

Exploration on compound water circulation system to solve water resources problems of North China Plain

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Abstract: In order to solve water resources problems in the North China Plain, this paper explored human-nature compound water circulation system from three aspects including urban flood control, surface drainage and saline water in the central and eastern of the North China Plain. Results show that: (1) The technical methods have achieved zero increase in rainwater runoff in urban areas, (2) surface drainage depletion problems can be solved through abandoned water and river water separation method, (3) and technical method through promoting rainwater infiltration would be used to solve problem of saline water in the central and eastern parts. This research provides a new perspective to the ultimate solutions to water resources problems in the North China Plain, and a fresh research direction for the development of hydro-geological science.

Keywords: North China Plain; Saline water; Rainwater; Water circulation; Compound system

Introduction

The shortage of water resources is faced due to the increasingly striking contradiction between supply and demand with the rapid development of social economy in the North China Plain (XU Guang-ming *et al.* 2009). As a type of valuable resources, rainwater has become an essential water source (TIAN Yu and LIU Zhi-qiang, 2012). However, heavy rain cannot form effective water resources because of uneven precipitation in time and space distribution, seepage coefficient increasing of underlying surface of low water in urban area, drying up of river and so on, which results in a series of problems like urban inland inundation, linear pollution along rivers and soil salinization.

Since the Middle Route of South-to-North Water Diversion Project started its Phase I operation, the serious water shortage has been

largely relieved, but not eliminated in Beijing, Tianjin, Hebei and Henan. As introduced by Department of Water Resources of Hebei Province at the news conference of Hebei Provincial People's Government, Hebei has to fill an annual gap of $50 \times 10^8 \text{ m}^3$ in water resources. Given the ecological water, Hebei's annual water deficit will exceed $100 \times 10^8 \text{ m}^3$. It's an urgent task to conduct a research on exploring the water resources with the aim of solving the water shortage problem in the North China Plain.

Rainwater is the source of all the renewable water resources on the earth (HUANG Yong-qiang *et al.* 2011). Appropriate exploitation and utilization of rainwater resources will be a significant solution to water resources problems in the 21st century (LI Xi-lin *et al.* 2013). Scholars have done a lot of research regarding the utilization of rainfall as resources, accumulating quite abundant experiences and yielding some fruitful results (JIA Hai-feng *et al.* 2014). As far as the geographic location is concerned, the North China Plain, which does not fall into the category of arid areas and water deficit zones, has an annual precipitation of more than 500 mm for years. Therefore, an

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ultimate solution to the water shortage in the North China Plain is to follow the pattern of water circulation, carry out recovery research on how human activities affect natural water circulation, and develop a new human-nature compound water circulation system that can contribute to the coordinated development between man and nature, and increase the rainwater utilization rate to provide available water resources.

1 Research contents

1.1 Regional background

Located in areas along the Yellow River, the Haihe River and the Luanhe River, the North China Plain features wide distribution of loose sediments. With an altitude of no more than 100 m and a terrain slope of 0.1–1‰, the North China Plain leans toward the Bohai Bay from the north, the west and the south. The local terrain and landform impose an impact on surface runoff and groundwater migration and enrichment.

The annual precipitation in the North China Plain is usually 500–600 mm, but is characterized by uneven distribution in terms of season, space and major inter-annual variations. Specifically, about 80% of annual precipitation happens within flood period (June–September), and mostly concentrates in July and August, if not a shorter period.

1.2 Urban rainwater management

When human activities change the natural environment in the North China Plain, the local water circulation system is also changed and the original water circulation balance has been disturbed. As infiltration channel for rainwater is blocked and surface runoff increases, there's an annual rise in urban floods. Due to the limited knowledge about the nature of rainwater resources, the traditional methods fail to take urban rainwater as valuable resources. When strong rainfall is treated as a natural disaster, these methods only stress the discharge of rainwater within a short period of time. On the one hand, it takes substantial labor and financial resources to discharge rainwater, in which process the fresh water resources are wasted. On the other hand, the

shortage of water resources becomes a serious problem (LU Xiao-feng *et al.* 2011). As an effective measure to control storm runoff, the original permeation technique has been put into wide use (Davis A P, 2008). The research work focuses on finding “a nearly natural approach to water conservation”. Measures such as region-specific local retention and permeation are adopted. Vadose zone is used as the rainwater repository layer and the rainwater infiltration system is constructed through building rainwater infiltration compensation channel. In this way, we can solve the problems like temporal concentration of rainfall and narrow pathway for conversion of surface water to underground, thus achieving the retention and infiltration of rainwater as much as possible, and minimizing the additional surface runoff caused by human activities and then reducing the effects of human activities on water circulation in nature. So rainwater can infiltrate almost as a natural part of water circulation. The participation of infiltration in underground water circulation is a good remedy to flood problems and also an important solution to shortage of water resources in the North China Plain.

1.2.1 Division of rainwater catchment areas

Some of rainwater on ground will infiltrate through the pores in the soil, but the rest has to gradually flow downward. To achieve the rational utilization of rainwater, it's imperative to properly control the catchment area and channel, and utilize rainwater before it grows into uncontrollable runoff. Since the macroscopic catchment areas can hardly be changed by human activities, so we can only start with the microscopic ones.

When the urban catchment areas are divided, we must consider terrain and landform, land use purpose and ownership, and ensure the division is coordinated with groundwater transport and storage space. To achieve immediate infiltration, the division of rainwater catchment areas should be clear in management responsibility, coordinate with such factors as climate, vegetation, landform characteristics and stratigraphic lithological condition, and take the fundamental factors such as stratigraphic infiltration ratio and underground reservoir into consideration. After all the relevant factors are taken into account, the urban rainwater

catchment areas should be arranged according to specific facilities and main benefits, such as urban welfare catchment areas, street catchment areas, road catchment areas, courtyard catchment areas, etc.

1.2.2 Precipitation retention

To ensure that human activities are in harmony with nature, the post-construction rainfall runoff should not be higher than the pre-construction level. The construction projects should guarantee the effective rainwater retention and utilization within the construction area and prevent any possible increase in rainwater runoff.

The original rainfall retention within the plains is mainly controlled by climate, terrain, landform, vegetation and soil. Soil is the main control factor. The thickness of dry soil layer (with water content of less than 10%) can reflect the degree of drought, and the rainfall retention can be calculated according to soil capacity of retaining rainfall. In general, it takes 5–10 mm of precipitation to ease dry soil layer of about 3 cm and 15–20 mm precipitation of 5 cm–10 cm. The cultivation layer in the North China Plain is 15 cm–20 cm thick. If the whole cultivation layer is treated as the dry soil layer, it takes 30–50 mm precipitation to ease the condition in the dry soil layer. We can estimate that precipitation should exceed 30–50 mm. According to GB50400-2006 Technical Specification for Rainwater Utilization Projects of Buildings and Residential Quarters, the standards on the

construction of rainwater storage facilities are as follows: the rainwater storage facilities with a size of no less than 500 m³ should be equipped for each hardened part with an area of 10⁴ m². If the land surface undulates greatly, the volume and size of these facilities should be increased accordingly.

1.2.3 Precipitation infiltration area

Rainwater infiltration is the function of time. In long rainfall period with considerable amount of rainfall, the rainwater storage tank alone cannot solve the infiltration problems. The increase in infiltration area is the best solution. We can arrange some porous water media with strong water permeability on the surface with weak water permeability, or clear away the soil covers with weak water permeability within the same water catchment area to expand the bedding area with strong permeability.

Infiltration V_p within the rainfall period of t can be calculated according to the following formula:

$$V_p = K \cdot J \cdot A_s \cdot 3600t$$

where K —infiltration coefficient, m/s, J —hydraulic slope; in case of low groundwater level, $J=1$, A_s —effective infiltration area, m².

The formula for infiltration may show that effective infiltration area is in reverse proportion to coefficient of infiltration when infiltration remains the same. Coefficient of infiltration is based on the actual measurement results. If the actual measurement materials are not available, one may refer to Table 1 or specification.

Table 1 Experience value of infiltration coefficient of North China Plain

Lithology	Infiltration coefficient (m/d)	Lithology	Infiltration coefficient (m/d)
Sandy pebbles	80	Fine silt	5–8
Sandy gravels	45–50	Silt	2–3
Coarse sand	20–30	Sandy loam	0.2
Medium-sand pebbles	22	Sandy-clayey loam	0.1
Medium sand	20	Clayey loam	0.02
Medium-fine sand	17	Clay	0.001
Fine sand	6–8		

Source: Hydrogeological Manual (Edition 2) (China Geological Survey, 2012)

1.2.4 Frequently employed technical measures for rainwater management

Many researches on urban rainwater development and utilization have achieved some

satisfactory results (SU Dong-bin *et al.* 2012) and provided the practical examples. For instance, the rainwater utilization project in one university of Tianjin involves such rainwater eco-techniques as low-elevation greenbelt, flowerbed filtration purifi-

cation and landscape lake purification system (SUN Huan *et al.* 2013). Based on the rainwater utilization results and years of experience, the

general technical measures for rainwater management are summarized in Table 2 (CHE Wu *et al.* 2010).

Table 2 Frequently employed technical measures for rain-flood control and utilization

Items	Frequently employed technical measures
Collection and transfer	Grassed swale, filtration pipe culvert and general rainwater pipe culvert
Interception and split-flow	Interception filter screen (cradle, filter screen and grill), initial split-flow device, vegetation buffer strip, rainwater precipitation well/tank and scum isolation well, <i>etc.</i>
Purification treatment measures	Sand filtration, soil infiltration system, Pre-posing precipitation tank and pre-posing pond
Retention and storage	Rainwater storage tank, landscape waterfront, rainwater pond/wetland
Infiltration	Low-elevation greenbelt, rainwater garden, porous pavement, filtration pipe culvert, filtration tank/pond, filtration well, removal of cover with poor infiltration performance, multi-pore water media with strong water permeability under the ground with weak artificial water permeability

It's worth pointing out that classification of these technical measures is not absolute. It should be purpose-specific. For instance, filtration pipe culvert can be a supportive measure for water collection and transfer, and also unit of a key measure for water filtration and utilization. The promulgation and implementation of such a national standard as Technical Specification for Rainwater Utilization Projects of Buildings and Residential Quarters (GB50400-2006) signalizes that design, construction, and check and acceptance of rainwater utilization projects are well developed. Here we will not give more description on the design and construction.

1.3 Improvement of shallow marginal water

1.3.1 Overviews of marginal water

According to the grading standard of groundwater quality, there is shallow marginal water that people cannot drink directly in distributing widely in the North China Plain. Type-IV shallow groundwater, which covers a total area of 41 083 km², is mainly found between piedmont plain and central plain, and within most part of the southern region. Salinity in it falls within the range of 1 000–2 000 mg/L and total hardness 450–550 mg/L. Chloride and sulfate water are the main contents. Total hardness, salinity, chloride and sulfate radical all exceed the standard. The groundwater level is mostly within 2.5 m and 6.5 m, and sometimes

even lower than 8.0 m. Type-V shallow groundwater, which has a total area of 65 365 km², is mainly found in the coastal plain, the central and eastern part of the North China Plain. Salinity in it is more than 2 000 mg/L and total hardness 550 mg/L. Sulfate water is the main content. Salinity, total hardness and chloride are far above the standard limit. The groundwater level is mostly between 0.5 m and 3.5 m.

Obviously, over half of shallow marginal water in the North China Plain could be improved, and half of rainfall should be better utilized. The simple calculation shows that the rainfall infiltration coefficient is about 0.2 and annual precipitation is more than 500 mm in the North China Plain. If an additional precipitation of 100 mm is retained (normal infiltration), every 1 km² means 10⁶ t of water. When creating and improving the microscopic compound water circulation system for shallow marginal water, if 1/4 infiltration of Type-IV distribution area is utilized, there will be an increase of about 200×10⁸ m³ in water resources. In this way, the pressure of water resources in the North China Plain will be relieved.

1.3.2 Key groundwater control level

Groundwater level is a key indicator to efforts of improving shallow groundwater by creating compound water circulation system. The key groundwater control level is a series of water level values for intra-annual precipitation and groundwater supply and discharge. Within different

periods of hydrological year and under different hydrological conditions, key groundwater control level varies. Thus, key groundwater control level is a dynamic indicator of the changes of compound water circulation system. Key groundwater control level uses marginal evaporation depth as main factors, which can be divided into normal level, alarming level and warning level. Normal level means that the geological environment problems will not occur and rainwater will have trouble getting absorbed at this level because groundwater remains in the “healthy” groundwater circulation process. Alarming level means that some geological environment problems may happen at or above this water level because groundwater remains in the “sub-healthy” groundwater circulation process. In this case, it’s necessary to strengthen groundwater development work, improve local water circulation through exploitation and recharge, tighten monitoring and prevent geological environment from getting worse. Warning level means that underground water will cause some geological environment problems at or above this water level because groundwater remains in the “unhealthy” groundwater circulation process. In this case, it’s necessary to strengthen exploitation, stop infiltration, tighten monitoring and prevent geological environment from getting worse.

Previous research on marginal evaporation depth reveals that the groundwater evaporation depth in most parts of the North China Plain comes close to 4–6 m. So this paper uses the groundwater depth of 6 m as the threshold for key control level, 4–6 m as alarming level and <4 m as warning level. To have sufficient space to contain the collected rainwater, it’s necessary to encourage exploitation of water in regions with alarming and warning water level prior to the rainy season.

In Type-IV shallow groundwater distribution zone of North China Plain, groundwater level mostly remains within the alarming regions of key control water level, so management work should be conducted to give incentives to groundwater development. If groundwater level remains lower than alarming level, it’s advisable to increase the exploitation of groundwater so that groundwater in excess of natural runoff can be exploited, and after the storage space of rainwater infiltration is increased, rainfall will access the underground

storage space through natural supply, so water resources are utilized and improved.

1.3.3 Analysis of water quality improvement technologies

The marginal water in the North China Plain is utilized mainly through irrigation, including direct irrigation, mixed irrigation of saline and fresh water, and rotational irrigation of saline and fresh water (WANG Wen *et al.* 2015). Nevertheless, irrigation of marginal water cannot remove salinity out of water. Instead, salinity tends to accumulate (QIAN and Mecham, 2005). Now we have achieved the non-local discharge of marginal water developed and utilized through industrial cooling water of chemical and electricity industry, and dual water supply in urban everyday life. Moreover, one emerging technique (air-conditioning of cooling ground temperature with water), which is widely used in the North China, can also discharge marginal water and help improve marginal water. This water-cooling technique has a low requirement on water quality, which means Type-IV and Type-V water are applicable. In areas with marginal water, open-circuit discharge technique can be used to prevent recharging of this water underground for recycling purpose. Therefore, the problem of underground thermal island is better solved. So we only need to build the discharge pipeline of surplus water to develop and exploit groundwater and remove salinity at the same time.

The phreatic aquifer is usually quite thin in the central and eastern part of the North China Plain, so it is hard to exploit groundwater through tube wells. In response to the widely distributed thin aquifer where development depth is merely above marginal evaporation depth, the technique of vacuum well point can be used to conduct planar exploitation. The cluster of vacuum well points can withdraw large quantities of groundwater to create artificial depression cone and facilitate the absorption of rainwater in rainy season. Theoretically, vacuum well points are applicable to the exploitation of groundwater at deep water level under one barometric pressure. The practical operation involves slightly shallower groundwater. The general rainfall depth in production is 6–7 m and the most relevant infiltration coefficient falls within the range of 0.5–50 m/d. Much sandy soil is available inside stratum. If it is necessary to exploit

groundwater at a lower level, we should lower the buried surface of well casing and pumping equipment, and the top elevation of well point system. The groundwater is mainly regulated by increasing the number of point wells, generating circular well points and raising exploitation quantity. To save cost, we can use the water-supply pipe well technique with PVC-U plastic pipes. This technique has been widely used in the lower and middle reaches of the Yellow River, and has become specified technique in the region.

The water extraction method is used for the cluster of vacuum point wells. The water-cooling air-conditioning system is used prior to rainy season, and several thin PVC well point pipes in the precipitable areas should be buried in aquifer. At the lower end is the filter tube and at the upper end, the piping system between winding pipe and header pipe. The water pumping equipment in piping system can extract groundwater through vacuum well points. This method can ensure the normal operation of water-cooling air-conditioning

system and lower the original groundwater level, so as to provide enough space for rainwater.

The water-cooling air-conditioning technique has been put into wide use in the North China Plain. As long as this technique is properly adjusted and the necessary discharge facilities are made available, we can create the positive water circulation system, improve the shallow groundwater and increase rainwater utilization in certain areas.

Researchers have completed some intensive research and obtained successful results on rainfall infiltration process (LIU Xiao-feng *et al.* 2014). We can use computers to predict the feasibility of obtaining underground water storage space by extracting groundwater, and calculate the rainfall infiltration based on precipitation infiltration coefficient. Infiltration coefficient should be based on the actual measurement results. If the actual measurement materials are not available, one may refer to Table 3.

Table 3 Precipitation infiltration coefficient values in the middle and eastern parts of North China Plain

Lithology of aeration zone	Groundwater depth (m)				
	<2	2–4	4–6	6–8	>8
Fine sand silty sand	0.25–0.36	0.36–0.40	0.40–0.28	0.28–0.24	0.24–0.22
Silt	0.14–0.24	0.20–0.28	0.29–0.22	0.26–0.20	0.18–0.16
Silty clay	0.12–0.19	0.15–0.26	0.26–0.18	0.18–0.14	0.14–0.12
Clay	0.11–0.13	0.13–0.15	0.15–0.13	0.13–0.12	0.12–0.11

There are many methods to calculate groundwater bearing space, of which specific yield proves the simplest and most practical method. The calculation formula goes as follows:

$$Q = \mu_i \times v_i$$

where:

Q—water bearing space (m^3),

v_i —Size of water-bearing sand layer (m^3),

μ_i —effective water yield.

In the formula, the effective specific yield (μ_i) within the thickness of water-bearing layer can be adopted based on the existing results of the Report on the Sustainable Groundwater Development and Utilization Prospect Achievements (Table 4). The minimum value can be used as the water-bearing estimation value.

Table 4 Statistics of water yield series values in water-bearing layer

Lithology	Rough sand	Medium sand	Fine sand	Silty sand	Silty clay
Water yield	0.18–0.21	0.15–0.18	0.13–0.17	0.09–0.13	0.06–0.10

Given the fact that Type-V water zone extends a considerable area and usually adjacent to Type-IV water zone in the North China Plain, we can improve water quality in Type-IV water zone to accumulate relevant experience before moving

to Type-V. In practice, the main method involves harvesting rainwater to build fresh water reservoirs. In 2010, China issued the national standard—Technical Specification for Rainwater Harvesting and Utilization Projects (GB/T50596–2010) to

regulate the design, construction, check and acceptance, management and economic evaluation of rainwater utilization projects, offering a technical support to rainwater utilization in coastal area.

1.4 Depletion of surface water system

The urban surplus water or the surplus water generated by the improvement of poor-quality

water should be discharged by rivers. It is a key step to create a man-nature compound water circulation system.

The North China Plain is located at the Yellow River, the Haihe River and the Luanhe River areas, has about sixty other rivers of various sizes that flow directly into the sea, including the Tuhai River and the Majia River. The characteristics of these rivers are described in Table 5.

Table 5 Major rivers in North China Plain

Rivers	Source	Length (km)	Drainage area (km ²)
Douhe River			647
Luanhe River	Fengning County, Hebi	877	44 900
Chaohe River	South of Guyuan	252	6 920
Baihe River	South of Guyuan	267	8 710
Chaobaihe River		458	18 180
Juhe River	Xinglong County, Hebei	139	2 440
Jiyun River		301	11 360
Wenyu River	Southern foot of Mount Yan		186
Baiyun River		97	2 440
Yanghe River	Southern edge of Mongolian Plateau	594	18 540
Sanggan River	Northern part of Shanxi Plateau	364	25 840
Yongding River		650	50 800
Hutuo River	South to Wutai Mountain	540	26 630
Fuyang River	East to Taihang Mountain	375	26 300
Ziya River		706	62 630
Daqing River north branch	Eastern slope of Taihang Mountain	308	10 000
Daqing River south branch	Eastern slope of Taihang Mountain	380	22 200
Daqing River		448	39 600
Zhanghe River	Shanxi	412	20 900
Weihe River		352	14 980
Nanyun River		1 021	49 120

Due to precipitation decrease and retention by reservoirs along the upper reach for over two decades, most rivers in the North China Plain remain dry for most part of the year or only undergo temporary overflow during the flood period. As a result they are not able to take the surplus water from human activities. The surplus water, which cannot get diluted or degraded and discharged in river timely, may infiltrate to underground or concentrate in dry riverbeds. In a short flood period, the flowing river water recharges groundwater with wastes, leading to the linear groundwater pollution along the river. To eliminate this pollution, it's imperative to separate surplus water from river water. Once separation is completed, rivers can regain some of their functions. People can make use of river course to retain rainwater, improve local climate and reduce dust.

Currently, as far as materials are concerned, the

construction sector may face overcapacity of sand, stones, cement, steel and construction machines, so it is hard to restore capacity. After the Middle Route of South-to-North Water Diversion Project is completed for operation, the construction process accumulated the abundant design and construction experience and technology for long-distance water transportation. Therefore, it's feasible to build the artificial channel for surplus water along the river and solve the problems of transporting surplus water of dry rivers after surplus water and river water are separated.

2 Results and discussions

The construction of the compound water circulation system is the basic solution to the

shortage of water resources in the North China Plain. The urban flood control, depletion of surface water system and saline water in the central and eastern parts of the North China Plain are three top problems that are restricting the development of the North China Plain. The above-stated analysis shows that these problems can be solved by creating the human-nature compound water circulation system.

We have lots of feasible methods to control urban flood in a technical sense. But water discharge produces no satisfactory results because of the inadequate hydrogeological survey. To achieve the effective urban flood control, it's imperative to have the detailed parameters like structure of vadose zone, water table and runoff in the local drainage basin for design and construction in original infiltration work.

It is not sustainable to exploit deep water to solve the problem of low-quality water plaguing the central and eastern parts of the North China Plain. The phreatic water in the central and eastern part of the North China Plain is usable. With the application of new technologies, water quality can be improved through improving water circulation, and this is the best solution. To do this, it is necessary to investigate stratigraphic structure of phreatic water, runoff parameter of exploited water and source of salinity in water.

The depletion of surface water system deprives this system of its ability to absorb human surplus water, thus the groundwater in some areas along the rivers cannot be used. If additional water cannot be provided to recharge the basic river flow, the construction of special channel for surplus water is the sole way to replace the river's transfer function. The construction of surplus water channel not just involves the building materials and the design and construction technologies, but requires a series of parameters like planned volume of surplus water and measures of flood discharge along river course.

Human activities are everywhere. It is unrealistic attempting to accomplish the natural balance of water circulation system under the heavy influence of human activities. The only way is to identify and conform to natural laws and create a human-nature compound water circulation system that is conducive to human production and life. This study explores some factors from the

perspective of urban rainwater infiltration recovery, transportation of surplus water in the dry rivers and improvement in poor-quality water through rainwater. It is concluded that there is condition for a human-nature compound water circulation system. This paper only makes a simple analysis on some technical factors, and does not compare the economic benefits or examine the possible consequences. As a multi-factor complicated project, human-nature compound water circulation system must change along with surrounding environment, which necessitates constant practices and research.

3 Conclusions

We cannot completely solve water resource-related problems generated by human activities unless we have examined, identified and respected the natural laws of water circulation, and created the human-nature compound water circulation system from the perspective of system theory. This paper explores the construction of human-nature compound water circulation system in the North China Plain based on several limited factors, offering a new perspective on way of completely solving the shortage of usable water in the North China Plain and on possible research direction in the hydrogeological field. It is hoped that this study can inspire more hydrogeological researches.

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References

- CHE Wu, ZHANG Wei, *et al.* 2010. Study on patterns of urban stormwater management in China. *China Water & Wastewater*, 26(16): 51–57.
- China Geological Survey. 2012. *Hydrogeological Manual* (Edition 2). Beijing: Geological Publishing House, 685.
- Davis A P. 2008. Field performance of bioretention: Hydrology impacts. *Journal of Hydrologic Engineering*, 13(2): 90–95.

- LIU Zhan-dong, LIU Zu-gui, *et al.* 2014. Rainfall infiltration characteristics and regression models in winter wheat field. *Journal of Soil & Water Conservation*, 28(3): 7–13.
- HUANG Yong-qiang, WU Tao, *et al.* 2011. The water balance calculation and benefit analysis of rainwater utilization demonstration project in Zhenjiang. *Industrial Safety & Environmental Protection*, 37(1): 41–43.
- JIA Hai-feng, YAO Hai-rong, *et al.* 2014. LID-BMPs planning for urban runoff control and case study. *Advances in Water Science*, 25(2): 260–267.
- LI Xi-lin, LIU Ling, *et al.* 2013. Rainwater utilization of building district in north of China and experiment. *Journal of Liaoning Technical University*, 32(9): 1242–1245.
- LU Xiao-feng, SUN Yi, *et al.* 2011. Utilization of rainwater resources in the urbanization process. *Research of Soil and Water Conservation*, 18(3): 267–271.
- QIAN Y L, Mecham B. 2005. Long-term effects of recycled wastewater irrigation on soil chemical properties on golf course fairways. *Agronomy Journal*, 97(3): 717–721.
- SUN Huan, LIU Zhi-qiang, *et al.* 2013. Analysis and research on the rainwater utilization on one campus of Tianjin. *Research of Soil & Water Conservation*, 20(2): 288–292.
- SU Dong-bin, CHEN Jian-gang, *et al.* 2012. Study on the mode and quantity of rainwater utilization in different urban regions. *Yellow River*, 34(2): 69–72.
- TIAN Yu, LIU Zhi-qiang. 2012. Prospect analysis of urban rainwater harvesting in Tianjin. *Environmental Science & Technology*, 35(3): 178–181.
- XU Guang-ming, LIU Li-jun, *et al.* 2009. Research on the adjustment of groundwater storage in North China Plain. *Resources Science*, 31(3): 375–381.
- WANG Wen, YANG Yun, CUI Wei. 2015. Methods and strategies of unconventional water resources in coastal areas. *Jiangsu Agricultural Sciences*, 43(4): 1–4.