EMCs of TN and DTN differed significantly between the city and the town, with 20%–60% and 10%–50% higher values recorded in the town, respectively.

Reasonable urban environment planning and management play important roles in the control of road runoff pollution. One such management method is urban greening, which includes urban landscape and road greening, Urban green areas in cities in China account for a larger proportion and better development than those in towns, and the vegetation on both sides of roads is dense and rich in variety. In contrast, China's small towns generally have two major characteristics: small geographical areas and large populations. These two characteristics are in conflict with each other; that is, increased population will result in more housing, businesses, production facilities, and other structures, which require sufficient numbers of buildings. However, these structures and some public infrastructures will occupy large geographical areas, which will lead to lower levels of surplus land resources and in turn land use problems in greening work (Huang 2020). Another factor is urban road cleanliness. Cities generally adopt more vigorous and efficient road cleaning methods, such as the employment of mechanical road sweepers, whereas small towns generally adopt manual road sweeping methods. Moreover, the road cleaning method affects the removal efficiency of mass road pollutants. In particular, a recent study reported that mechanical cleaning can effectively collect nanoparticles and organic pollutants from roads, which significantly reduces the amount of pollutants migrating to receiving water bodies (Polukarova et al. 2020).

Industrial production discharges NO_x into the atmosphere through which dry and wet deposition processes release these pollutants into rainwater runoff from urban roads. Ammonia-N in the atmosphere can form $(NH_4)_2SO_4$ and NH_4NO_3 through the combined reactions of H_2SO_4 and HNO_3, respectively, to form water-soluble secondary pollutants in rainfall runoff (Ling-xiao et al. 2007, Shun et al. 2015). One possible reason for the discrepancy in pollution degree between the city and the town could lie in the differences in industrial configuration. For example, the glass industry, which discharges NO_x pollution into the atmosphere, is well developed in Shajiabang.

Fig. 4 shows that the concentration and variation of P in the city's commercial (CC) and residential (RC) areas were higher than those in industrial (IC) areas. In particular, the EMCs of the TP and DTP in the city were CC = RC = 1.5 IC, and the EMC variation coefficients of the two pollutants in the CC and RC areas of the city were 2.3–3.1 and 1.6–2.1 times those in the IC area, respectively. The concentration and variation difference among the various functional areas in the city could have resulted in P sources. In CC areas, the intensive catering industry continually produces food waste and garbage; and in in RC areas, animal feces and domestic garbage accumulate. These activities could discharge P into the road systems, which would then increase runoff P content in the commercial and residential areas. The most likely reason for the variability difference is that the commercial and residential areas are more easily affected by random human recreational activities, the occurrences of which are easily affected by various factors such as weather conditions and the time of year, such as holidays.

In contrast, no such regularity was noted in the town. As shown in Fig. 4, the EMCs of the TP and DTP in the town’s industrial (IS) areas were higher than those its residential (RS) and commercial (CS) areas. In particular, the EMC variation coefficients of the two pollutants in the IS area were 1.5–1.8 and 1.7–2.3 times those in the CS and RS areas, respectively. Compared with those in the IS areas, the relatively low concentration and variation of P in the RS and CS areas occurred possibly because the runoff P was less affected by human recreational activities in the small but developing town.

Dissolved P could have contributed to the reduction of dissolved oxygen (DO) and increase of turbidity in aquatic ecosystems. Fig. 4(b) revealed that the DTP in the IC, CC, and RC areas accounted for 87.5%, 58.3%, and 50% of the TN respectively, as well as 83.3%, 76.9%, and 88.9% of the TP in the IS, CS, and RS areas, respectively. Dissolved P was a major component of the TP, which agrees with that reported in previous research (Brezonik &Stadelmann 2002). Compared with that in the city, the proportion of DTP in the CS and RS areas was higher, which could be attributed to road cleaning and management methods.

3.3 Urban runoff quality around the world

Table 4 Summary of pollutant concentrations in urban pavement runoff among different countries

Location	Year	Ammonia	Nitrate	TN	TP	COD	Reference
Guangzhou	2006	-	6.36	11.71	0.49	373	(Huayang et al. 2006)
Beijing	2008	-	-	13.62	0.46	278.6	(Yufen et al. 2008)
Chongqing	2010	1.26	1.07	3.35	0.72	122.79	(Qian-qian et al. 2012)
Yangzhou	2014	-	-	19.8	2.4	441	(Kang et al. 2016)
America	2006	-	0.43	1.13[a]	0.13	64	(Barrett et al. 2006)
Poland	2007	0.27	2.87	-	-	-	(Klimaszewska et al. 2007)
France	2000	1	6.7	2.1[a]	-	80	(Pagotto et al. 2000)
Italy	2005	0.43	4.8	-	-	-	(Mangani et al. 2005)
Germany	1997	0.72	-	-	0.91	103.7	(Stotz 1987)
Korea	2010	-	-	4.3	0.8	33.3	(C.Maniquiz et al. 2010)
Australia	2000	-	-	4.1	0.81	-	(Drapper et al. 2000)
Changzhou*	2016-2017	0.87	0.65	2.22	0.11	25.4	
Shajiabang*	2016-2017	1.01	0.99	3.13	0.11	46.8	

Note: * This research [a] TKN

The EMCs of the runoff pollutants including ammonia-N, nitrate, TN, TP, and COD in this study were compared with the results of similar studies conducted in other countries. Table 4 shows that the degree of runoff pollution varied strongly among the different countries and among cities in China, which demonstrates the significant regional discrepancies of nonpoint-source pollution worldwide. The pollutant concentrations of ammonia-N and TN in the present study were lower than those of most other countries in China but were higher than those of the United States and European countries. The concentration of pollutants in stormwater runoff is significantly affected by the surrounding environment, including soil and vegetation near the roads (Drapper et al. 2000), as well as road management and maintenance. Accordingly, the low concentration of pollutants could be attributed to China's increasing attention to road maintenance and the greening of environments surrounding roads. In addition, the concentration of pollutants in stormwater runoff is affected by traffic volume (Kayhanian et al., 2012). Compared with that in Beijing, Guangzhou, and some foreign cities, the traffic in Changzhou and Shajiabang is relatively light and thus has a lower impact on rainwater runoff pollution.

Many developed countries have performed a series of measures on rainwater management in recent decades, including sustainable stormwater management (SSWM), which employs best management practices (BMPs), sustainable urban drainage systems (SUDS), green infrastructure (GI), water-sensitive urban design (WSUD), and low-impact development (LID) (Fletcher et al. 2015). This concept was implemented in China's specific urban water management approach known as the sponge city initiative since 2013. This approach has adopted the concept of LID and set the total runoff control rate as a rigid index to realize a low impact on urban development, which upholds the pre-developed landscape hydrological characteristics in urban development (Shao et al. 2020). Sponge citifies show multiple advantages in reducing urban runoff loads, improving water quality of aquatic ecosystems, storing runoff water, and mitigating greenhouse gas emissions (GHGs) (Wang et al. 2018). Moreover, the sponge city approach has demonstrated effective regulation of urban rainfall runoff and runoff contaminant loads in China (Shao et al. 2020). The Chinese government has invested heavily for successful implementation of the sponge city strategy throughout the country, with 30 cities selected as pilot sponge cities between 2015 and 2016 (Chan et al. 2018). Although enacting the sponge city strategy in China is hampered by numerous challenges, effort in the program continues; the Chinese government intends to complete the transformation of 80% of cities into sponge cities by 2030.

3.4 Correlation analysis between water pollution parameters

Table 5 Liner correlation coefficients of water pollution parameters in various sampling locations

Functional areas	Pollutants	Pearson correlation coefficient				
		Ammonia-N	NO_3^--N	TN	TP	COD
IC	Ammonia-N	1				
	NO_3^--N	0.146	1			
	TN	***0.488*****	***0.745*****	1		
	TP	***0.311****	-0.050	0.132	1	
	COD	***0.763*****	***0.325****	***0.530*****	***0.379*****	1
IS	Ammonia-N	1				
	NO_3^--N	0.236	1			
	TN	***0.834*****	0.29	1		
	TP	0.096	-0.219	0.239	1	
	COD	***0.841*****	***0.398*****	***0.891*****	0.047	1
CC	Ammonia-N	1				
	NO_3^--N	***0.685*****	1			
	TN	***0.659*****	***0.776*****	1		
	TP	***0.570*****	***0.530*****	***0.663*****	1	
	COD	***0.325****	***0.687*****	***0.760*****	***0.349****	1
CS	Ammonia-N	1				
	NO_3^--N	0.192	1			
	TN	***0.812*****	***0.431*****	1		
	TP	0.274	0.013	0.066	1	
	COD	***0.652*****	0.071	***0.716*****	***0.541*****	1
RC	Ammonia-N	1				
	NO_3^--N	***0.731*****	1			
	TN	***0.610*****	***0.489*****	1		
	TP	***0.469*****	***0.513*****	0.148	1	
	COD	0.162	0.217	***0.508*****	0.063	1
RS	Ammonia-N	1				
	NO_3^--N	***0.414*****	1			
	TN	***0.825*****	***0.752*****	1		
	TP	-0.160	-0.123	-0.160	1	
	COD	***0.866*****	***0.442*****	***0.788*****	-0.025	1

As shown in Table 5, widely positive correlations were found between COD and various forms of N, whereas negative correlations were present between P and N, COD respectively. Positive (negative) correlation denotes similar (different) pollution sources. Significant correlation was present between COD and ammonia-N in industrial areas, with correlation coefficients of 0.763 and 0.841 in the IC and IS areas, respectively. This result could be linked to industrial production. Strong correlations were present between COD and TN in commercial areas, with correlation coefficients of 0.760 and 0.716 in the CC and CS areas, respectively. This result could be attributed to the intensive catering industry. Similarly, good correlations were present between COD and TN in residential areas, with correlation coefficients of 0.508 and 0.788 in the RC and RS areas, respectively. Compared with that in the city, correlation among COD and various forms of N was stronger in the town, illustrating a stronger similarity of pollutant sources in Shajiabang. Previous research proposed toilet exhaust as a major source of urban atmospheric ammonia-N pollution (Jing et al. 2016).

For stormwater management projects, a shorter list of components could reduce monitoring efforts and save analysis costs (Kayhanian et al. 2012). Therefore, COD can be monitored as a substitute for N, which could be used for assessing trends in runoff characteristics, developing strategic monitoring plans, estimating mass loads, and implementing treatment practices.

Conclusion

(1) In 75% of the cases, the outflow concentrations of N in the town at the beginning of runoff formation were higher than those in the city, and 67% of the peak N values were also higher in the town. The second peak values of P in the town, which were reached during the middle of the runoff process, were higher and occurred earlier than those in the city.

(2) The EMC variation coefficients of ammonia-N, nitrate, TN, and DTN in the town were 1.2–2.9, 1.2–2.1, 1.5–3.7, and 1.6–2.7 times of those in the city, respectively. The EMCs of TN and DTN in the town were 20%–60% and 10%–50% higher than those in the city, respectively. In addition, the EMCs and EMC variation coefficients of TP and DTP in commercial and residential areas were higher than those in industrial areas in the city; however, opposite results were observed for the data in the corresponding areas in the town.

(3) Compared with that in the city, the proportion of DTP in the TP was higher in the town. The DTP accounted for 50%–87.5% and 76.9%–83.3% of the TP among different functional areas of the city and those of the town, respectively.

(4) The pollutant concentrations of ammonia-N and TN in our study were lower than those of most other countries in China but were higher than those of the United States and European countries. This result demonstrates China’s recent progress in controlling rainwater runoff pollution.

(5) General correlations were present among COD and various forms of N in the runoff of cities and towns, which indicates that these pollutants might share common pollution sources. Compared with that in the city, the correlation among COD and various forms of N was stronger in the town, which illustrates a stronger similarity of pollutant sources in Shajiabang.

Declarations

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6. **Declarations**

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Conflicts of interests/ Competing interests

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in our manuscript.

Ethics approval

Ethics approval was not required for this research.

Consent

All authors whose names appear on the submission agreed with the content and gave explicit consent to submit, and they obtained consent from the responsible authorities at the institute/organization where the work has been carried out, before the work is submitted.

Data

The datasets used during the current study are available from the corresponding author on reasonable request.

Authors' contribution statements

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Xiaodong Liu, Peng Wang, Zulin Hua and Li Zhao. The first draft of the manuscript was written by Li Zhao, and the revision of the manuscript was performed by Li Zhao, Yuan Zhang and Hongqin Xue. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

References

Andres-Domenech I, Hernandez-Crespo C, Martin M, Andres-Valeri VC (2018): Characterization of wash-off from urban impervious surfaces and SuDS design criteria for source control under semi-arid conditions. Science of the Total Environment 612, 1320-1328 https://doi.org/10.1016/j.scitotenv.2017.09.011

Barrett ME (1998): Characterization of Highway Runoff in Austin, Texas, Area. Journal of Environmental Engineering 124, 131-137 DOI:10.1061/(ASCE)0733-9372(1998)124:2(131)

Barrett ME, Kearfott P, Jr JFM (2006): Stormwater Quality Benefits of a Porous Friction Course and Its Effect on Pollutant Removal by Roadside Shoulders. Water Environment Research 78, 2177-2185 DOI:10.2175/106143005X82217

Bertrand-Krajewski J-L, Chebbo G, Saget A (1998): Distribution of pollutant mass vs volume in stormwater discharges and the first flush phenomenon. Water Research 32, 2341-2356 https://doi.org/10.1016/S0043-1354(97)00420-X

Bjorklund K, Bondelind M, Karlsson A, Karlsson D, Sokolova E (2018): Hydrodynamic modelling of the influence of stormwater and combined sewer overflows on receiving water quality: Benzo(a) pyrene and copper risks to recreational water. Journal of Environmental Management 207, 32-42 https://doi.org/10.1016/j.jenvman.2017.11.014

Brezonik PL, Stadelmann TH (2002): Analysis and predictive models of stormwater runoff volumes, loads, and pollutant concentrations from watersheds in the Twin Cities metropolitan area, Minnesota, USA. Water Research 36, 1743-1757 https://doi.org/10.1016/S0043-1354(01)00375-X

C.Maniquiz M, Lee S, Kim L-H (2010): Multiple linear regression models of urban runoff pollutant load and event mean concentration considering rainfall variables. Journal of Environmental Sciences 22, 946-952 https://doi.org/10.1016/S1001-0742(09)60203-5

Chan FKS, Griffiths JA, Higgitt D, Xu S, Zhu F, Tang Y-T, Xu Y, Thorne CR (2018): “Sponge City” in China—A breakthrough of planning and flood risk management in the urban context. Land Use Policy 76, 772-778 https://doi.org/10.1016/j.landusepol.2018.03.005

Cheng M, Qin H, Fu G, He K (2020): Performance evaluation of time-sharing utilization of multi-function sponge space to reduce waterlogging in a highly urbanizing area. Journal of Environmental Management 269, 110760https://doi.org/10.1016j.jenvman.2020.110760

Drapper D, Tomlinson R, Williams P (2000): Pollutant Concentrations in Road Runoff: Southeast Queensland Case Study. Journal of Environmental Engineering 126, 313-320 DOI:10.1061/(ASCE)0733-9372(2000)126:4(313)

Field R, Borst M, O'Connor TP, Stinson MK, Fan CY, Perdek JM, Sullivan D (1998): Urban wet-weather flow management: Research directions. Journal of Water Resources Planning and Management 124, 168-180 DOI:10.1061/(ASCE)0733-9496(1998)124:3(168)

Fletcher TD, Shuster WD, Hunt WF, Ashley R, Butler D, Arthur S, Trowsdale S, Barraud S, Semadenidavies A, Bertrandkrajewski JL (2015): SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. Urban Water Journal 12, 525-542 DOI:10.1080/1573062X.2014.916314

Gasperi J et al. (2014): Micropollutants in urban stormwater: occurrence, concentrations, and atmospheric contributions for a wide range of contaminants in three French catchments. Environmental Science and Pollution Research 21, 5267-5281 http://dx.doi.org/10.1007/s11356-013-2396-0

Geng X, Wen S-L, Sun P-R, Xu C-T, Li D-P, Huang Y (2019): Environmental Significance of Phosphorus Fractions of Phytoplankton-and Macrophyte-Dominated Zones in Taihu Lake. Huan jing ke xue 40, 5358-5366 DOI:10.13227/j.hjkx.201907015

Hou J, Zhu M, Wang Y, Sun S (2020): Optimal spatial priority scheme of urban LID-BMPs under different investment periods. Landscape and Urban Planning 202, 103858https://doi.org/10.1016j.landurbplan.2020.103858

Huang F (2020): Problems and Countermeasures of greening in small towns. Modern Horticulture 43, 155-156 DOI:10.14051/j.cnki.xdyy.2020.17.076

Huayang G, Muning Z, Dingqiang L, Yongzhang Z (2006): Water quality characteristics of urban road runoff in Guangzhou. Ecology and Environment, 969-973 DOI:10.16258/j.cnki.1674-5906.2006.05.016

Janet B, Sergio P, K SM (2008): First flush in a combined sewer system. Chemosphere 71, 827-833 https://doi.org/l0.1016/j.chemosphere.2007.11.049

Jing Z, Yuwen Z, Zhongzheng W, Chun L, Shuqi Z, Wei L (2016): Characteristics of Ammonia Nitrogen Pollution in Natural Rainfall of Chinese Northern City. Environmental Science & Technology 39, 129-134 DOI:10.3969/j.issn.1003-6504.2016.06.024

Kang A, Lou K, Xiao P, Kou C (2016): Study on pollution characteristics and emission law of pavement runoff in Yangzhou City. HIGHWAY 61, 212-216

Kayhanian M, Fruchtman BD, Gulliver JS, Montanaro C, Ranieri E, Wuertz S (2012): Review of highway runoff characteristics: Comparative analysis and universal implications. Water Research 46, 6609-6624 https://doi.org/10.1016j.watres.2012.07.026

Klimaszewska K, Polkowska Z, Namiesnik J (2007): Influence of Mobile Sources on Pollution of Runoff Waters from Roads with High Traffic Intensity. Polish Journal of Environmental Studies 16, 889-897

Ling-xiao Y, Lu-jian H, Bo L, Wen-xing W, Xue-hua Z, Zhe W, Yang Z, Shu-hui C (2007): Study on the water-soluble ions in fine particle matter and the long-range transport of air masses in the city of Jinan. JOURNAL OF SHANDONG UNIVERSITY (ENGINEERING SCIENCE), 98-103 DOI:10.3969/j.issn.1672-3961.2007.04.021

Liu Q, Gao Y, Xu X (2012): An Ecological Dynamics Model of Algae Growth in Taihu Lake and the Analysis of Its Influencing Factors. In: Iranpour R, Zhao J, Wang A, Yang FL , Li X (Editors), Advances in Environmental Science and Engineering, Pts 1-6. Advanced Materials Research, pp. 4961-4966 DOI:10.4028/www.scientific.net/AMR.518-523.4961

Lucke T, Drapper D, Hornbuckle A (2018): Urban stormwater characterisation and nitrogen composition from lot-scale catchments - New management implications. Science of the Total Environment 619, 65-71 https://doi.org/10.1016/j.scitotenv.2017.11.105

Mangani G, Berloni A, Bellucci F, Tatàno F, Maione M (2005): Evaluation of the Pollutant Content in Road Runoff First Flush Waters. Water, Air, and Soil Pollution 160, 213–228 DOI:10.1007/s11270-005-2887-9

Muller A, Osterlund H, Marsalek J, Viklander M (2020): The pollution conveyed by urban runoff: A review of sources. The Science of the total environment 709, 136125-136125 https://doi.org/10.1016/j.scitotenv.2019.136125

Müller A, Österlund H, Nordqvist K, Marsalek J, Viklander M (2019): Building surface materials as sources of micropollutants in building runoff: A pilot study Science of the Total Environment 680, 190-197 https://doi.org/10.1016/j.scitotenv.2019.05.088

Paerl HW, Xu H, McCarthy MJ, Zhu G, Qin B, Li Y, Gardner WS (2011): Controlling harmful cyanobacterial blooms in a hyper-eutrophic lake (Lake Taihu, China): The need for a dual nutrient (N & P) management strategy. Water Research 45, 1973-1983 https://doi.org/10.1016/j.watres.2010.09.018

Pagotto C, Legret M, Cloirec PL (2000): Comparison of the hydraulic behaviour and the quality of highway runoff water according to the type of pavement. Water Research 34, 4446-4454 https:/doi.org/10.1016/S0043-1354(00)00221-9

Peng H-Q, Liu Y, Wang H-W, Gao X-L, Ma L-M (2016): Event mean concentration and first flush effect from different drainage systems and functional areas during storms Environmental Science and Pollution Research 23, 5390-5398 http://dx.doi.org/10.1007/s11356-015-5657-2

Polukarova M, Markiewicz A, Bjorklund K, Stromvall A-M, Galfi H, Skold YA, Gustafsson M, Jarlskog I, Aronsson M (2020): Organic pollutants, nano- and microparticles in street sweeping road dust and washwater. Environment International 135, 105337 https://doi.org/10.1016/j.envint.2019.105337

Qian-qian Z, Xiao-ke W, Li-ling H, Pei-qiang H, Zhi-yun O (2012): Characterization and Source Apportionment of Pollutants in Urban Roadway Runoff in Chongqing. ENVIRONMENTAL SCIENCE 33, 76-82 DOI:10.13227/j.hjkx.2012.01.026

Shao W, Zhou J, Liu J, Xie P, Yang Z, Li W (2020): Characteristics and effectiveness of water management methods for 'sponge cities' in China. Proceedings of the Institution of Civil Engineers-Water Management 173, 163-171 https://doi.org/10.1680/jwama.19.00016

Shun G, Lili T, Wei Q, Ming D, Mindong C (2015): Characteristics Analysis of Haze and Water-soluble Ion in Nanjing

in Autumn. Environmental Science & Technology 38, 99-104 DOI:10.3969/j.issn.1003-6504.2015.02.019

Stotz G (1987): Investigations of the properties of the surface water run-off from federal highways in the FRG. Science of the Total Environment 59(1987), 329-337 https://doi.org/10.1016/0048-9697(87)90456-6

Wang H, Mei C, Liu J, Shao W (2018): A new strategy for integrated urban water management in China: Sponge city. Science China Technological Sciences 61, 317-329 DOI:10.1007/s11431-017-9170-5

Wang L, Wei J, Huang Y, Wang G, Maqsood I (2011): Urban nonpoint source pollution buildup and washoff models for simulating storm runoff quality in the Los Angeles County. Environmental Pollution 159, 1932-1940 https://doi.org/10.1016/j.envpol.2011.03.019

Wu J, Ren Y, Wang X, Wang X, Chen L, Liu G (2015): Nitrogen and phosphorus associating with different size suspended solids in roof and road runoff in Beijing, China. Environmental Science and Pollution Research 22, 15788-15795 http://dx.doi.org/10.1007/s11356-015-4743-9

Xi Z, Yun Z (2019): Problems and countermeasures of controlling cyanobacteria bloom in Taihu Lake. Journal of Environmental Engineering Technology 9, 714-719 https://doi.org/10.12153/j.issn.1674-991X.2019.07.080

Xiang C, Wang Y, Liu H (2017): A scientometrics review on nonpoint source pollution research. Ecological Engineering 99, 400-408 https://doi.org/10.1016/j.ecoleng.2016.11.028

Yu C, Li Z, Xu Z, Yang Z (2020): Lake recovery from eutrophication: Quantitative response of trophic states to anthropogenic influences. Ecological Engineering 143, 105697DOI:https://doi.org/10.1016/j.ecoleng.2019.105697

Yufen R, Xiaoke W, Zhiyun O, Hua Z, Xiaonan D, Hong M (2008): Stormwater Runoff Quality from Different Surfaces in an Urban Catchment in Beijing, China. Water Environment Research 80, 719-724 DOI:10.2175/106143008X276660

Zgheib S, Moilleron R, Chebbo G (2012): Priority pollutants in urban stormwater: Part 1-Case of separate storm sewers. Water Research 46, 6683-6692 https://doi.org/10.1016/j.watres.2011.12.012

Zhenyao S, Jin L, Guzhanuer A, Yongwei G (2016): A comparative study of the grain-size distribution of surface dust and stormwater runoff quality on typical urban roads and roofs in Beijing, China. Environmental science and pollution research international 23, 2693-2704 http://dx.doi.org/10.1007/s11356-015-5512-5

Figures

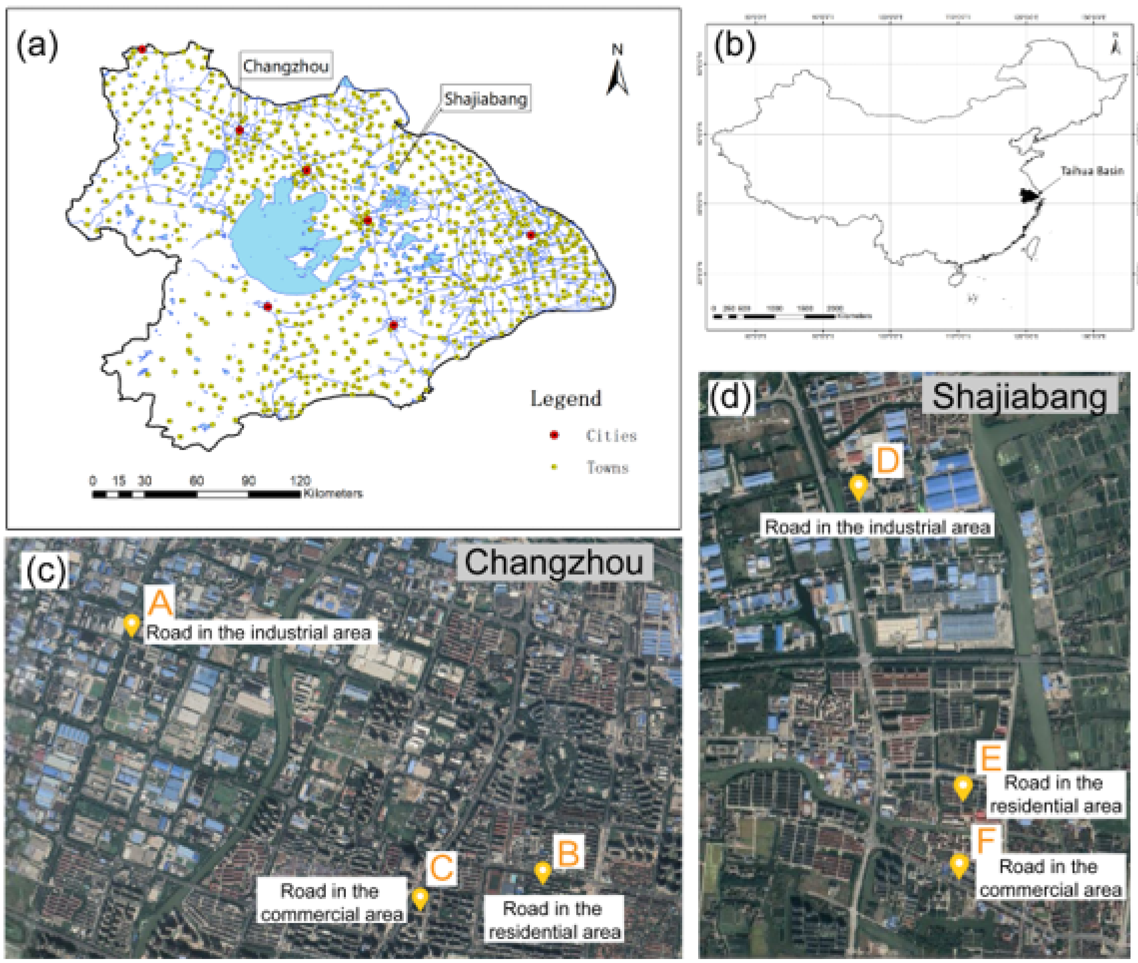

Figure 1

Study area and locations of sampling sites in the Taihu Basin, China. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

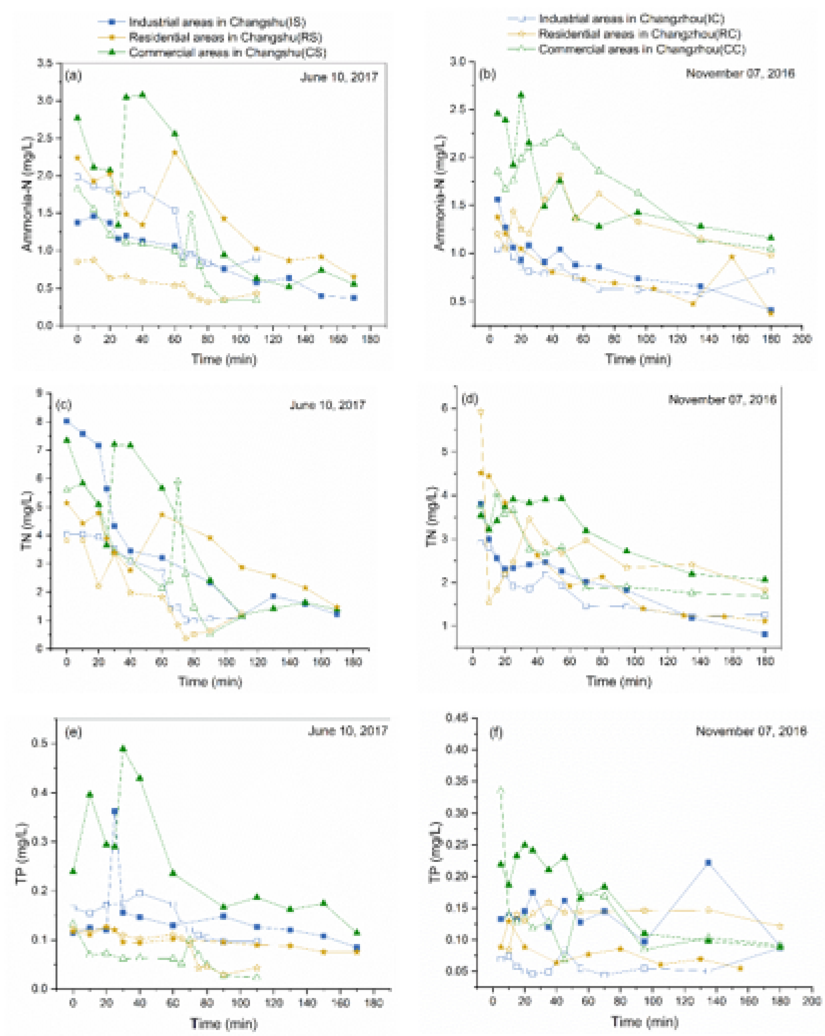

Figure 2

Outflow concentrations of ammonia-N, TN, and TP during the two representative rainfall events

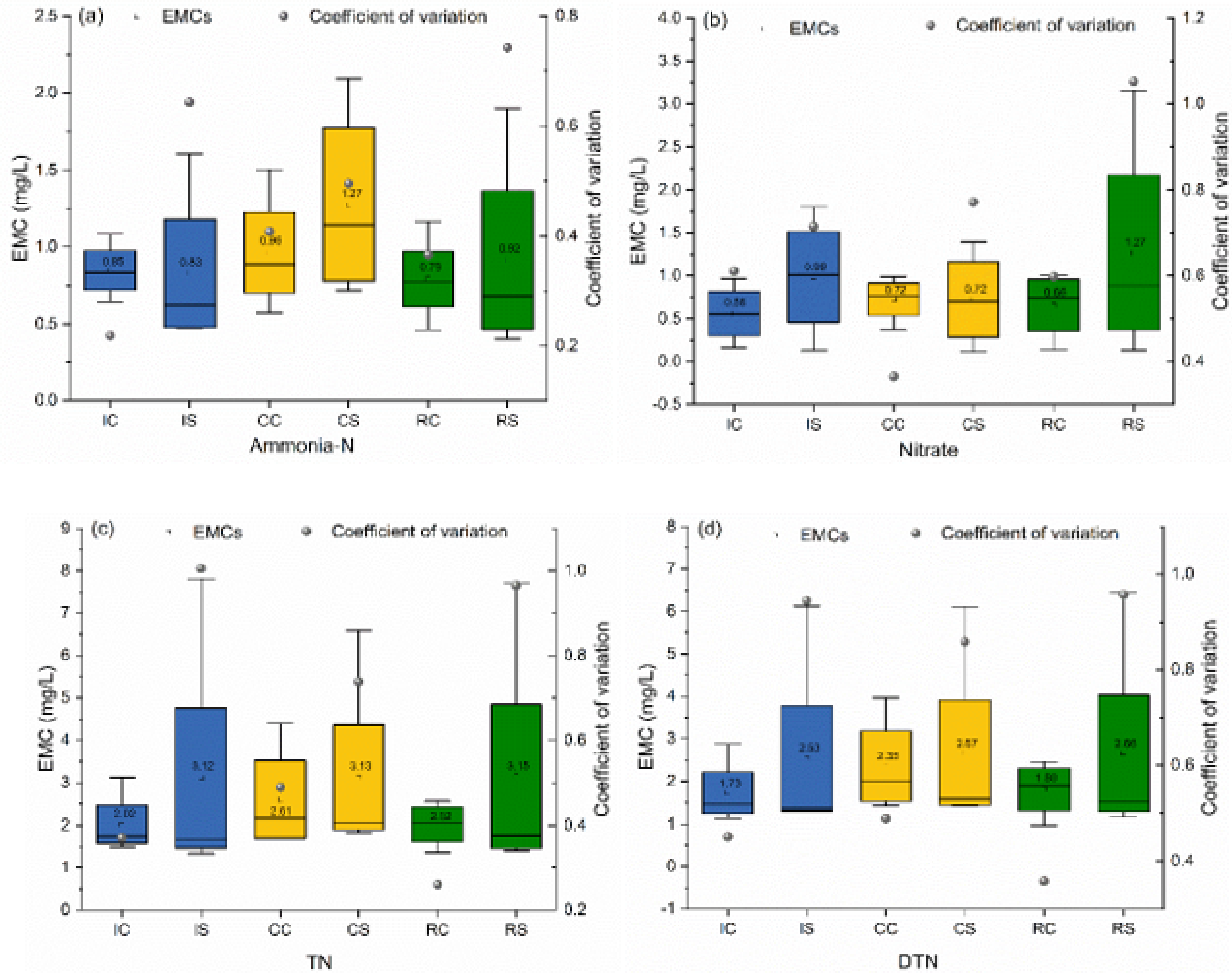

Figure 3

Box-plot for EMC values of ammonia-N, nitrate, TN, and DTN

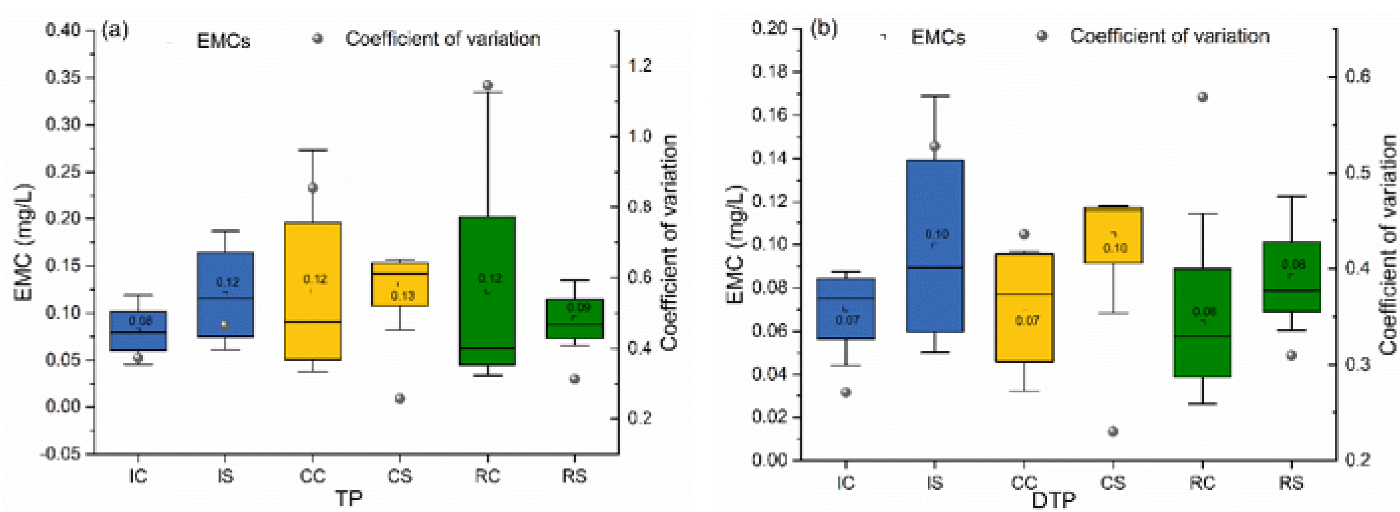

Figure 4

Box-plot for EMC values of TP and DTP

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