Maintenance of low-impact development facilities : A case study of pilot sponge cities in China

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A lack of maintenance

- Substantial investments have been invested in design and construction, but once built, **LID facilities often lack maintenance or even are completely neglected** (Blecken, et al.2017).

- Lack of maintenance is **a common situation** in the implementation of LID facilities in many countries (Qiao, et al. 2018).

LID facilities in a community

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Huarun Village in Zhenjiang, Jiangsu Province, China （2021.7.6）

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Maintenance is crucial for LID functioning effectively

- 12 **rain gardens** in Minnesota are not functioning properly due to lack of maintenance (Asleson et al. 2009).
- In order to maintain the function of **wet ponds**, it is necessary to carry out routine monitoring and regular sediment removal (Drake, and Guo, 2008).
- A survey of **279 LID facilities** along highways in Prince George's County, Maryland, USA, indicated that these facilities needed extensive maintenance (Li 2015).

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Maintenance is crucial for LID functioning effectively

- Due to aging and lack of proper maintenance, **the reduction of pollutants** in bio-retention ditches **decreased two years** after its construction (Reyes et al. 2018).

- **Even with regular maintenance and management**, the effectiveness of LID diminishes over time (Pour, et al. 2020).

- **Regular monitoring and maintenance** allows LID facilities to operate sustainably and is one of the key drivers of urban stormwater management (Lakshmi et al 2022).

Lack of maintenance funding

- In the case of LID facilities, **lack of maintenance funds** has also become a common problem in many countries (Gao, et al., 2016; Tanellari et al., 2015).

- LID is reportedly **expensive to maintain**, which limits its wider implementation (Shafique, et al.,2018; Bixler, et al.,2019; O'Donnell, et al.,2020).

- To ensure the normal operation of LID, it needs to **hire many professional and technical personnel** (Shafique, et al.,2018).

Public participation in LID maintenance

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- Australia, Canada, Germany, and the United States have proposed **stormwater fees** as a dedicated and stable source of funding to pay for maintenance (Meng & Hsu,2019).

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A lack of alignment with local perspectives

- Seddon et al.（2021）: **Local communities** are often labeled as ignorant and in need of training or capacity building, rather than being recognized as agents with a wealth of local knowledge capable of making choices and decisions.
- Seddon et al.（2021）: Being out of step with local views can discourage active engagement and disempower local communities, which in turn can harm local support for LID facilities and jeopardize their success.
- Seddon et al.（2021）: In order to deliver effective, resilient, legal and equitable outcomes, all relevant stakeholders (especially local people and local communities) should be involved in the design, implementation, management, monitoring and evaluation of LID facilities.

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Pilot Sponge cities in China

- In the 2014, the Chinese government initiated the construction of pilot sponge cities. In 2015 and 2016, in total 30 cities were selected as pilot cities.

- However, the Chinese government only provide construction funding for the local government of the pilot sponge cities.

Pictures took in 2017 in Xi'Xian New City

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Unknown the maintenance current status

To date, there is little knowledge about the current status of LID facilities in the pilot sponge cities after their construction of about 5–7 years.

Specifically, there is no information on whether these facilities are still functioning well, to what extent these facilities need maintenance, and residents' attitudes regarding the maintenance of LID facilities.

Without such knowledge, the construction of LID facilities risks high investment costs with little return for stormwater management goals.

Pictures took in 2017 in Xi'Xian New City

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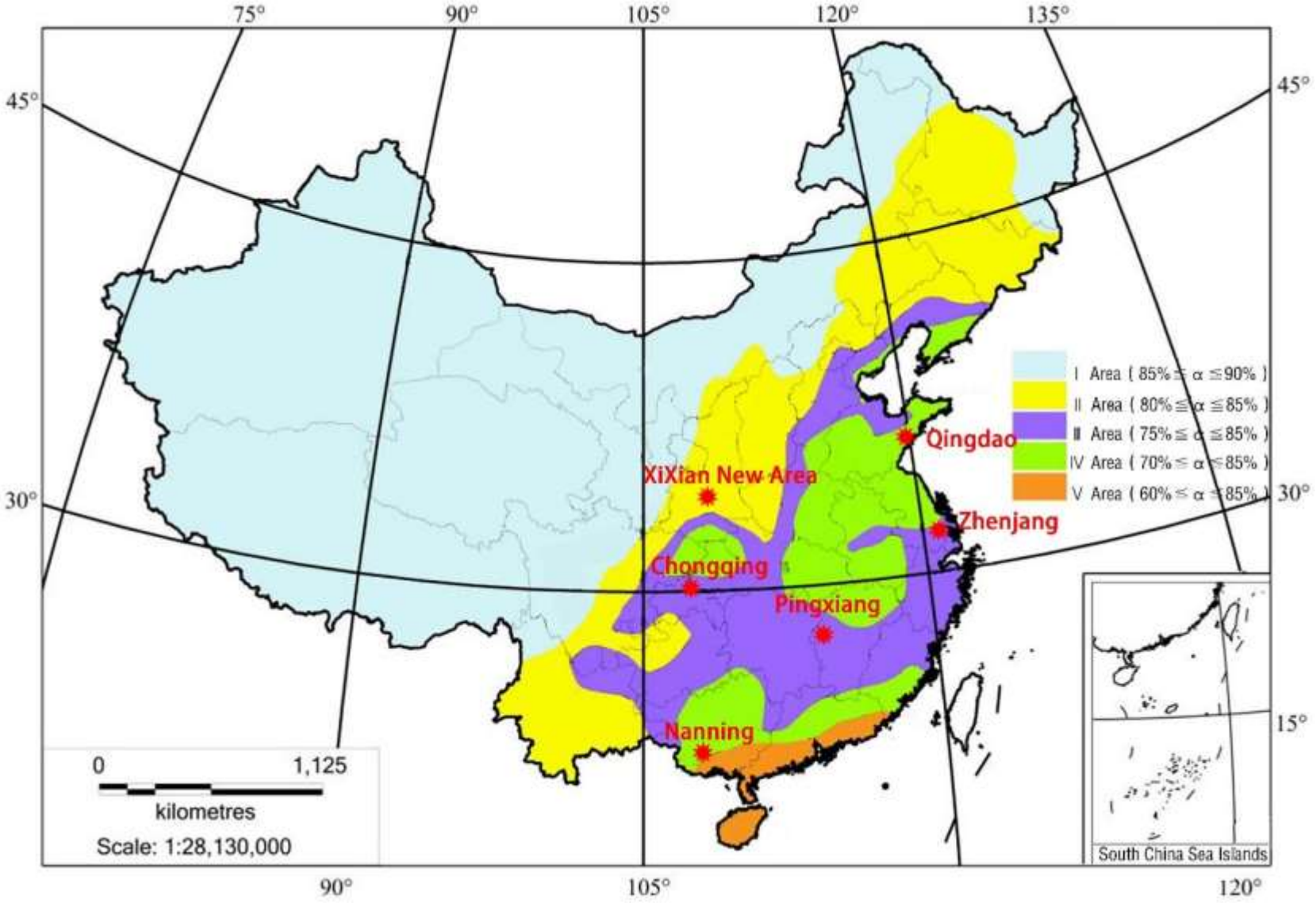
Case cities selected



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LID facilities in a residential community pilot Sponge City

Fengxi New City in Shaanxi Xixian New District （2018.07.15）

Licang District Yujing Villa community in Qingdao, Shandong Province （2021.08.01）

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LID facilities in a residential community in pilot Sponge City

Licang District Yujing Villa community in Qingdao, Shandong Province （2021.07.30）

Jindian city community in Pingxiang, Jiangxi Province （2021.07.07）

LID facilities in a residential community in pilot Sponge City

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Lijiang Mansion in Hebi, Henan Province（2022.08.08）

Tourist Garden in Hebi, Henan Province（2022.08.08）

The willow bank of the Li River in Hebi, Henan Province （2022.08.08）

The willow bank of the Li River in Hebi, Henan Province （2022.08.08）

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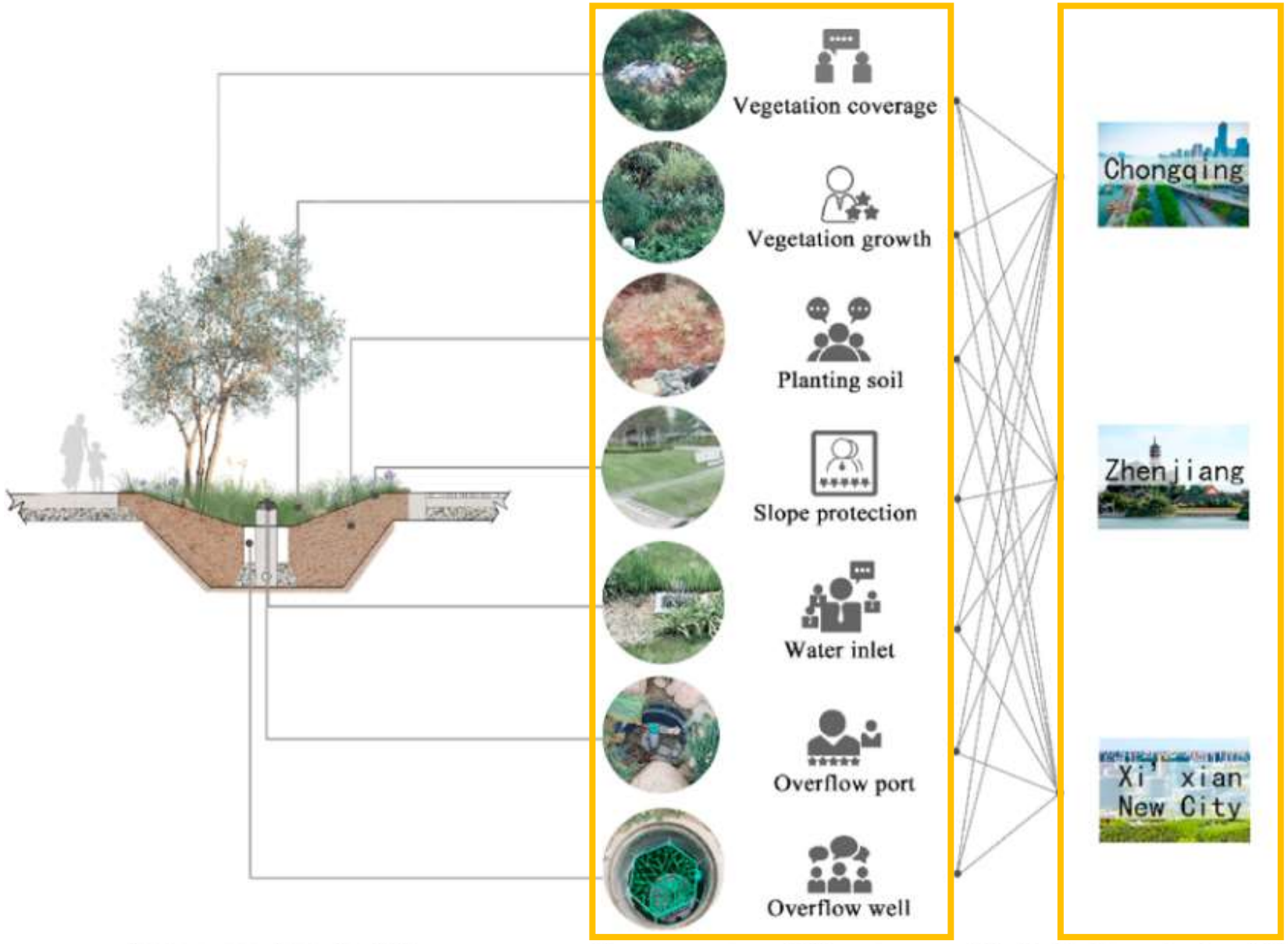
Field trip to survey the maintenance situation of LID facilities in three pilot sponge cities



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Evaluation parameters and description of the status quo of low-impact development facilities in sponge city construction

Parameters	Codes	Description
Vegetation coverage	1	The facility is well covered with vegetation.
	2	0-25% of the facility is not covered with vegetation.
	3	26-50% of the facility is not covered with vegetation.
	4	51-75% of the facility is not covered with vegetation.
	5	The facility is completely without vegetation coverage.
Vegetation growth	1	The vegetation growth of the facility is very good.
	2	The vegetation growth of the facility is good.
	3	The vegetation growth of the facility is not good.
	4	The vegetation growth of the facility is poor.
	5	All vegetation in the facility has died.
Planting soil	1	The planting soil is loose, without soil loss.
	2	The planting soil is relatively loose, with less soil loss.
	3	The planting soil is slightly hard, with less soil loss.
	4	The planting soil is hard, soil loss is heavy.
	5	The planting soil is very hard, soil loss is heavy.
Slope protection	1	The slope protection structure of the facility is complete.
	2	The slope protection structure of the facility is basically intact and the function is not affected.
	3	A small part of the slope protection structure is damaged, and the function is affected to a certain extent.
	4	Most of the slope protection structure is damaged and the function is greatly affected.
	5	The slope protection structure is seriously damaged and completely ineffective.
Water inlet (sewage interception frame, deposit and blockage)	1	The water inlet is not blocked and the sewage interception frame is intact.
	2	The water inlet is slightly blocked and the sewage interception frame is slightly damaged, with a slight impact on the water inlet.
	3	The water inlet is blocked to a certain extent, and the sewage interception frame is damaged to a certain extent, which has an impact on the water inlet.
	4	The water inlet is blocked heavily, and the sewage interception frame is blocked, which seriously affects the water inlet.
	5	The water inlet is completely blocked, the sewage interception frame is blocked and damaged, and the water inlet is completely ineffective.
Overflow port	1	The overflow port is unobstructed, with no siltation or blockage.
	2	The overflow outlet is slightly silted and blocked, which has little impact on rainwater overflow.
	3	The overflow outlet is silted and blocked to a certain extent, which has a certain impact on rainwater overflow.
	4	The overflow port is seriously silted and blocked, which seriously affects the rainwater overflow.
	5	The overflow port is completely silted and blocked.
Overflow well	1	There is no siltation, garbage or fallen leaves in the overflow well, and it is well connected with the drainage pipe.
	2	There is some siltation, garbage, residue and fallen leaves in the overflow well, and it is well connected with the drainage pipe.
	3	There is a lot of siltation, garbage and litter in the overflow well. Although the drainage pipe is well connected, the siltation affects the outflow of overflow rainwater to a certain extent.
	4	There is a lot of siltation, garbage, residue and fallen leaves in the overflow well, and the drainage pipe is not connected smoothly. The overflow rainwater function is seriously affected
	5	The overflow well has high levels of siltation, garbage, residual branches and leaves. There is no drainage pipe connection, so the overflow rainwater cannot be discharged.

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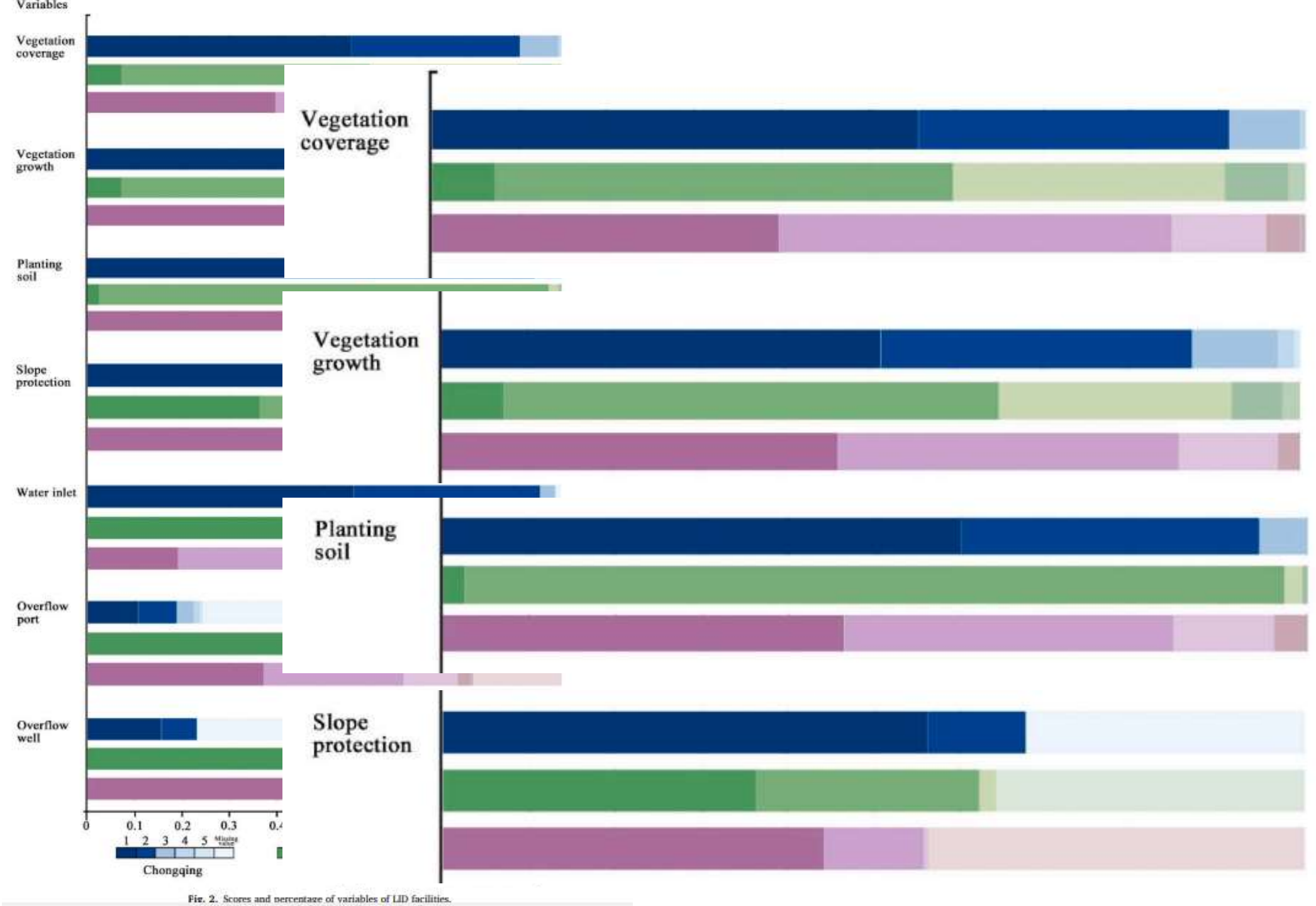

Fig. 2. Scores and percentage of variables of LID facilities.

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Respondents' attitudes towards maintenance of LID facilities

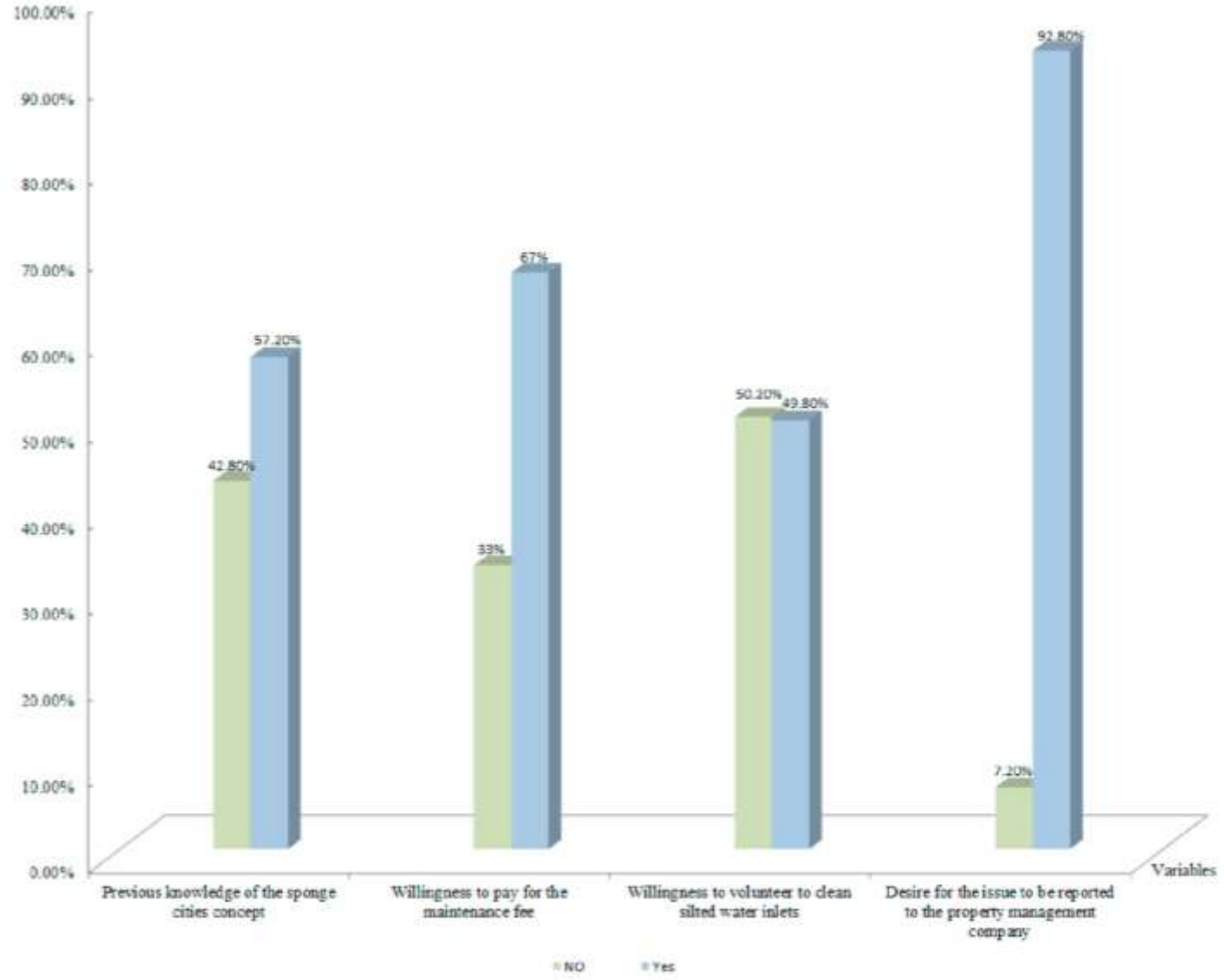

Fig. 4. Respondents' attitudes towards maintenance of LID facilities.

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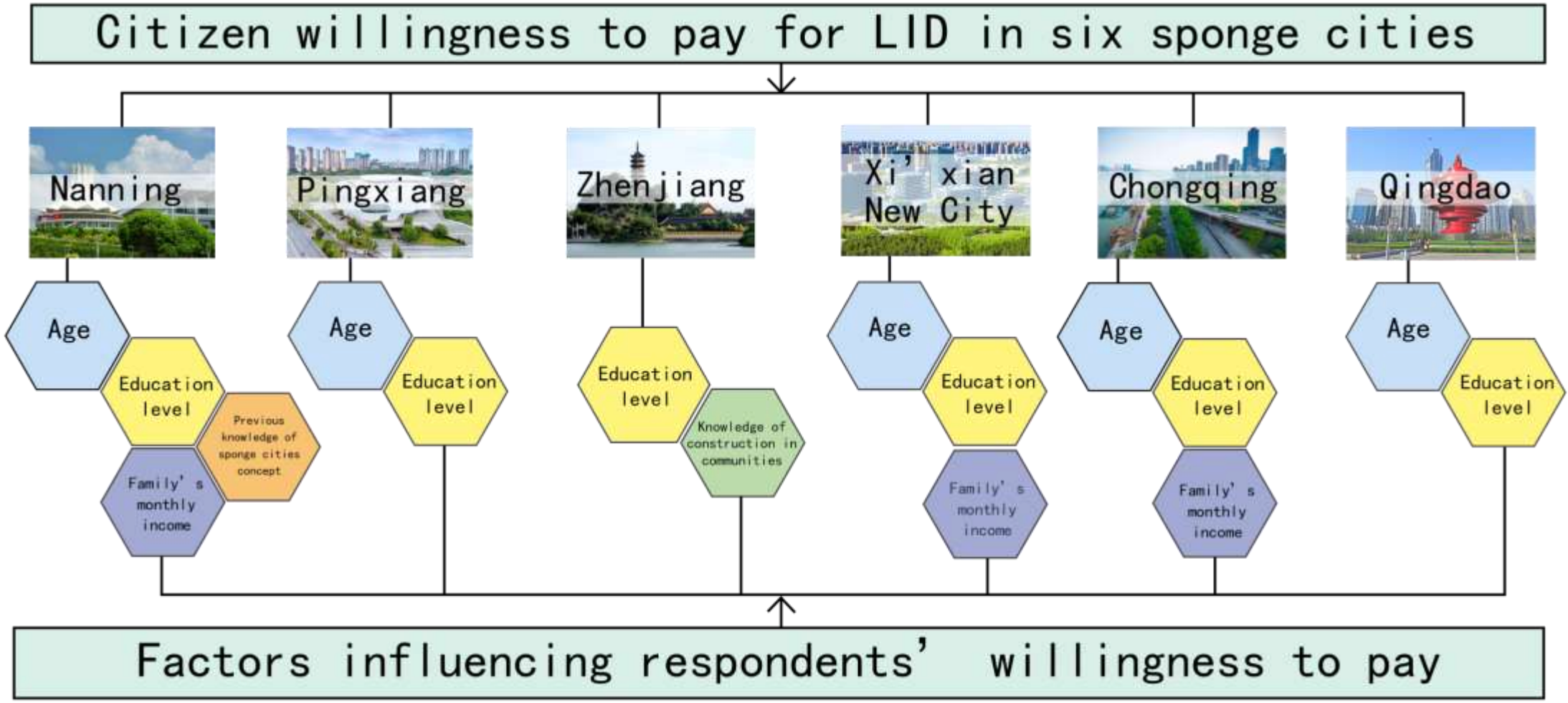
Results of Correlation Analysis



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Results of Binary Logistic Regression

Table 4. Factors influencing respondents' WTP for urban green infrastructure.

City		B	Std. Err	Wald	$p > \|z\|$	Exp (B)	[95% Conf.	Interval]
Nanning	Previous knowledge of the concept	1.209	0.393	9.467	0.002	3.349	1.551	7.233
Zhenjiang	Knowledge of construction in communities	0.854	0.421	4.112	0.043	2.348	1.029	5.359
Chongqing	Age	−0.048	0.016	8.835	0.003	0.953	0.924	0.984
	Gender	0.756	0.379	3.973	0.046	2.129	1.013	4.478

Improving respondents' knowledge of the sponge city concept had a significant, positive effect on increasing WTP for urban green infrastructure in Nanning.

For the Zhenjiang local government, more demonstration projects constructed in communities are useful for a wider implementation of urban green infrastructure.

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Conclusions and recommendations

For cities such as Chongqing **(a negative correlation between age and WTP)**, we suggest that age-appropriate landscape design could be added in the construction of urban green infrastructure in sponge cities.

It may enhance the participation of the elderly and increase their WTP to some extent.

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For cities such as Nanning **(a positive correlation between WTP and previous knowledge of sponge city concept)**, we suggest that the local government strengthens the publicity of the sponge city and carries out science popularization activities related to the sponge city.

It can improve residents' awareness of urban green infrastructure development and residents' WTP for LID.

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Conclusions and recommendations

For cities such as Nanning and Zhenjiang **(a positive correlation between WTP and knowledge of construction in communities)**, we suggest increasing the construction of the sponge city LID within the community and vigorously publicizing it within the community.

This may enhance residents' sense of identity on urban green infrastructure and their WTP.

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Does the public's Cognitive degree of LID really affect the public's choice and attitude toward LID facilities?

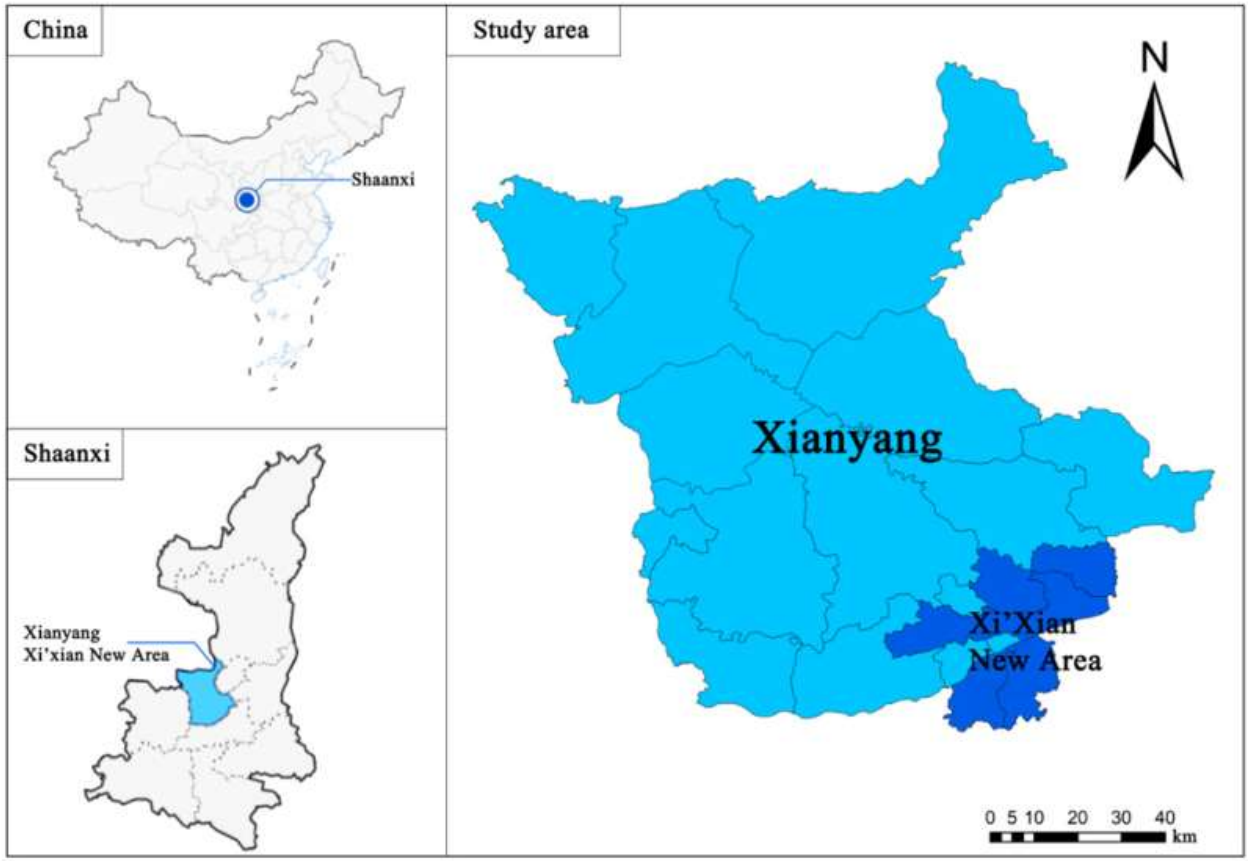

Figure 1. Study area.

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Determination of the **attributes** and **levels** of low impact development facilities

Table 1. Attributes and levels.

Attributes	Levels	Explanation
Reduction in run-off pollutant	0%	Status quo
	40–80%	Reduce leaves and impurities brought by part of the rainwater
	80–100%	Reduce the leaves and impurities brought by most of the rainwater, making the rainwater meet the standard of reclaimed water, and reduce the sewage treatment fee
Degrees of ponding	Level three	Status quo
	Level two	Shoes get wet but there are no splashes when stepping on it
	Level one	Shoes do not get wet while the ground gets wet
Plant type	***	Status quo
	****	One level higher than the status quo
	*****	Two levels higher than the status quo
Planting aesthetics	***	Status quo
	****	One level higher than the status quo
	*****	Two levels higher than the status quo
Cost	0 yuan	Status quo
	5% of water fee	5% of personal annual average water bill
	10% of water fee	10% of personal annual average water bill
	15% of water fee	15% of personal annual average water bill
	20% of water fee	20% of personal annual average water bill
	25% of water fee	25% of personal annual average water bill

Note: *** means status quo, **** means one grade better than the status quo, ***** means two grades better than the status quo.

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Questionnaire Design

The questionnaire included **three main parts**.

① Information regarding respondents' socioeconomic characteristics, e.g., gender, age, education, monthly family income and housing type, were collected.

② The questions about respondents' knowledge and perceptions of LID were asked.

③ Surveyors explained attributes and the attribute levels of LID benefits and their descriptions to the respondents and **sample selection sets** (Table 2).

Table 2. An example of choice set.

Attribute	Status Quo	Option 1	Option 2
Reduction in run-off pollutant	0%	80–100%	40–80%
Degrees of ponding	Level three	Level one	Level three
Plant type	***	***	*****
Planting aesthetics	***	*****	***
Cost	0 yuan	141.31 yuan	141.31 yuan
Your choice:	☐	☐	☐

Note: *** means status quo, ***** means two grades better than the status quo.

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Table 4. Regression results of Xianyang.

Attributes	Model I			Model II		
	Coefficient (SE)	(95% CI)	SD (SE)	Coefficient (SE)	(95% CI)	SD (SE)
ASC	3.7432 *** (1.2194)	(1.3532, 6.1332)		3.5325 (5.9240)	(−8.0783, 15.1432)	
Cost	−0.0044 (0.0047)	(−0.0136, 0.0048)		−0.0052 (0.0050)	(−0.1495, 0.0045)	
Reduction in run-off pollutant	−0.2753 (0.1876)	(−0.6431, 0.0924)	0.7260 ** (0.3399)	−0.3085 (0.1968)	(−0.6942, 0.0772)	0.8336 *** (0.3180)
Degrees of ponding	0.6185 ** (0.1482)	(0.3280, 0.9090)	0.5225 ** (0.2629)	0.6547 *** (0.1585)	(0.3441, 0.9654)	0.5902 ** (0.2585)
Plant type	−0.3878 ** (0.1808)	(−0.7422, −0.0335)	0.9251 *** (0.3071)	−0.4193 ** (0.1904)	(−0.7926, −0.0460)	1.0112 *** (0.3107)
Planting aesthetics	−0.0050 (0.1376)	(−0.2746, 0.2646)	0.0676 (0.4238)	−0.0007 (0.1438)	(−0.2826, 0.2812)	0.0595 (0.3539)
ASC × Gender				5.1656 * (2.6704)	(−0.0683, 10.3996)	−9.9350 *** (2.8239)
ASC × Age				−1.0310 ** (0.4911)	(−1.994, −0.0684)	1.1117 *** (0.3429)
ASC × Monthly family income				0.1850 (0.7066)	(−1.2000, 1.5700)	0.2625 (0.3277)
ASC × Education				1.0995 (1.0231)	(−0.9058, 3.1048)	0.0202 (0.2773)
ASC × Housing type				1.7843 (2.0058)	(−2.1470, 5.7157)	0.6936 (0.9188)
ASC × Understanding level				−1.5961 (1.1123)	(−3.7762, 0.5840)	1.0909 ** (0.4715)
Number of observations	1314			1314		
Chi2	195.33			177.90		
Log likelihood	−360.02 ***			−344.56 ***		

Note: * means significant at 10% level, ** means significant at 5% level, *** means significant at 1% level.

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Table 5. Regression results of Xi'xian New Area.

Attributes	Model I			Model II		
	Coefficient (SE)	(95% CI)	SD (SE)	Coefficient (SE)	(95% CI)	SD (SE)
ASC	1.0451 (1.0029)	(−0.9206, 3.0107)		10.5644 (4.9308)	(0.9003, 20.2286)	
Cost	−0.0022 (0.0044)	(−0.0108, 0.0064)		−0.0025 (0.0044)	(−0.0111, 0.0062)	
Reduction in run-off pollutant	0.1803 (0.1763)	(−0.1653, 0.5258)	0.0207 (0.4247)	0.1669 (0.1722)	(−0.1675, 0.5073)	−0.0483 (0.5668)
Degrees of ponding	0.4920 *** (0.1424)	(0.2129, 0.7710)	0.5732 ** (0.2395)	0.4863 *** (0.1365)	(0.2187, 0.7538)	0.4828 ** (0.2407)
Plant type	−0.1123 (0.1927)	(−0.4900, 0.2654)	0.9086 *** (0.3221)	−0.0956 (0.1849)	(−0.4581, 0.2669)	0.8537 *** (0.3023)
Planting aesthetics	0.2692 ** (0.1619)	(−0.0482, 0.5866)	−0.0727 (0.4429)	0.2557 * (0.1577)	(−0.0534, 0.5649)	0.0597 (0.3021)
ASC × Gender				−2.3637 * (1.3495)	(−5.0086, 0.2812)	0.3663 (1.4813)
ASC × Age				0.4277 (0, 4713)	(−0.4961, 1.3515)	2.5550 *** (0.7107)
ASC × Monthly family income				0.1534 (0.5096)	(−0.8454, 1.1522)	0.0207 (0.2104)
ASC × Education				0.3172 (1.2523)	(−2.1373, 2.7716)	−0.0256 (0.2297)
ASC × Housing type				−3.9394 ** (1.7776)	(−7.4234, −0.4554)	−0.0530 (0.7155)
ASC × Understanding level				−2.4101 ** (1.0495)	(−4.4671, −0.3530)	0.8684 ** (0.3526)
Number of observations	1089			1089		
Chi2	171.13			150.18		
Log likelihood	−301.97 ***			−284.17 ***		

Note: * means significant at 10% level, ** means significant at 5% level, *** means significant at 1% level.

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Table 8. Marginal willingness to pay of residents.

Area	Attributes	MWTP [Yuan/(Family·Year)]	Confidence Interval	
Xianyang	Degrees of ponding	139.8469	74.1564	205.5374
	Plant type	−87.6946	−167.8135	−7.5757
Xi'xian New Area	Degrees of ponding	197.8169	88.9740	306.6597
	Planting aesthetics	104.0322	−21.7299	229.7944

Residents in Xianyang were willing to pay for the improvement of degrees of ponding, but not for the plant type. Moreover, the additional annual fee they were willing to pay for was 140 yuan per family per year.

For residents in Xi'xian New Area, they had stronger WTP for the improvement of degrees of ponding than that in Xianyang, with the additional annual fee of 198 yuan per family per year. Meanwhile, residents in Xi'xian New Area were willing to pay for the plant type improvement, which was quite different from the residents in Xianyang.

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The residents of Xianyang and Xi'xian New Area, China had **positive attitudes** towards the degree of ponding and were willing to pay for it.

It is worth noting that there was a heterogeneity preference and WTP regarding functions of plant types and planting aesthetics.

In Xianyang, residents were willing to pay approximately 139 yuan per family per year for the improvement of degrees of ponding, but they did not show the same willingness to pay for plant types.

On the other hand, **in Xi'xian New Area,** residents were willing to pay about 197 yuan per family per year to improve degrees of ponding and 104 yuan for planting aesthetics.

These findings suggest that the degree of support for various LID projects varied among the two regions and was influenced by factors such as the extent to which the government promoted LID facilities and residents' subjective perceptions of the benefits. Although improving degree of ponding has always been the top priority of government officials, improving planting aesthetics in the community and other LID facilities projects may gain higher levels of public support.

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Do past flood experiences really influence public choices and attitudes to LID facilities?

City	Zhengzhou	Hebi
Permanent resident population (million)	1274.2	157.2
Per capita GDP (the thousand Yuan)	2.49	1.73
Sponge city construction start time (year)	2015	2018


a. Extraordinarily heavy rainfall, Zhengzhou


c. Damage in the city, Hebi


b. Serious casualties, Zhengzhou


d. Agriculture and farming industry , Hebi

Figure 1 | Illustration of pilot cities.

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Determination of the **attributes** and **levels** of low impact development facilities

Table 1 | Attributes and level values of LID facilities

Attributes	Function configuration scheme (horizontal value)
Rainwater drainage	Rainwater drainage 30% Rainwater drainage 50% Rainwater drainage 70%
Rainwater utilization	After purification, discharge is not reused After purification, water reuse for agricultural water areas and general landscape After purification, water can be used for general industrial water area and recreational water area
Recreation and entertainment	Provides recreation and entertainment functions No recreation or entertainment function.
Landscape environment	Single landscape green environment. Rich landscape green environment. Rich and sustainable landscape environment.
Payment	(Zhengzhou) $0, $1.5, $4.4, $7.38, $10.3, $13.3, $17.7 (Hebi) $0, $0.7, $1.5, $2.2, $2.9, $3.7, $4.4

Note: $1 = 6.78 RMB.

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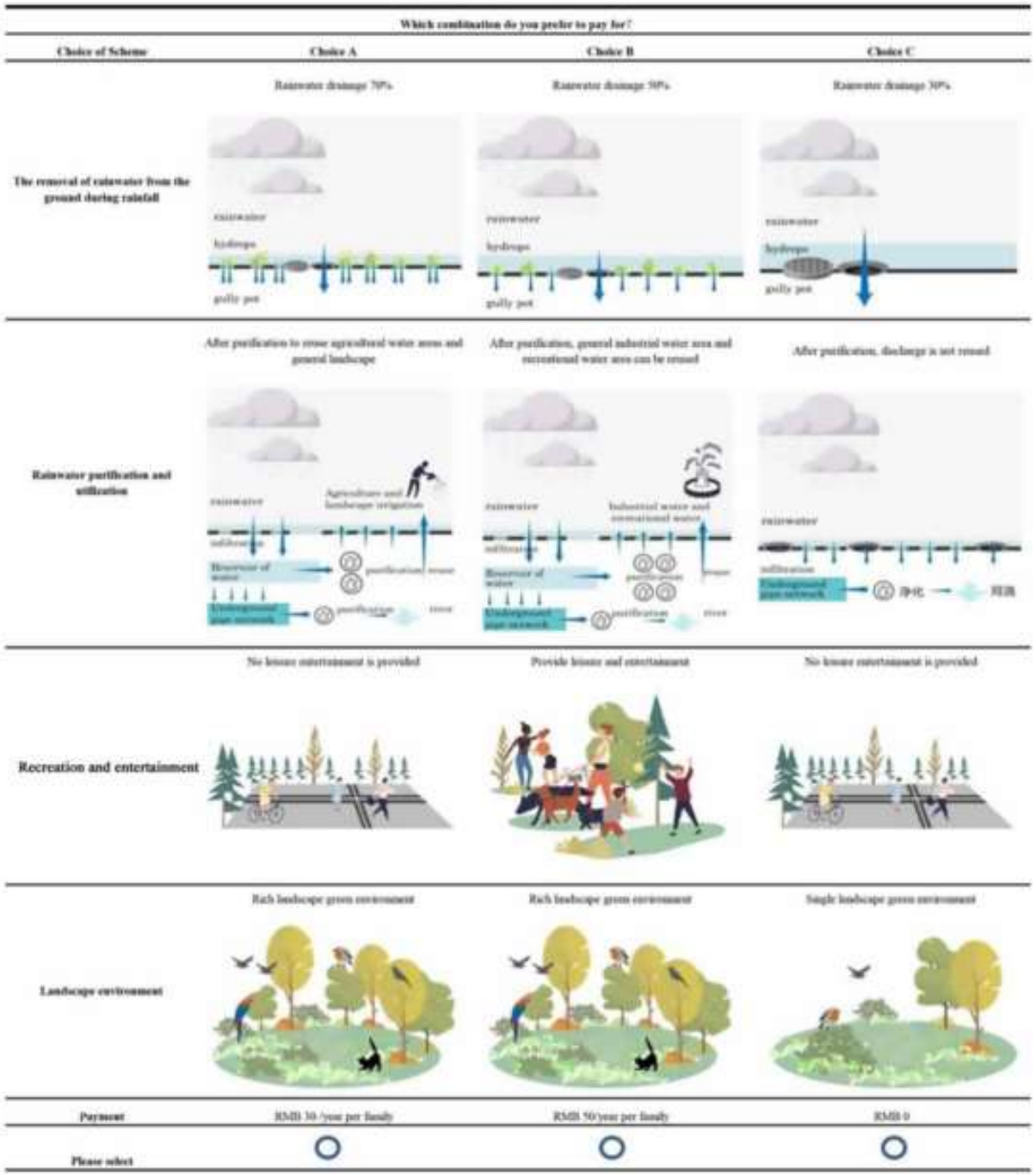

Figure 2 | A sample choice set of the LID functions. *Note:* $1 = 6.78 RMB.

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Investigate residents' willingness to participate in, maintain and pay for LID facilities in sponge city (2022.08)

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Table 3 | Mixed Logit model estimation results Zhengzhou ($N = 958$) and Hebi ($N = 646$)

Variable	Model Zhengzhou 1	Model Hebi 1	Model Zhengzhou 2	Model Hebi 2
Fixed parameter				
ASC	−0.5049576* (0.1970054)	1.870516** (0.0159923)	2.001839* (0.5365864)	−0.1428739 (0.8580435)
Payment	−0.0297792* (0.002617)	−0.0356139* (0.0159923)	−0.24805* (0.0021871)	−0.044061* (0.0151395)
ASC × flood experience			−0.9879207* (0.2605255)	
ASC × promotion activities			[illegible]	
ASC × distance (the distance of their community from the natural environment)				0.4112988** (0.1806772)
ASC × LID community (Does the community have LID facilities?)			1.386959* (0.3590994)	
ASC × attitude (Is it believed that sponge cities can alleviate flooding?)			−1.059592* (0.2889641)	
ASC × LID community (Would you like to live in an LID community?)			−2.501959* (0.3085308)	−3.2148* (0.6132224)
ASC × age			0.8977065* (0.1423852)	1.555057* (0.2480725)
ASC × education			−0.5370086* (0.1378054)	

Table 4 | Marginal willingness to pay attribute level and status quo

Choice (mean WTP)	Zhengzhou	Hebi
Constant	−16.95672* (6.193337)	52.52207** (29.83622)
Rainwater drainage 50%	60.27532* (6.187779)	73.21378*** (32.06785)
Rainwater drainage 70%	102.1372* (9.540904)	122.0977*** (53.14298)
After purification water reuse for agricultural water areas and general landscape	35.00064* (5.584728)	11.76457 (10.83526)
After purification, water reuse for general industrial water area and recreational water area	34.98253* (5.565661)	16.88652 (10.45819)
Provide recreation and entertainment	46.54071* (5.791197)	46.05753*** (20.83587)
Rich landscape and green environment	31.65867* (6.918104)	88.94627*** (38.43701)
Rich and sustainable landscape environment	57.1485* (7.511897)	104.0555*** (43.28533)

Note: *$p < 0.01$, **$p < 0.1$, ***$p < 0.05$.

- Respondents showed a significant WTP for LID facilities, with a desire to support rainwater drainage, recreation and entertainment, and the landscape environment.
- Experience of flooding had a significant effect on Zhengzhou respondents, but not on Hebi respondents.
- Rainwater drainage should still be considered the most important function of LID facilities.
- At the same time, educational level and flood experiences may not affect the public's WTP.

Why focus on the maintenance of LID

Survey of the current status of LID maintenance

Public willingness to pay for LID maintenance

Increased public awareness and education on sponge cities is recommended

Since residents' cognitive degree of sponge cities is positively correlated with WTP, it is suggested that the local government strengthen the publicity of sponge cities and carry out science popularization activities related to sponge cities to improve residents' cognitive degree of sponge cities.

THANKS