Design optimization for bioretention systems
植物滞留系统结构优化

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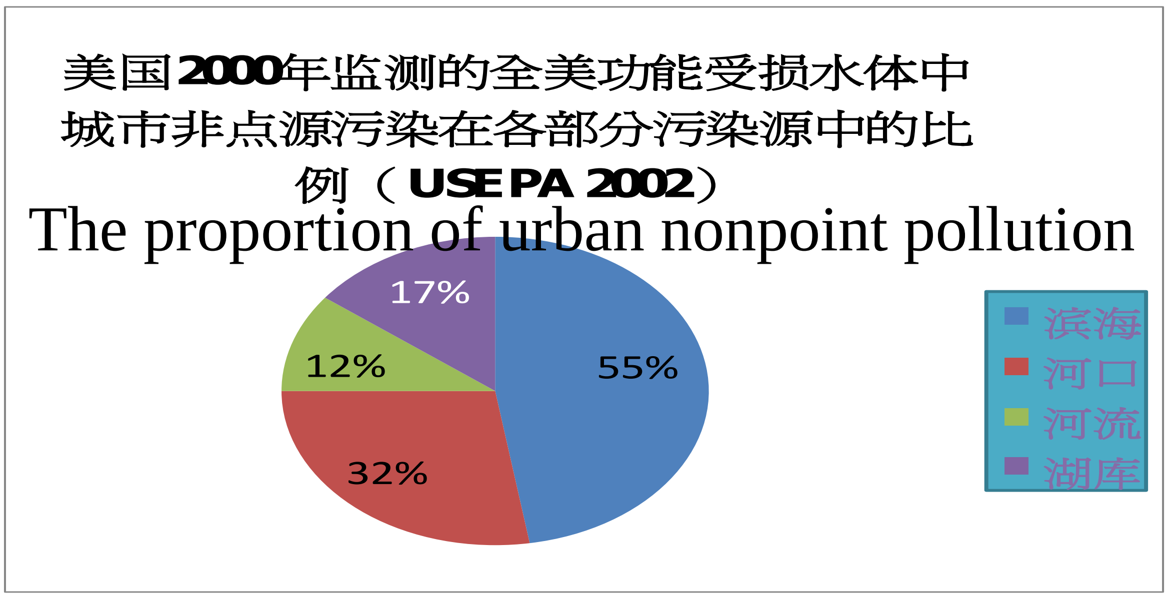
Contents

1. Background

- Rainfall runoff is the driving force of urban nonpoint source pollution.
- Urban or rural nonpoint source pollution is already close to or more than point source pollution.

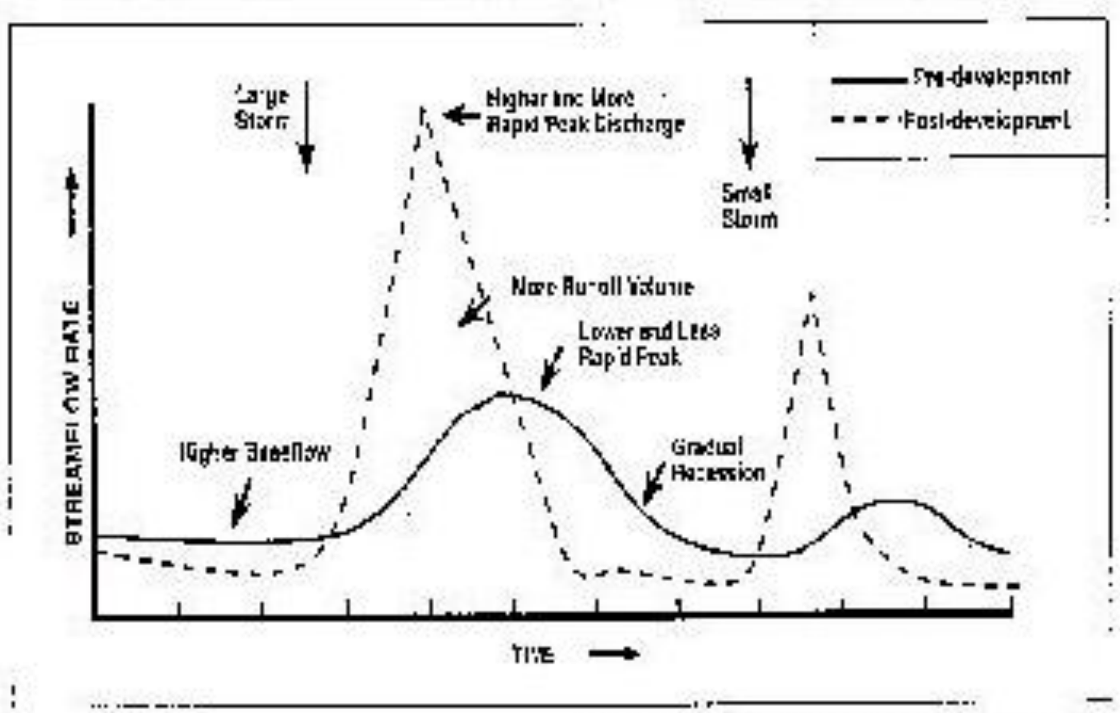


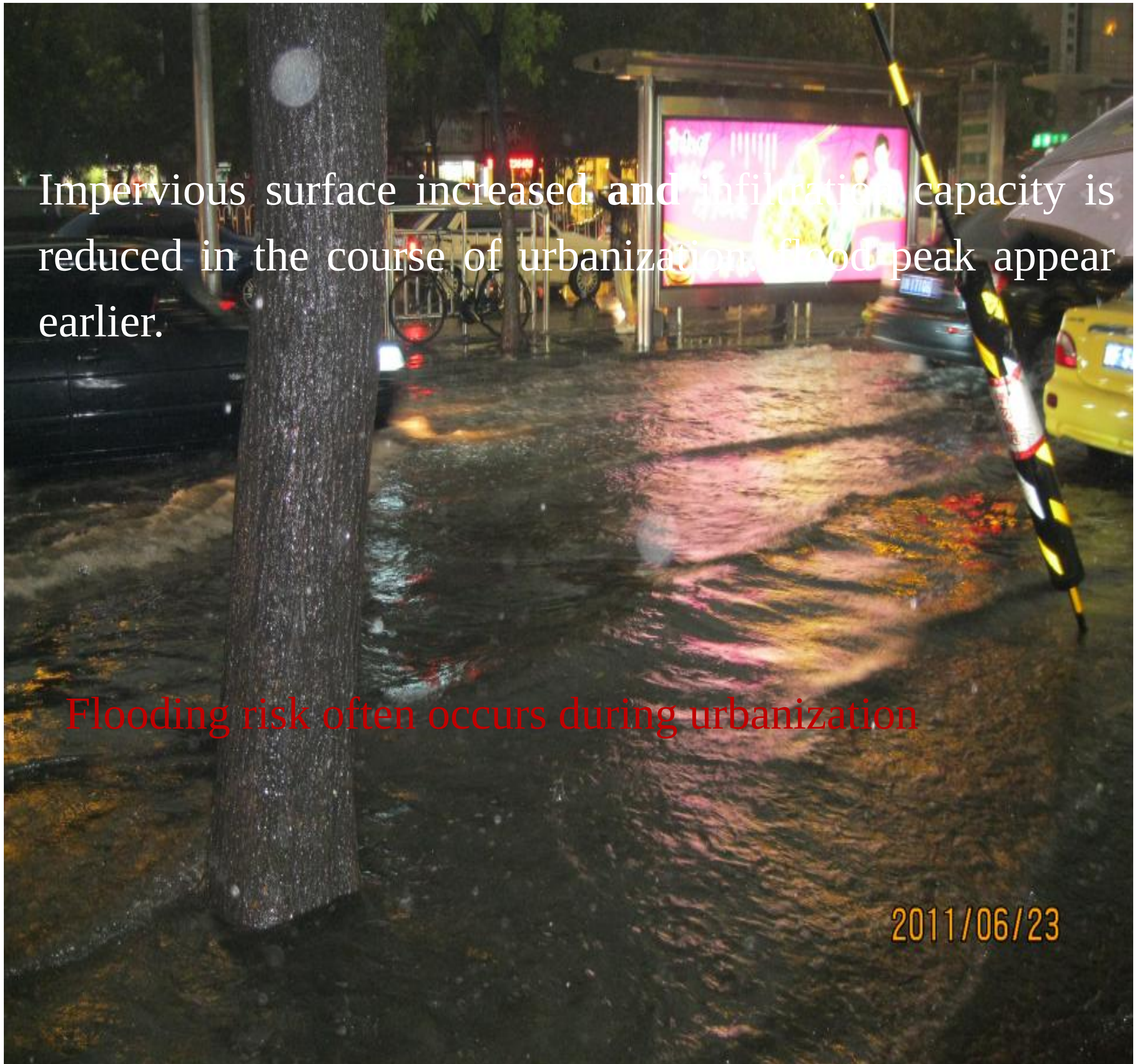
The proportion of urban nonpoint pollution

Water quality deterioration due to urban nonpoint source pollution

Hydrology in the urbanized condition

This graph illustrates the effects of urbanization on hydrograph peak discharge. In pre-developed conditions, flow gradually increases to a relatively flat peak and gradually descends to a low flow condition. In the urbanized condition, flow rapidly increases to a peak and just as sharply descends, often to a lower flow condition than pre-development.





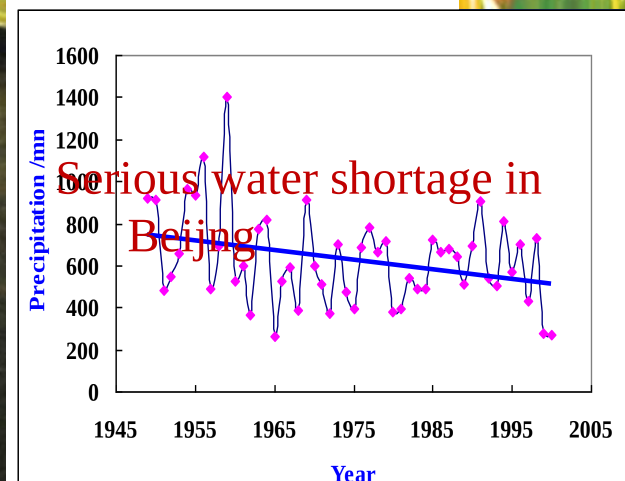
Impervious surface increased and infiltration capacity is reduced in the course of urbanization. Flood peak appear earlier.

Flooding risk often occurs during urbanization

Urban Stormwater：

北京市在严重缺水的同时，还面临着汛期雨洪的威胁.

Serious water shortage in Beijing



Average precipitation in Beijing

Management practices for controlling urban nonpoint source pollution:

- Best Management Practice (BMP) /LID in America
- Sustainable Urban Drainage System(SUDS) in England
- Low Impact Urban Design and Development System in New Zealand
- Water Sensitive Urban Design in Australia

- Bioretention system is one of the most important BMPs/LID for controlling urban nonpoint source pollution.

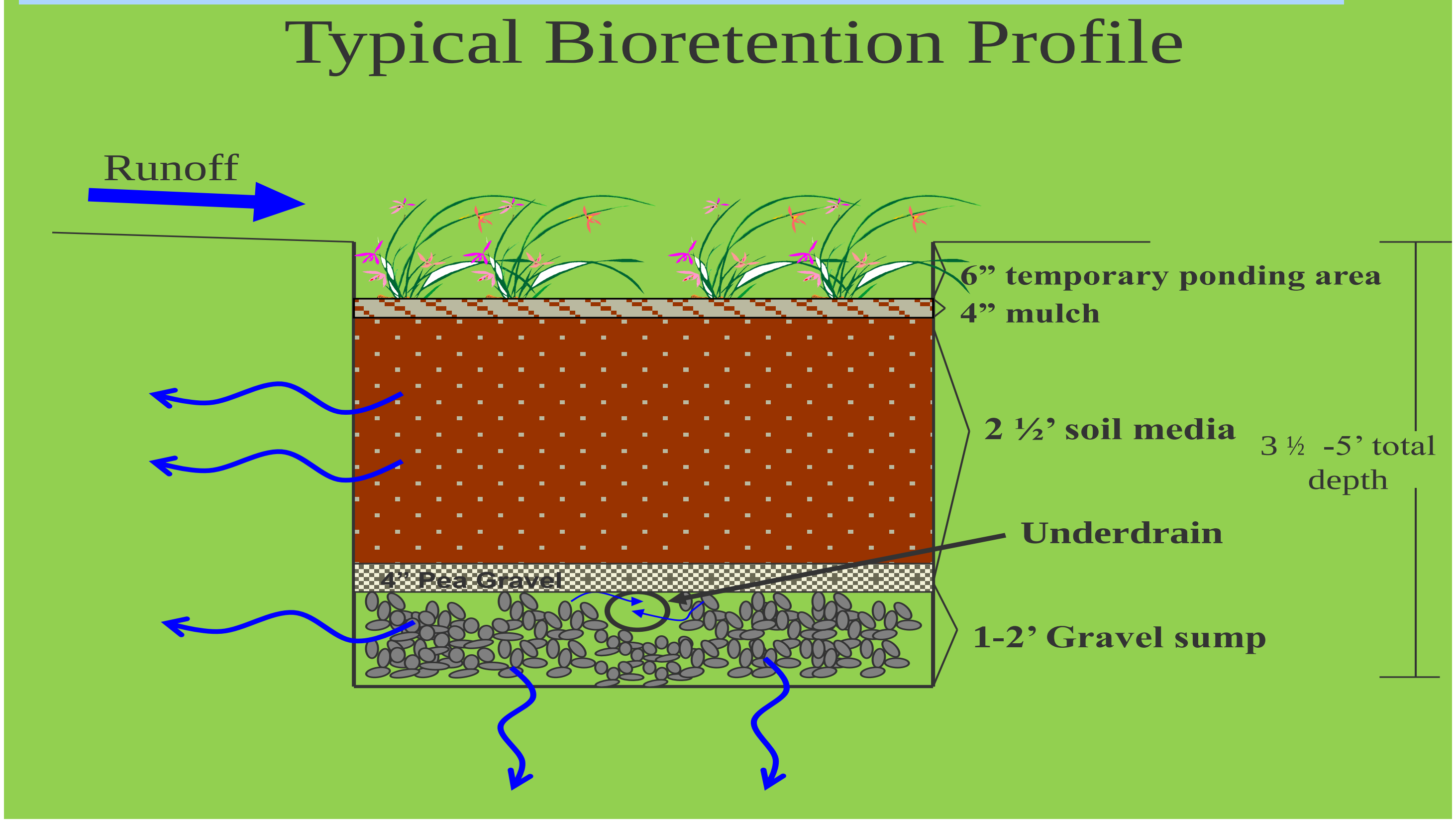
Bioretention functions

- Water Quantity Treatment
- Water Quality Treatment
- Groundwater Recharge
- Wildlife Habitat
- Micro-Climate Alteration
- Vegetative Buffering
- Natural Area Protection
- Aesthetic Improvement

Bioretention structure

Source from http://www.google.com.hk/imgres?imgurl=http

滞留层、覆盖层、种植层、土壤层、砂砾层等



Bioretention systems in America

Bioretention system planning in Beijing

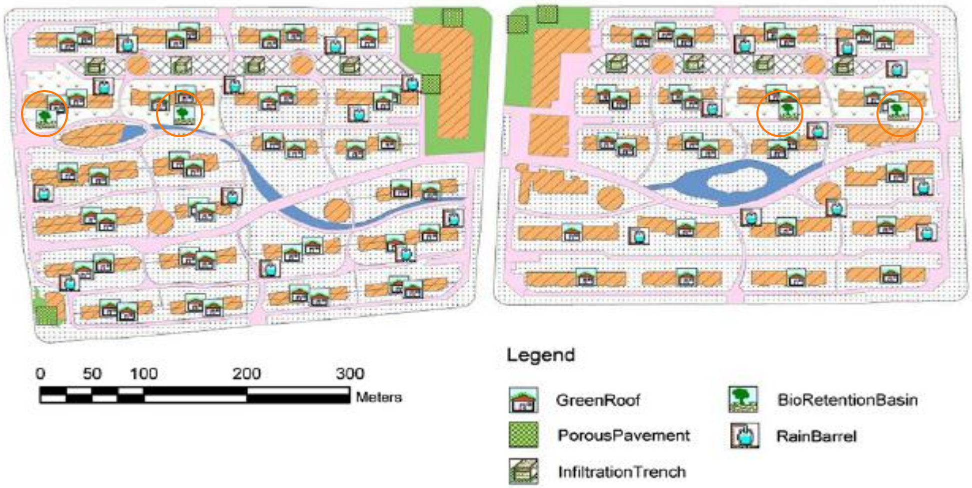


Figure – Jia et al.,2012.

The Goal of The Present Study

- **It is difficult to design the bioretention systems so that their effectiveness can be maximized. Design optimization includes the optimal selection of media and plants. Research is needed to provide good guidance on designing bioretention systems.**
- **Planners and designers also need efficient and reliable tools to simulate the processes and evaluate the effectiveness of these facilities so that an optimal stormwater management system can be identified.**
- **The goals of the study are to determine the optimal selection of the media and plants for a bioretention system, and to develop an assessment tool for such systems.**

A study on bioretention system

Design optimization

- **Soil media selection for pollutant removal**
- **Plant selection for pollutant removal**
- **Comprehensive assessment tool development**

2. Soil selection

Soil media selection for pollutant removal

- Sampling
- Experiment
- Analysis

Sampling

采样点 ①

采样点 ②


①
Soil media
2011/06/11


②
2011/06/12


③
2011/06/12


④
2011/06/12

- Vermiculite
- Haydite
- Perlite
- Bark of white poplar
- Bark of sophora japonica

①

②

⑤

③

④

Experiment

Construction of experimental device

Experiment

Analysis

Table 1 Characteristics of bioretention media

					Sand	Clay	Silt	Classification
mm	d_{10}	d_{60}	d_{60}/d_{10}	PH	%	%	%	Sand
Media I	0.072	0.22	3	9.05	96	4	0	Sand砂土
Media Ⅱ	0.05	0.1	2	9.11	90	10	0	Sand砂土
Media Ⅲ	0.005	0.088	17.6	8.68	61	37	2	Sandy clay砂质粘土
Media Ⅳ	0.05	0.23	4.6	9.17	89	11	0	Loamy sand砂质壤土
Media V	0.02	0.11	5.5	8.79	72	28	0	Sandy clay loam砂质粘壤土
Media Ⅵ	0.026	0.246	9.5	9.03	85	15	0	Loamy sand砂质壤土
Media VII	0.009	0.061	6.8	8.28	52	44	4	Sandy clay砂质粘土

Removal efficiency of each pollutant for soil media selection

Analysis

NH^+_4 –N Removal rate (%)

NO^-_3 –N Removal rate (%)

TP Removal rate (%)

Index

Different Media

Different Media Depths

Different Inflow concentrations

Different media

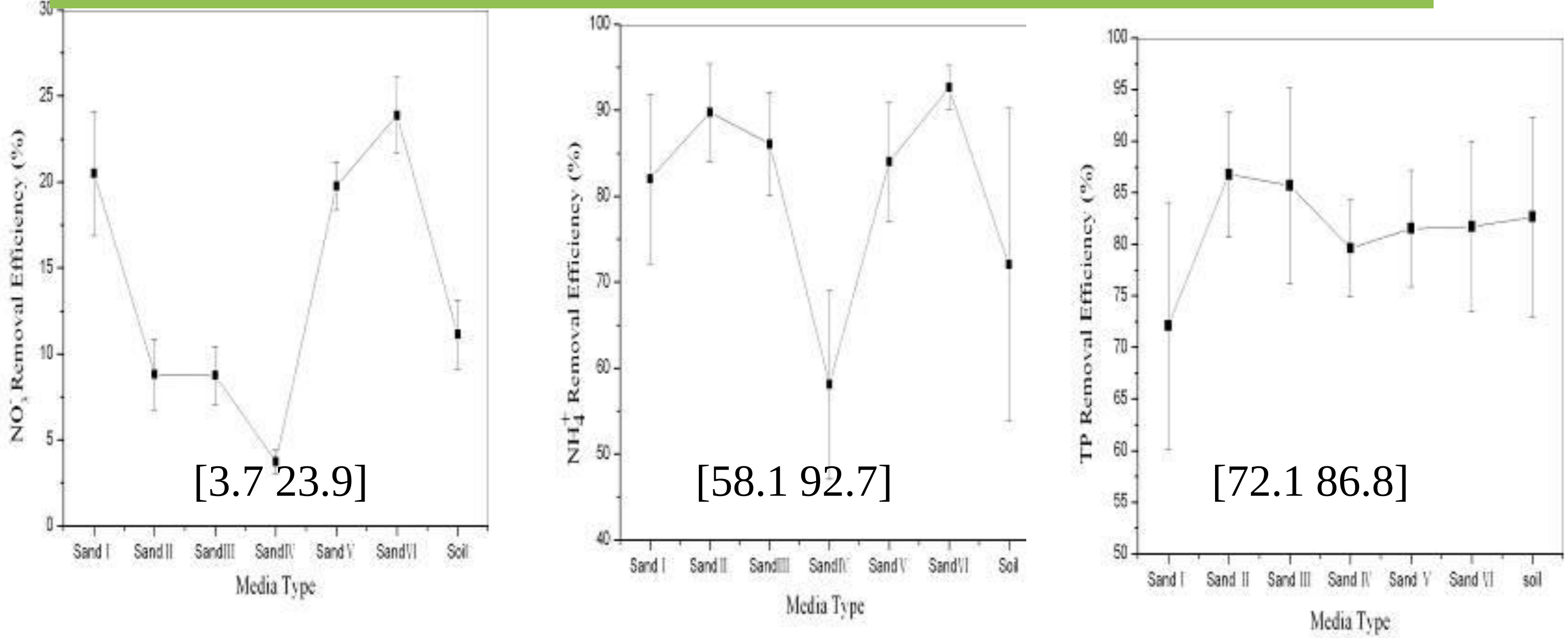
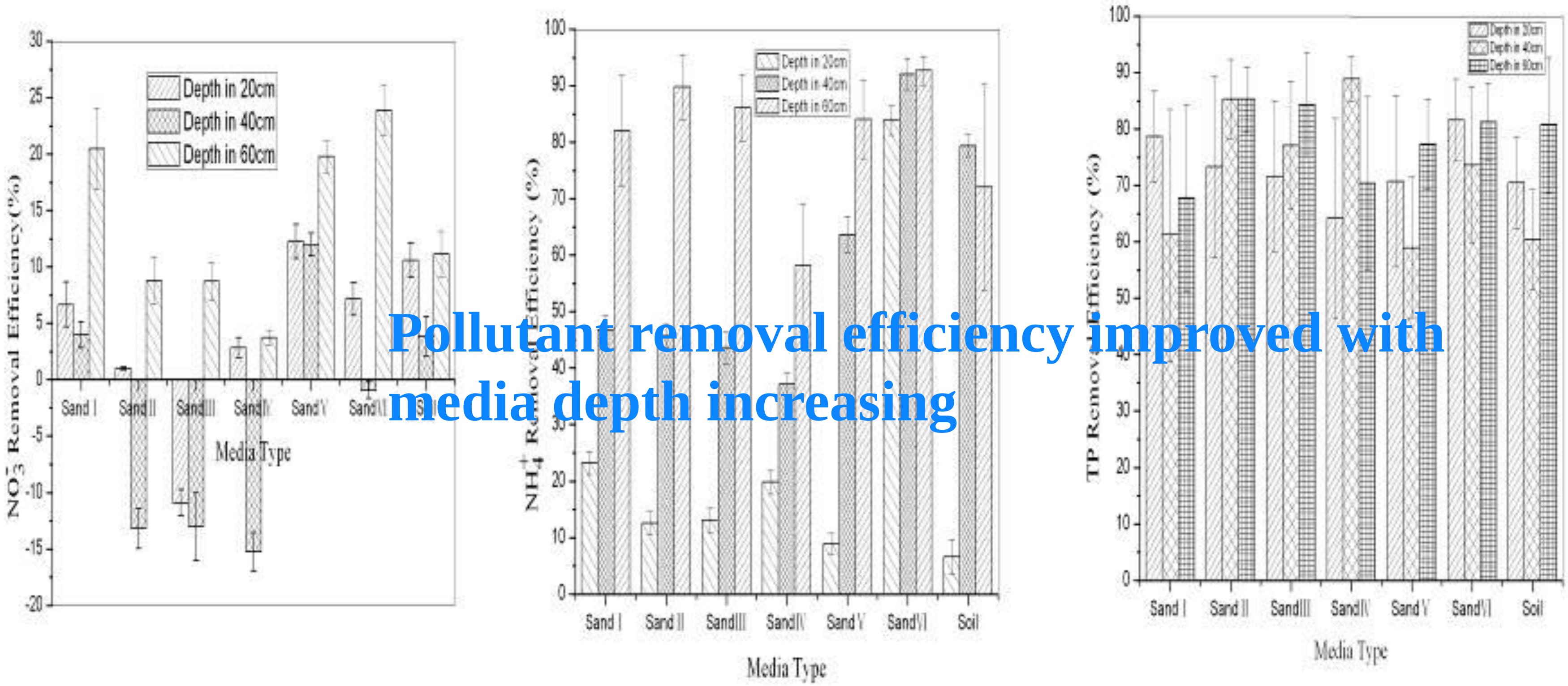


Figure 1 Pollutant removal efficiencies by different media

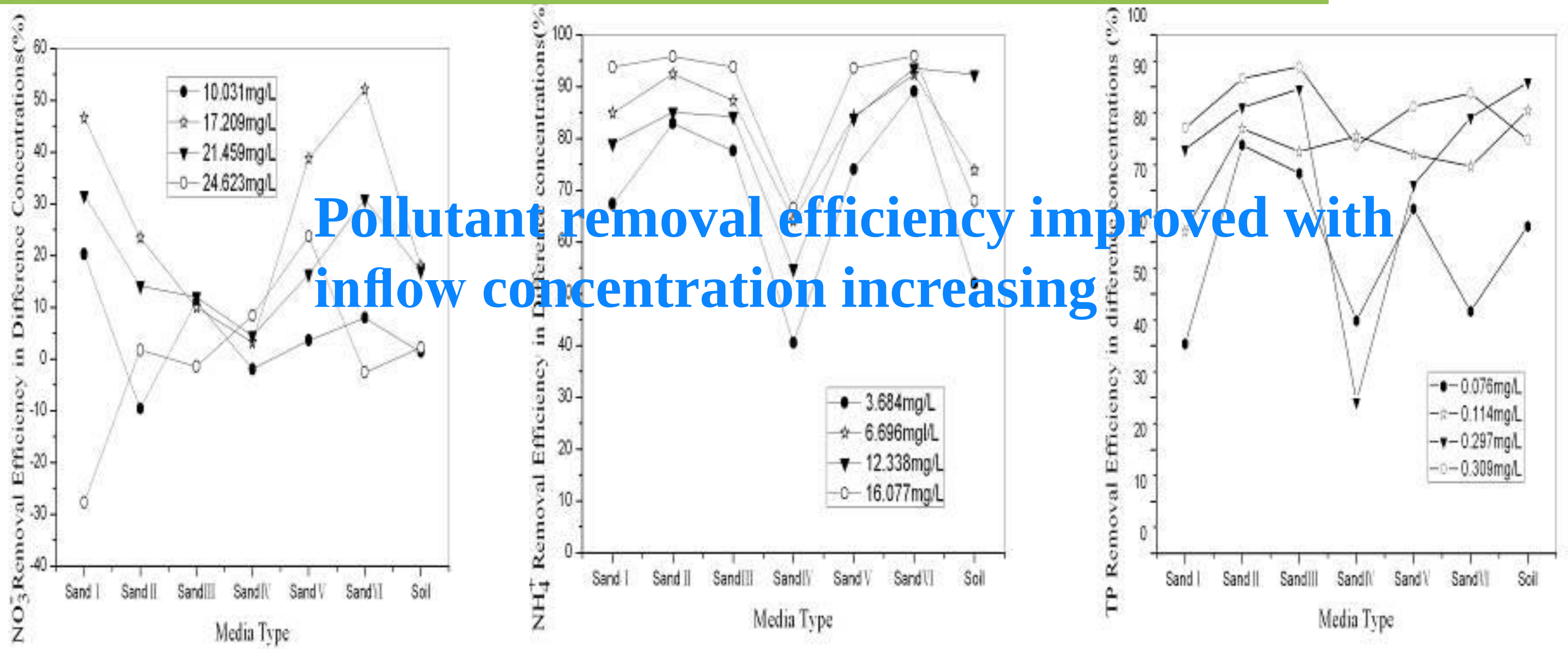
Different media depths



Pollutant removal efficiency improved with media depth increasing

Figure 2 Pollutant removal efficiencies for different media depths

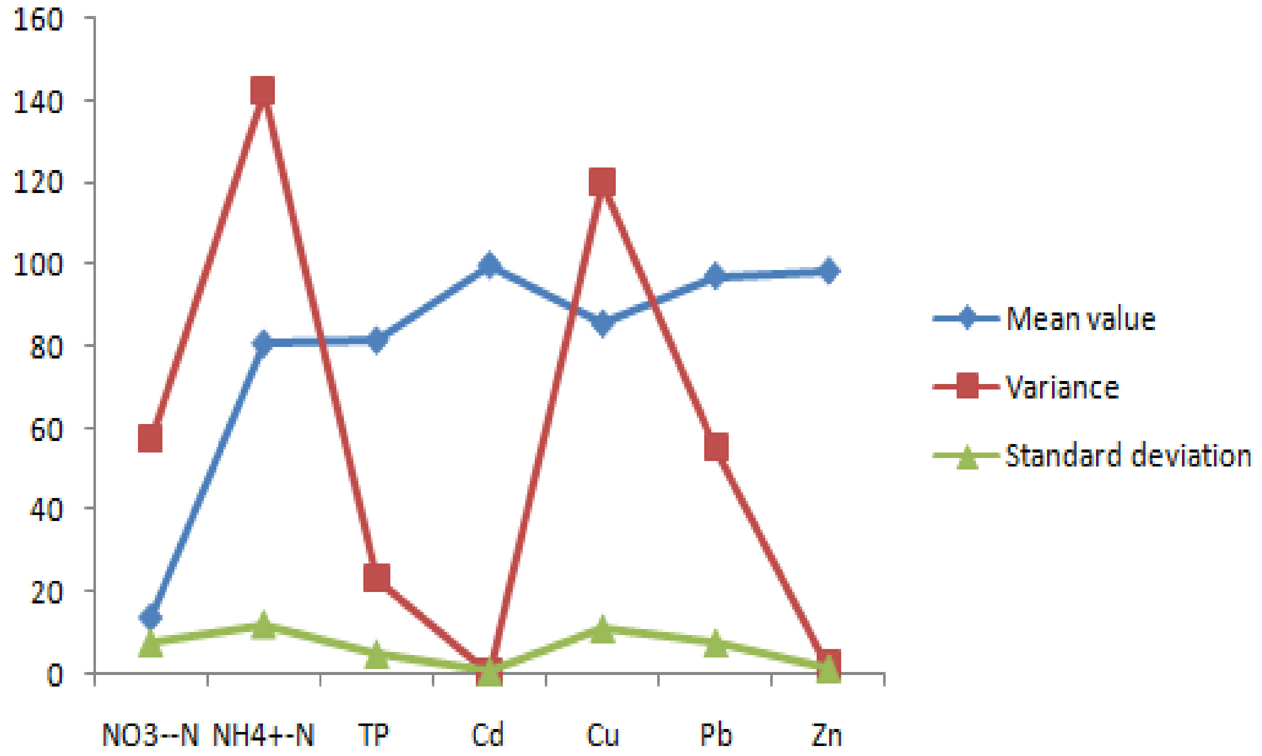
Different inflow concentrations



Pollutant removal efficiency improved with inflow concentration increasing

Figure 3 Pollutant removal efficiencies in the different inflow concentrations

Statistical analysis for pollutant removal efficiency



3. Plant selection

•Selection condition

All species are native;
Each species can be alive in a sandy loam;
Plants are potentially suitable both in wet and in dry condition.

•Simulation experiment

Pollutants: NO^-_3 –N ， NH^+_4 –N ，TP，Cd，Cu，Zn，Pb;
Plants:20 species

•Result analysis

Pollutants: NO^-_3 –N ， NH^+_4 –N ，TP，Cd，Cu，Zn，Pb
Plants:20 species

Selection condition

Plant transplanting

黄花菜1Hem citLiliaceae/Hemerocallis citrina Baroni、景天2Hyl eryCrassulaceae*Hylotelephium erythrostictum* (Miq.) H. Ohba 景观植物在校园里有种植。

景观植物在校园里有种植





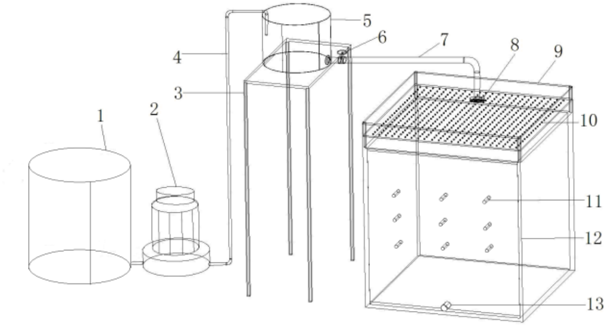
植物：
马唐、车前、狗尾草、
反枝苋、山麦冬、葎草等。

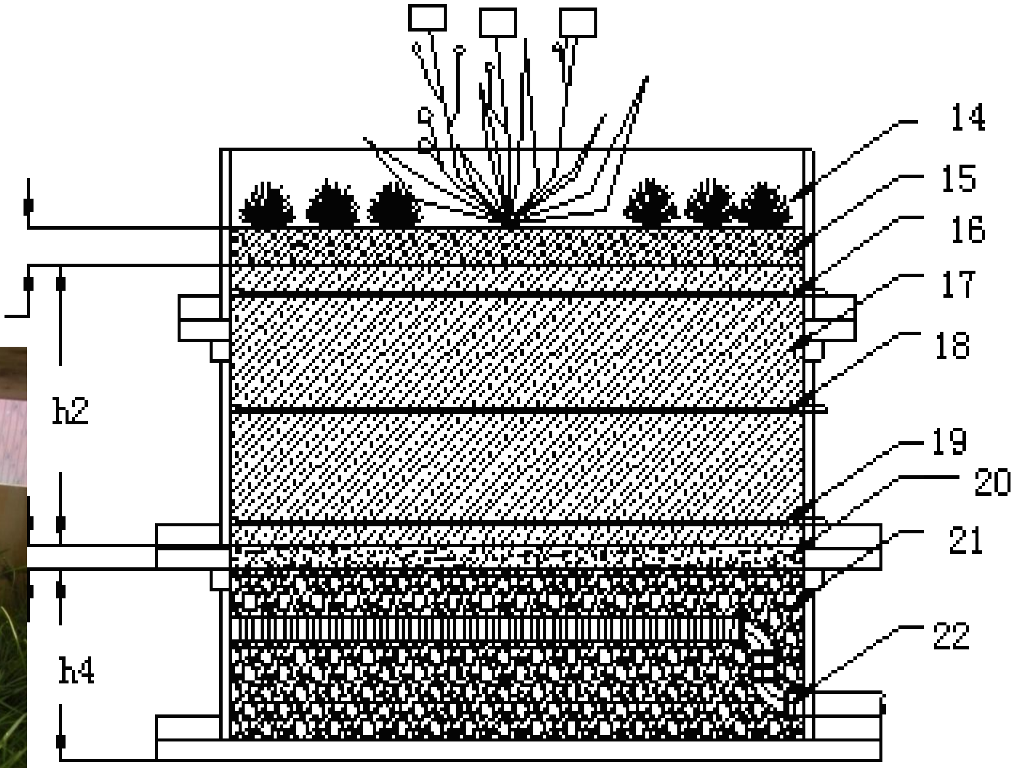
Plant classification

Table 2 Plants used in experiment

Order	Abbreviation of Species	Species
1	H. C.	*Hemerocallis citrina*
2	H. E.	*Hylotelephium erythrostictum*
3	P.A.	*Plantago asiatica*
4	A.R.	*Amaranthus retroflexus*
5	A.T.	*Aster tataricus*
6	P.A.	*Pennisetum alopecuroides*
7	S.I.	*Saussurea iodostegia*
8	C.A.	*Chenopodium album*
9	R.G.	*Rehmannia glutinosa*
10	H.S.	*Humulus scandens*
11	L.S.	*Liriope spicata*
12	S.O.	*Sonchus oleraceus*
13	H.P.	*Hosta plantaginea*
14	A.I.	*Artemisia iavandulaefolia*
15	S.O.	*Sanguisorba officinalis*
16	D.S.	*Digitaria sanguinalis*
17	A.M.	*Abelmoschus manihot*
18	H.T.	*Herba Taraxaci*
19	C.L.	*Chlorophytum laxum*

Simulation experiment

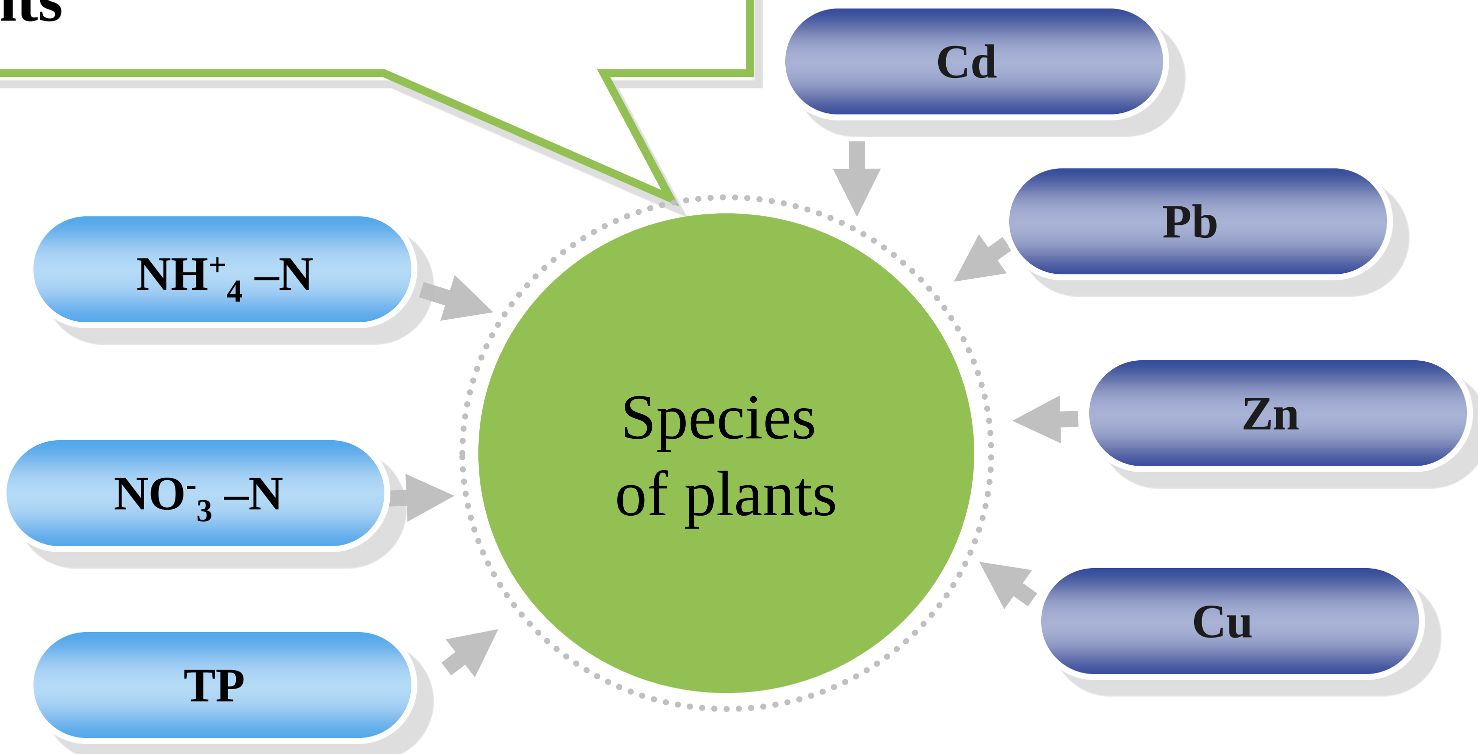




Experimental device

Simulation experiment

Pollutants removal by plants



Plant species and pollutants used in experiments

Synthetic stormwater

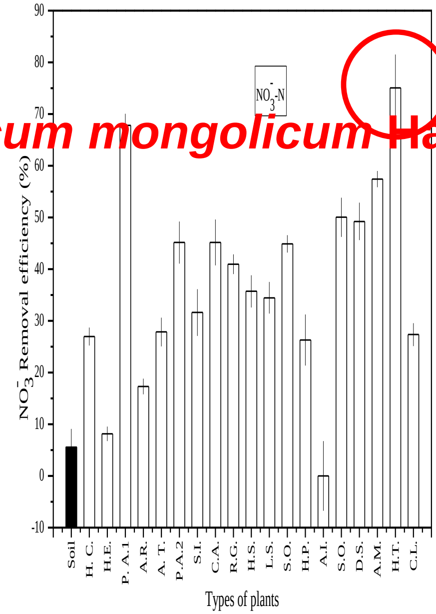
Table 3 Characteristics of the synthetic stormwater in experiments

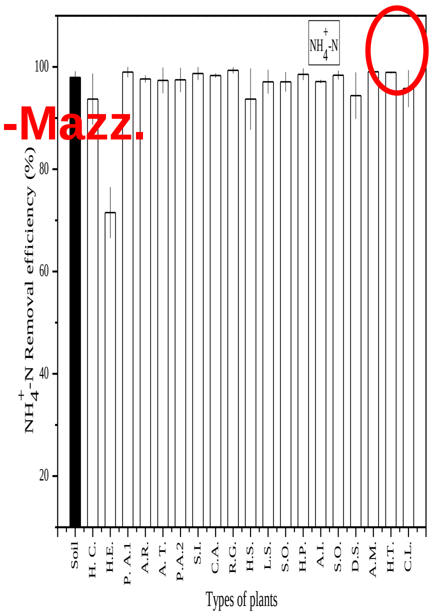
Pollutants	Chemical	Concentration(mg/L except for PH)
PH	HCl or NaOH	7.0±0.5
Nitrate (mg/L as N)	$NaNO_3$	30 (as N)
Ammonium (mg/L as N)	NH_4Cl	21 (as N)
Phosphorus (mg/L as P)	Na_2HPO_4	0.7 (as P)
Cadmium	$Cd(NO_3)_2$	0.048
Zinc	$ZnCI_2$	1.44
lead	$PbCl_2$	0.16
Copper	$CuSO_4$	0.17

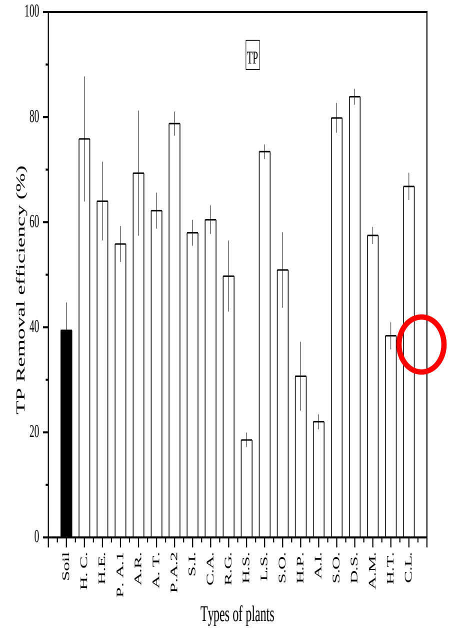
Result analysis

蒲公英

Taraxacum mongolicum Hand.-Mazz.



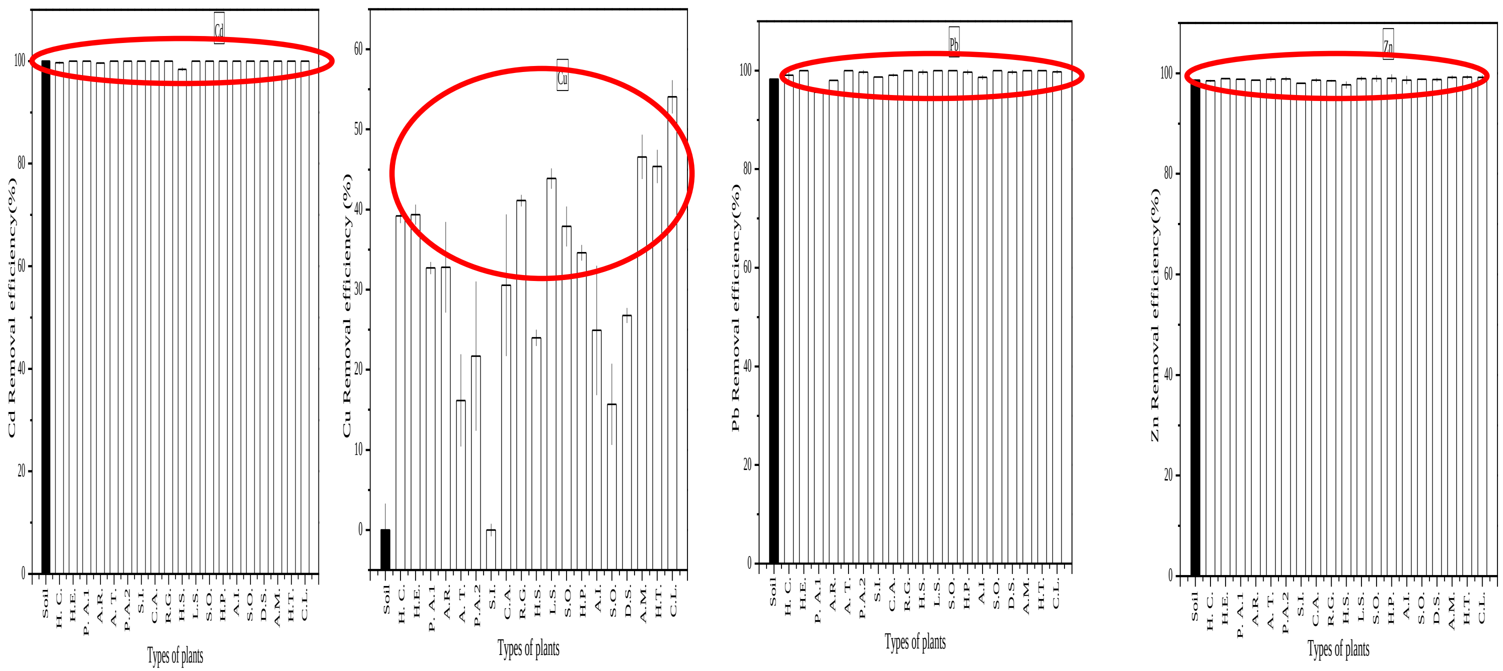




NO_3—N:15%, NH_4^+-N :>90%,TP:[19 91]

Removal efficiency of **NO^-_3 –N,** NH_4^+-N,TP

蒲公英：81、99、38



Cd:98%,Cu:20%,Pb:95%,Zn:97%

Removal efficiency of Cd、Cu 、 Pb 、 Zn

蒲公英：100、45、100、99

4. Comprehensive assessment

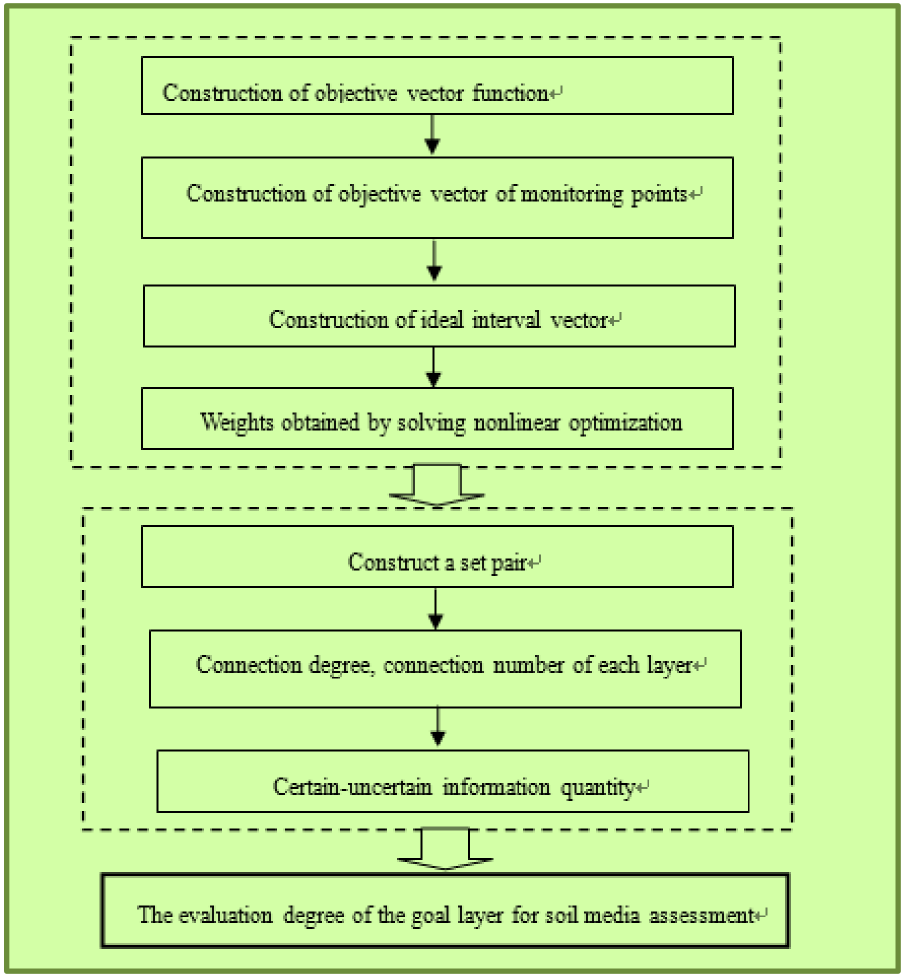
Mathematical models for assessing pollutant removal by media and plants were developed.

- **Assessment Indexes （ NO^-_3 –N ， NH^+_4 –N ， TP ，Cd ，Cu ，Zn ，Pb ）**

- **Assessment Grade**

- **Optimal Set Pair Analysis (OSPA) Model**
- **Artificial neural network model based on Genetic algorithm(ANNGA) Model**

OSPA model



Flow chart of OSPA model for the comprehensive assessment to soil media

Table 4 The calculation method of multivariate connection number of μ_{mq}

OSPA formulas	Index system for cost index	Index system for benefit index
$1+0i_1+\cdots+0i_{n-2}+0j$	$t_{mq} \le a_{mq1}$	$t_{mq} \ge a_{mq1}$
$\frac{\lvert t_{mq}-a_{mq2}\rvert}{\lvert a_{mq1}-a_{mq2}\rvert}+\frac{\lvert t_{mq}-a_{mq1}\rvert}{\lvert a_{mq1}-a_{mq2}\rvert}i_1+0i_2\cdots+0j$	$a_{mq1} \le t_{mq} \le a_{mq2}$	$a_{mq1} \ge t_{mq} \ge a_{mq2}$
$0+\cdots+\frac{\lvert t_{mq}-a_{mq(s+1)}\rvert}{\lvert a_{mqs}-a_{mq(s+1)}\rvert}i_{s-1}+\frac{\lvert t_{mq}-a_{mqs}\rvert}{\lvert a_{mqs}-a_{mq(s+1)}\rvert}i_s+\cdots+0j$	$a_{mqs} \le t_{mq} \le a_{mq(s+1)}$	$a_{mqs} \ge t_{mq} \ge a_{mq(s+1)}$
$0+\cdots+0i_{n-3}+\frac{\lvert t_{mq}-a_{mqn}\rvert}{\lvert a_{mq(n-1)}-a_{mqn}\rvert}i_{n-2}+\frac{\lvert t_{mq}-a_{mq(n-1)}\rvert}{\lvert a_{mq(n-1)}-a_{mqn}\rvert}j$	$a_{mq(n-1)} \le t_{mq} \le a_{mqn}$	$a_{mq(n-1)} \ge t_{mq} \ge a_{mqn}$
$0+0i_1+\cdots+0i_{n-2}+1j$	$t_{mq} \le a_{mqn}$	$t_{mq} \ge a_{mqn}$

Comprehensive assessment results for media selection

Table 5 Connection number and evaluation degree of bioretention media.

Media type	Five-member connection degree	Connection number	Evaluation grade
Media I	$\mu_{s1} = 0.716141 + 0.099851 i_1 + 0.1764 j$	0.5897	High
Media II	$\mu_{s2} = 0.4335 + 0.012788 i_1 + 0.204018 i_2 + 0.106564 j$	0.2249	High
Media III	$\mu_{s3} = 0.6404 + 0.156732 i_1 + 0.202868 j$	0.3592	High
Media IV	$\mu_{s4} = 0.299 + 0.093492 i_1 + 0.082908 i_2 + 0.5246 j$	-0.2671	Low
Media V	$\mu_{s5} = 0.808443 + 0.191558 i_1$	0.9042	Higher
Media VI	$\mu_{s6} = 0.659036 + 0.134064 i_1 + 0.2069 j$	0.5192	High
Media VII	$\mu_{s7} = 0.395433 + 0.079962 i_1 + 0.17619 i_2 + 0.512938 i_3$	0.1789	Medium

CONCLUSIONS

is study has presented and established a new SPA model ed on the principles of AHP and SPA to select the timal bioretention media.

Based on the assessment results of the SPA, Media V is timal media for removing pollutants in bioretention. SPA del is able to fully take advantage of compatible and ompatible information, and it is a good assessment del for managing the optimal selection of bioretention dia.

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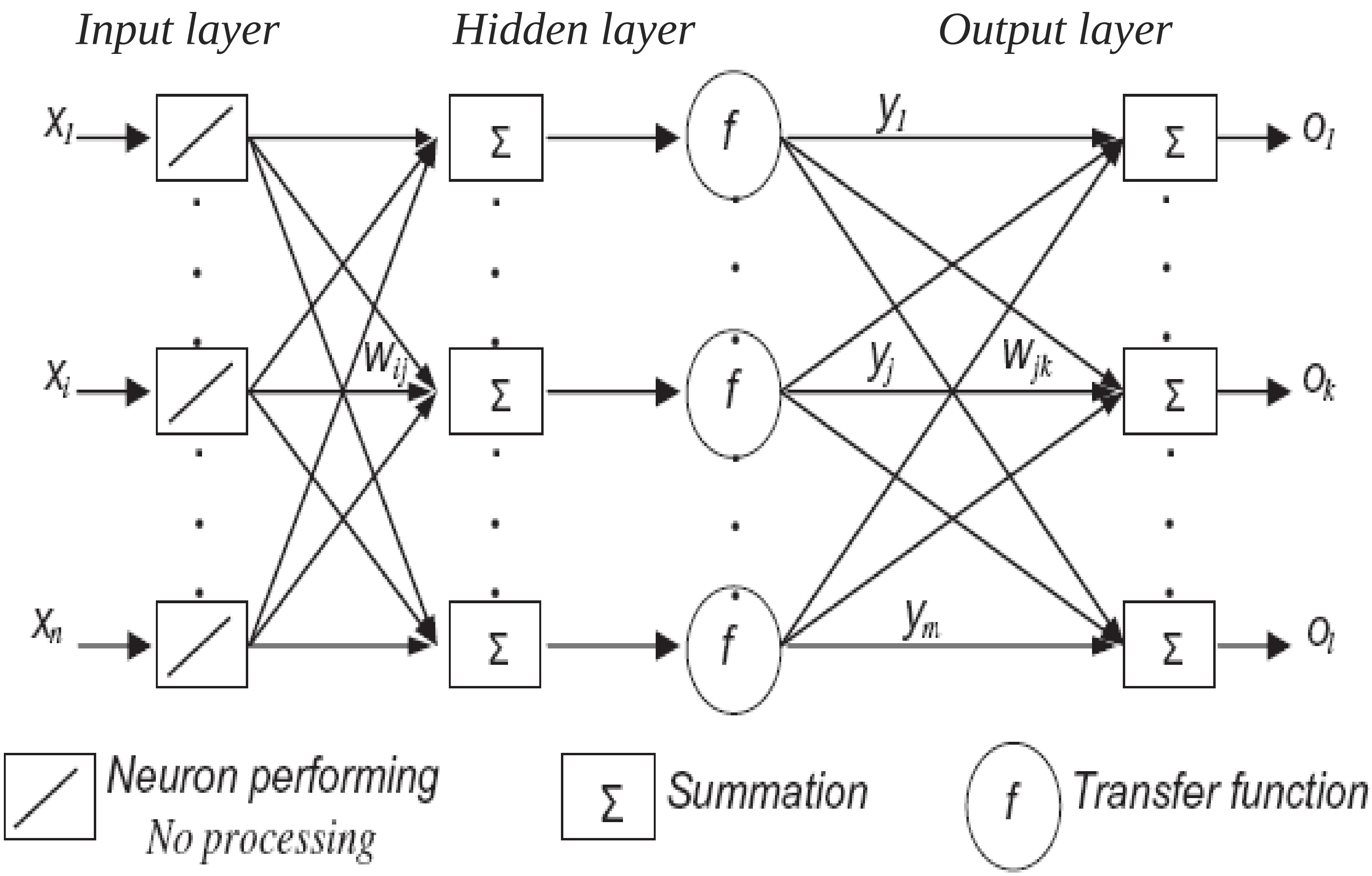
2. Y. Mei, and X. H. Yang, The Effect of Nutrients Removal for Bioretention System in Rainwater Runoff, 2011 International Conference on Remote Sensing, Environment and Transportation Engineering, Nanjing, China, June (2011).
3. B. E. Hatt, A. Deletic and T. D. Fletcher, Water Sci Technol. 55, 201 (2007).
4. K. Q. Zhao, Set Pair Analysis and Its Application, Zhejiang Science and Technology Press, Hang Zhou (2000).
5. X. H. Yang, X. J. Zhang, X. X. Hu, Z. F. Yang and J. Q. Li, Nonlinear Processes in Geophysics. 18, 599 (2011).
6. X. J. Zhang and X. H. Yang, Water Resources Vulnerability Assessment Based on Eigenvector Set Pair Analysis Model under Climate Change 2011

Media V

ANNGA model


Input layer
Hidden layer
Output layer
X1
Xi
Xn
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y1
yj
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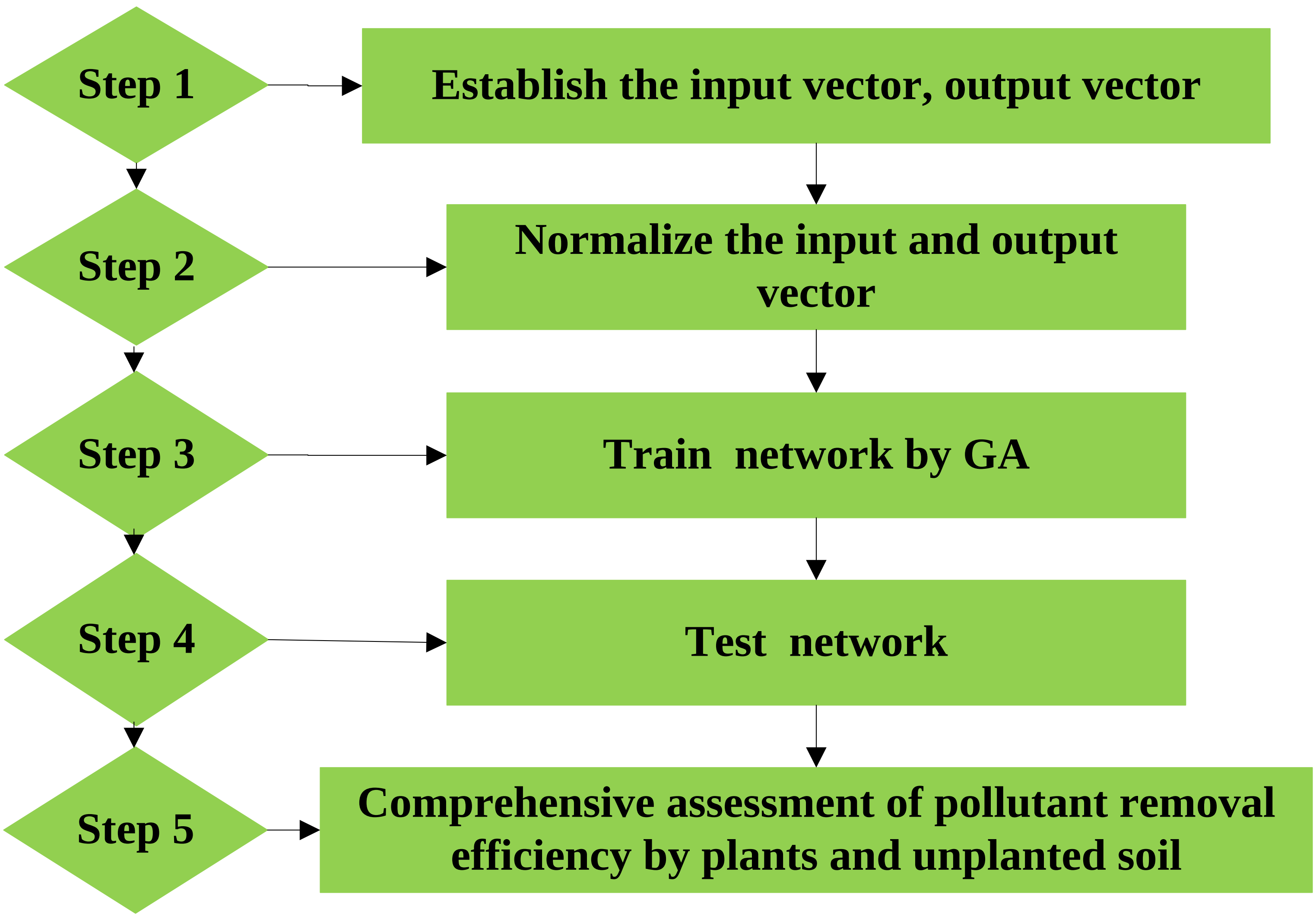
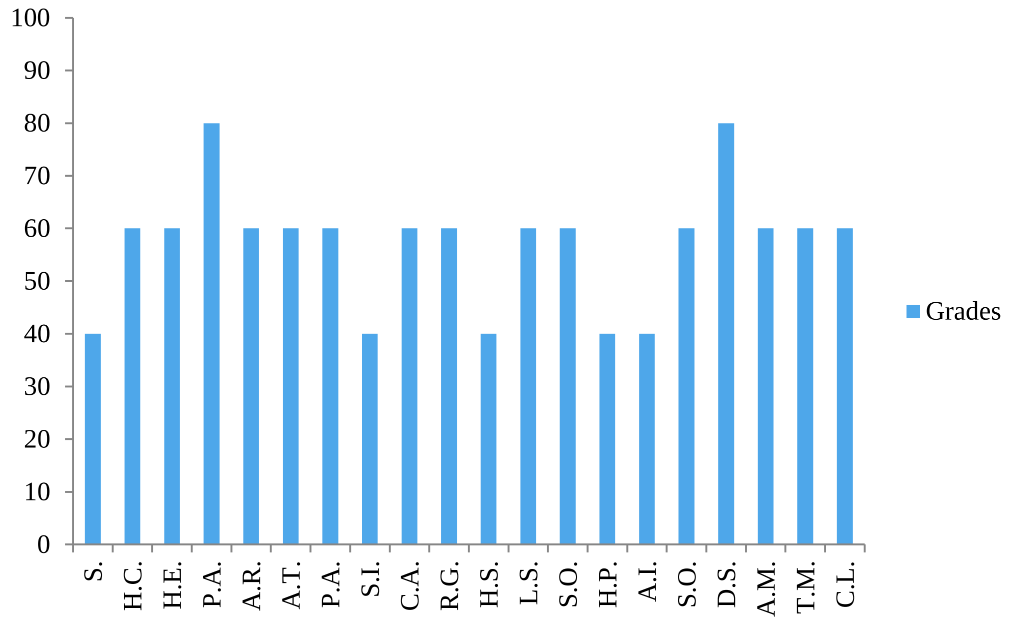
Wij
Wjk
O1
Ok
Ol
Neuron performing
No processing
Summation
Transfer function

ANNGA Procedure



Comprehensive assessment results for plant selection



Comprehensive assessment results for plant selection

Plantago asiatica

车前，多年生草本，早熟禾

Comprehensive assessment results for plant selection

Digitaria sanguinalis

马唐，一年生草本，早熟禾

再生力强，耐修剪。在北方及中部地区，南方部分冷凉地区广泛用于公园、机关、学校、居住区、运动场等地绿化。

5. Publications

1. The effect of nutrients removal for bioretention system in rainwater runoff, *2011 International Conference on Remote Sensing, Environment and Transportation Engineering*, 2011, 2:1791-1794.
2. Chaotic Bayesian optimal prediction method and its application in hydrological time series. *C.M.A.*, 2011, 61:1975–1978 .
3. Comprehensive assessment of pollutants removal in bioretention. *A.S.L.*, 2012.
4. Set pair analysis for optimal selection of bioretention media. *A.S.L.*, 2012.
5. Set pair analysis of eco-environment quality using maximum entropy. *A.S.L.*, 2012.
6. New optimal weight combination model for forecasting precipitation. *M.P.E.* vol. 2012.

Projects

1. Intelligent simulation of water quality and quantity in urban bioretention system and its application, 2010-2013；
2. Stochastic intelligent simulation and structure optimization for water quality and quantiity in urban bioretention system based on low impact development, 2010-2013；
3. Study on effect of nitrogen removal based on structure optimization method for bioretention system, 2011；
4. Statistical analysis for water quantiity in bioretention system and intelligent simulation model, 2012.

Thanks for your comments !