

Application of the “Accurate Control Groundwater Resources” Theory in Containment of Groundwater Resource Exhaustion Trend

Jiansheng Shi^{1,a}, Hongtao Liu^{2,b}, Zhiyuan Liu^{3,c}, Tieliu Chen^{4,d},
Wenhong Zhao^{5,d}, Yanming Sun^{1,e}

¹ Institute of Hydrogeology and Environmental Geology

² Department of Housing and Urban-Rural development of the Henan Province

³ Shanxi Province Economic and Information Technology Committee

⁴ Earthquake Administration of Chongqing Municipality

⁵ Institute of World history, CASS

a: tiger7886@263.net;

Abstract:: The continued sustainable economic development of china depends in part, to the scientific management of China’s precious groundwater resources in the coming years. Groundwater resource scarcity is a common underlying problem across China, in addition, the large-scale groundwater exploitation for human consumption over recent decades has resulted in a series of environmental geological problems. As a result of these problems, the national economics in china have been seriously affected. In order to prevent groundwater resource exhaustion and environmental geology deterioration, “accurate control of groundwater resources (ACGR)” theory and its support system were established in this article, and the related prevention measures of the ACGR theory, such as accurate irrigation, accurate supply water, and accurate subsidies, were proposed. This paper highlights the ACGR theory as an efficient and essential way to achieve the sustainable groundwater resource management, which can be applied to countries such as China.

Keywords: groundwater; environmental geology; accurate; economic; exploited; ACGR

Introduction

Soon after the general economic reforms began in the early 1980s, China’s economic development has made remarkable achievements attracting worldwide attention; meanwhile, environmental deterioration and resource consumption have been the high price to pay for it (M. J. Currell et al. 2012; J. Zhao et al. 2009; R. Ma et al. 2013; Y. Xue 2010). Under the condition of the shortage of

China’s total water resources and per-capita water resources volume, special attention is needed to address the problem of water resource extensive use and poor management. The scientific management of groundwater resources is essential in order to minimise groundwater resource exhaustion and pollution trends, and the long-term of supporting role of groundwater resources on the sustainable development of the social economy.

1 Current water resources in China

1.1 Groundwater

Total water resources are scarce in China, with per-capita water resources less than 1/4 of the total global water resources, with groundwater resources accounting for 1/3 of the total water resources in China. In the current structure of water use of the country, groundwater accounts for 20% of China's total water supply, 70% of drinking water, 40% of agriculture irrigation water, and 38% industrial water (China water resource bulletin 2011). Within north China, the ratio of groundwater to drinking, agriculture irrigation and industrial water are higher, even exceeding 80% in some local areas, and the structure of water use is not expected to change in the short term.

1.2 Groundwater resources support economic growth

The population of China accounts for approximately 20% of the global population, however, accounts for only ca. 5–7% of global freshwater resources. The per-capita water resources are less than 1/4 of the global water resources, which are essential not only for ensuring the development of industrialization and urbanization, but also to maintain long term food safety. Over recent decades, the North China Plain (NCP) has consumed less than 2% of the total national water resources to support 10% of the total national population, 12% of total national GDP and 10% of total national food output. In such areas such as Southwestern red clay region, loess plateau, Northwestern inland basins, unwatered uplands, north regions with endemic drinking water induced diseases, and ones with Kaschin-Beck diseases in Sichuan Province, more than 2 million wells were successively dug to ensure safe drinking water for more than 8 million people (Z. Shen et al. 2010). The problem of supplying drinking water to several million people has been solved by the construction of wells to combat drought in dealing with extreme climate events.

1.3 Uneven distribution of groundwater In China

Shallow groundwater is circulative and renewable, however the rate of deep groundwater renewal is somewhat slower. Groundwater is the most active controlling factor in the ecosystem; the complexity of groundwater quality makes itself not only have availability (e.g. mineral water), but also with harmfulness (e.g. water with higher arsenic and fluoride levels). According to the latest literature, the annual natural recharge of fresh groundwater resources in China is about $9 \times 10^{11} \text{ m}^3/\text{a}$, in which the north and south areas receive 32.3% and 67.7% of this resource respectively. The total minable quantity of underground fresh water is about $3.5 \times 10^{11} \text{ m}^3/\text{a}$, with the north areas accounting for 43.6% of this resource, and the south areas accounting for 56.4%. The distribution of water resources in China is very unevenly distributed and mainly converged into different large plain basins. According to statistics (China water resource bulletin 2011; Z. Shen et al. 2010; J. Wang et al. 2007), the total annual amount of groundwater exploited throughout China is ca. $1 \times 10^{11} \text{ m}^3/\text{a}$, which is 30.0% of the total groundwater resource. There is a distinct spatial difference between the degree of water exploitation China, with northern China exploiting significantly more than southern China. Currently, the degree of exploitation in the NCP is the highest in China with 114%. 105% of the groundwater exploited annually is from shallow aquifers and 177.2% from deep aquifers; highlighting the significant overexploitation of deep groundwater. Almost 100% of the annual extraction occurs in the six basins of Shanxi and 132.7% in the Taiyuan basin. Although some areas are heavily overexploiting groundwater resources, there are basins that exhibit further potential of exploitation for human consumption.

1.4 Groundwater resources issue in china has already attracted worldwide attention

The issue of groundwater resources is

<http://gwse.iheg.org.cn>

inextricably linked to concerns regarding drinking water safety, food security, engineering safety, and ecology safety, with international groups increasing investigating these concerns. Brown Lester reported that the groundwater overexploitation in China reduced the aquifer to regenerate and was unsustainable; threatening the food safety of China (L. R Brown 2009). Between 2006 and 2007, the International Herald Tribune and The New York Times published numerous reports on the problem of NCP's groundwater, which related groundwater with food security and urban expansion. "The water crisis is not unique to China," stated Frank Schwartz, an attending hydrologist at Ohio State University in Columbus, "But the problem here is orders of magnitude bigger than anywhere else" (F. Schwartz 2010).

2 Exhaustion, contamination, and ecological recession

The situation of groundwater overexploitation is serious due to the requirement of water resources to supply the needs of a fast growing economic society, which has brought about a series of problems, including groundwater quantity decline, groundwater quality degradation, and ecological environment destruction, the overall status increasingly appears to be serious.

2.1 Groundwater depletion

The water table is declining due to the overexploitation of the groundwater in some areas, which makes these areas faced with groundwater resources exhaustion. The overexploited regions are mainly distributed in Yellow River and Huai River basins, six basin of Shanxi Province, Guanzhong Plain, Songnen Plain, Liaohe Plain, Shiyanghe Basin in the Northwest. Whilst the shallow groundwater in piedmont of the Taihang Mountain and central NCP have been partly depleted. The deep groundwater level declines are more serious near large cities, such as Beijing, Tianjin, Hebei province, and the Shandong province, where major cones of depression have

<http://gwse.iheg.org.cn>

formed below cities. For example, water table are lower than the seal level in the cone of depression below the above cities, this cone of depression is the largest in world at 70,000 km². Similarly, in Northwest China, the groundwater level in major basins has been steadily declining, causing the oases decreasing and springs exhaustion. The Beijing Yuquan Mountain spring was praised as "clear spring water like a jade, looks like a rainbow, its temperature and quality outstanding", however by May 1975, was completely exhausted. Xintai City, Hebei Province, known for thirty-six springs, irrigates almost 270 km² of agricultural land, however, from 1981 to 1987 these springs were gradually exhausted, the scene "hundreds of springs and artesian wells" had disappeared. The Niangziguan spring, located in Pingding county of Shanxi province, experienced an outflow decrease of more than two thirds, with other springs completely drying up, including the Nanlao spring, which dried up in 1994. Currently, the water table in the Jinci spring region is falling at a rate of more than 1.5 m per year (Q. Guo et al. 2005). Thus, the "groundwater flow look like jade in Jinci" scene described by Libai is disappeared forever. It was reported that 72 springs dried up in Jinan City for 890 days around 2001.

2.2 Groundwater contamination

According to the Ministry of Land Resources (China land resources bulletin 2011), the groundwater quality monitoring data from 200 cities in 2011, indicated that the nationwide groundwater quality is overall "not optimistic"; 55% of the cities were shown to be experiencing "poor and worse" groundwater quality. The number of hydrochemical variables in most cities are gradually increasing for groundwater quality assessment, including total dissolved solids (TDS), total hardness (TH), nitrate, nitrite, sulfur, iron, manganese, chemistry oxide demand (COD), ammonia and nitrogen, to name but a few. There are pollution elements with high concentrations that fall above guideline values set by the World

Organize Health (WHO) (2006), involving TDS, TH, three nitrogen, sulfate, chloride, fluoride, chromium, phenol, arsenic, mercury, cyanide, bacteria, and coli group. Most of the three nitrogen content exceeds the guideline value, and higher level of TDS and TH are mainly distributed in northeast, northwest, southwest, and north china, iron and manganese out of limit in northeast and southern part of China. Besides inorganic pollutants, the organic containments were also detected in groundwater and over standard in some local areas. These organic pollutants include chlorinated hydrocarbons, benzopyrene, and persistent organic pollutants, which could lead to cancer, malformation, and mutation. 26 noxious organic indices were detected in shallow groundwater in the NCP. At present, about 300 million rural residents and an urban population of 50 million still consume substandard drinking water.

2.3 Environmental consequences

Due to the exploitation of deep confined groundwater, land subsidence has occurred in large cities and other overexploited regions. Areas experiencing severe land subsidence include the NCP, Yangtze River Delta, and Fenwei basin. Disturbingly, the center subsides of different region in NCP are still developing with an oncoming trend of joining them together. The land subsidence center in NCP is located in Cangzhou and Renqiu cities with deepest accumulative subsidence of 2,457 mm. In Tianjin, the maximum cumulative subsidence has reached 3,220 mm and the total affected area is nearly 8,000 km²; the areas with subsidence depth of more than 1,000 mm and the total affected area exceed 8,500 km² (L. Yi et al. 2011; R. Hu et al. 2002), and that more than 2,000 mm exceed 940 km² in NCP. In Xian city, the groundwater overexploitation has caused damage to more than two thousand buildings as a result of land subsides and ground fissures. More than 400 ground fissures are found in Hebei, Shanxi, Shanxi, Shandong, and Henan province.

The accumulative area of sea water intrusion is 3,076.4 km² in east part of Shandong province.

2.4 Desertification and Wetland Recession

Due to many of the rivers in the northwest inland basin being intercepted, Weili lake located at the edge of desert is facing to being withered, a result of the combination of the dry climate, ecological environment deterioration, and the shrinking of the oasis area. In the past twenty years, wetland recession is the most significant characteristic of ecological environment change in Songnen plain (Abbott et al. 2013); the wetland area reduced by 65.80 ha, the average annual decrease is 4.39 ha. The surface water in the wetland has decreased by 1.274×10^5 ha, and the swamp area has decreased by 5.306×10^5 ha. There were more than 4,000 bogs in Sanjiang plain, however, 67.7% of bogs have withered due to the decline of groundwater level. This loss of bogs and wetlands will have a significant effect on the carbon storage of these soils, increasing the loss of carbon into the atmosphere (Abbott et al. 2013). Furthermore, large lakes have been atrophying day by day, with small lakes already disappeared.

2.5 Unsustainable human demand

During the rapid development of the Chinese economy, several aspects have resulted in the accelerated collapse of groundwater resources and the growing groundwater contamination; firstly, the overexploitation of groundwater resources without considering its carrying capacity; secondly, the natural water circulation system has been randomly destroyed; lastly, the impact of climate change, which should not be forgotten. For example, within the NCP, previous studies (F. Huang et al. 2006) concluded that there had been four major reasons that had caused groundwater level decline and various environmental issues. The first was that the large-scale water projects influenced the runoff and decreased the recharge of surface water to groundwater; secondly, as China's industrialization, urbanization and fast-forward

agriculture expands, so will its demand for groundwater; thirdly, climate changes result in precipitation decline; finally, groundwater level decline disordered the aquifer, which has led to the decrease of its water storage capacity. The realization of the extent of water resource exploitation has resulted in the technology improvement and implementation of saving water measures. Unfortunately, due to the spatial variability of groundwater resources, plain areas where huge water consumption is still in overexploitation situation, the water crisis will continue to exist, and even become more severe in future.

3 The ACGR theory

3.1 The ACGR theory for groundwater resource irrigation utilization

The ACGR theory is an effective way to prevent groundwater resources exhaustion, and the following section will discuss the requirement for the ACGR to become established in order to maximize the efficiency of groundwater resource irrigation utilization without exploitation.

3.1.1 Groundwater resources management of China is still extensive

Although the water conservation strategy and its related decisions have been established in China, these policies are too extensive to be practically implemented. On the whole, groundwater resources management confronts some problems, such as the total natural amount of groundwater resources ambiguity, the insufficient groundwater management tools, ambiguous policies, and insufficient investment in infrastructure. For instance, groundwater distribution laws and its assessment are not accurate enough; groundwater monitoring systems are incomplete; groundwater exploitation data are inaccurate; and many other weak management links still exist (e.g. lacking management on self-prepared wells inside cities, ineffective control of geo-thermal resources).

Previous studies (R. Ma et al. 2013; S. Feng et al. 2011; N. Don et al. 2006) believed that bad management is the main reason for water resource exhaustion; water crisis will be alleviated if the effective groundwater management measures are applied. To implement the effective groundwater management measures, more accurate scientific and technological support and management rules are required. Therefore the ACGR is the necessary choice to prevent groundwater resource deterioration.

3.1.2 The experience of water utilization from developed countries is worth to reference

Internationally, modern, technology-intensive water saving agriculture techniques were implemented. For example, in Israel the use of these water saving techniques, the utilization ratio of irrigation water reached 0.95, almost double that seen in China, with only a 0.5 utilisation ratio of irrigation water (J. S. Neal et al. 2011; Y. Li et al. 2012). Developed countries like the U.S. transformed their strategy to enhance water utilization and subsequently improve water utilization ratio; it is not only for the alleviation of water shortage, but also for decreasing the environment pressure to a large extent. Even in Canada where water resources are abundant, some water-saving measures have been employed (K. Nelson et al. 2011). In comparison with the advanced experience of water utilization and management, there are significant differences between China and developed countries in the sustainable utilization for water resources.

3.1.3 The basic connotation of ACGR theory

Under the guidance of national water policies and established plans, and in accordance with the high-accuracy hydrogeological surveys and groundwater resource assessment, a high-density groundwater dynamic monitoring network will be used to achieve a high-standard and full-coverage groundwater exploitation measurement. In addition, there will be a related information-based support

system, in which the quantity, quality and ecological function of groundwater utilization are unity regulated. The relationship between the economic and social development and groundwater carrying capacity will be coordinated, with a precisely designed experiment, allowing a suitable and feasible policy of constraint, control, encouragement, and subsidy, to promote groundwater management with high accuracy, precision and efficiency, establishing the coupling system between technology and management of national water resources strategy and fully implement it.

3.1.4 Planning and coordination of ACGR theory

With respect to groundwater quantity, the embodiment of “saving water is prior, comprehensive controlling water” is to realize that saving water is the basic principal. Comprehensive water-saving measures shall be implemented as soon as possible, and the utilization ratio of water shall be improved, thus the problem of water resources shortage can be minimized and even solved. Only when water shortage is due to a resource-based shortage, water-saving measures are difficult to support development, the engineering project such as water transfer measures can be employed (Y. Gao et al. 2010). In order to avoid the destruction of the ecological environment in the water-transfer region; the interregional water transfer project must be prudently carried out. With regard to water quality, the concept that “water pollution prevention priority, combining control with prevention” needs to be embodied. Subsurface strata are complex and groundwater flow slowly. Therefore, groundwater pollution is characterized by a slow contamination course, which are inherently difficult to restore, difficult to locate, and often difficult to manage. Thus once groundwater is polluted, even though the contamination source may be completely removed, groundwater quality may take more several decades or even hundred years to revert to

its non-contaminated supply, and in some case the groundwater cannot be repaired. As a result, the idea of “first pollution and then treatment” must be abandoned, and the prior prevention policy is employed. With respect to ecosystem, it is necessary to embody “prior ecology and harmonious between human and water”. At present, the situation in North China is that almost every river dries up, each water catchment has some degree of pollution, there is a continuous drop of groundwater level which has a slurry of subsequent problems as discussed, including spring depletion, ecology environment deterioration, and diffused groundwater pollution. In comparison with past nice ecological scenery and livable environment, the status is difficultly accepted by the generally public. Therefore, the requirement of ecological protection must be a priority before water resource exploitation. The necessary water volume that could support the ecosystem must be maintained and conserved, in which the basic groundwater level required by ecology environment is maintained. Only in this way the basic idea of the harmonious relations between human and water can be reflected

3.1.5 Applying the ACGR theory

At mentioned previously, the basic national condition in China is that the temporal-spatial distribution of groundwater is uneven. The embodiment of harmony between human and water is to adapt to the resource endowment characteristic. Based on the actual situation of local area, saving water, and groundwater resources bearing capacity as the constrain condition, through the reversal top design; industrial development layout is projected on the constraint condition of water resources. Those layouts that against water resources endowment need to be timely reshaped to achieve the positive interaction between industrial development and water resources circulation substitution. Just as NCP do, it has a double cropping system of growing wheat in winter and maize in summer.

However, because there is very little precipitation on the NCP in winter, this draws deeply on groundwater supplies. Policy decision maker must rethink its agriculture structure because the current strategy is completely unsustainable (X. Liu et al. 2003), it must be changed to conform to the season characteristic of NCP (e.g. decreasing the winter wheat and increasing the summer maize planting in future).

According to some investigations, there are few accurate groundwater quality assessments for various uses in China, which has resulted in insufficient basic information of groundwater and impractical saving water measures. There is also a significant difference of the quantity of irrigation water utilised amongst farmers, even in the areas executing irrigation water saving techniques. Although the same method is applied, the pipeline conveyance border irrigation technology, in spring irrigation of winter wheat, the amount of irrigation water ranges from 600 to 1, 500 m³/ha, which is difficult to control accurately. This result indicates that the potential of water saving is large; and warns us that the technology platform must be timely established to improve the precise of science and technology. The improvement of science and technology precision can provide support for the improvement of management accuracy. Via the improvement of management accuracy, various object of water resource management may be achieved, and every policy and measure may be implemented by accurate operations.

3.2 ACGR application

3.2.1 Supporting system of ACGR requires to be established according to enlarging the basic infrastructure investment

In order to reach this target, three measures should be implemented as soon as possible: first, large scale hydrogeology surveys and groundwater resource assessments must be carried out in major cities, economic zones, and main agriculture

<http://gwse.iheg.org.cn>

producing regions; secondly, implementation of the national groundwater monitoring engineering, and establishment groundwater dynamic monitoring net system; finally, overall planning high-standard basic farmland construction and rural water conservancy infrastructure construction. Standardized devices for accurate metering are suggested to be installed for each well in order to master accurate water consumption, and reinforce the studies on basic theory in groundwater field and informatization establishment. Through implementing the above measures, the support system of ACGR will be formed, which consists of the accurate hydrogeology survey, the precision groundwater monitoring, the precision water consumption measurement, and the regulation and controlling informatization platform of scientific distribution groundwater resources. These measure in addition to the mechanism of the duplicate controlling water by interdepartmental balance and cooperation, could potentially provide a guarantee for the full achievement of the national strict groundwater management strategy.

3.2.2 The agriculture structure and irrigation system that is fit for the groundwater resources characteristic need to be adopted to carry out accurate irrigation

In order to achieve the goal that average water utilization coefficient will increase from 0.5 at present to 0.6 in 2030 in irrigation zones (N. Don et al. 2006), soil water regulation function is required to be scientifically applied. The agricultural industry structure and crop products structure can match the soil water optimum period by observing the law of season change of the precipitation and soil water. With respect to the situation of north China, increasing the planting area of cotton and coarse cereals that are sowed in summer and harvested in autumn, and decreasing the planting area of winter wheat. Accordingly, the soil water can be efficiently used to reduce the irrigation water demands. Studies (Y. Wang et al. 2006) on typical areas illustrates that under the

condition of increasing the grain yield, more than 20% irrigation water is capable of being saved through optimizing irrigation system of winter wheat and summer maize rotation system, thus optimization of irrigation system would be widely employed in future.

3.2.3 The “accurate subsidy” application is to be promoted by leaning the increment of agriculture subsidizes towards saving water effect

Considering the large potential of water saving and the restrictive function of water resources to food security, it is suggested that the increment of agriculture subsidy of major grain producing areas should be added in water saving effect; the relationship between protecting the farmer’s planting enthusiasm and saving water should be appropriately handled; making the policy of water consumption subsidize within basic standard quotas, and the policy of extra price beyond the basin standard quota; accompanying with the optimization of planting structure in the constraints of proper planting scale and water resources, ratio of water utilization will be improved to realize the objective of water saving.

3.2.4 Application of “accurate water supply” that means establishment the system of “double sources and different water quality for various purposes” during the process of urbanization

In order to apply “accurate water supply”, several measures are proposed as follows: combining the new city district establishment with old city district infrastructure transformation, to establish the system of different water quality for various uses; enhancing the self-drilled well management; strengthening exploitation and control of geothermal resources; prompting the rainwater collection and water resources recycling. Most of the cities in China have a single water supply source, especially in south China, in which surface water is the major source of water. In recent years, not only the extreme drought and

flooding events have occurred, but also water pollution is increasingly occurring. Therefore, emergency and reserve water supply mechanisms have become the inevitable choice for ensuring drinking water security and improving the ability to deal with the extreme climate and emergent water pollution events.

3.2.5 Focusing on the groundwater contamination prevention and implement “accurate prevention”

The assessment of the environment vulnerability and pollution of groundwater needs to be carried out to provide support for the industrial structure adjustment. The following are several measures proposed to protect water resources and environment, including improving industrial production technologies, forbidding the use of seepage wells and pits to discharge sewage, rational application of nitrogen fertilizer, carrying out irrigation water saving, decreasing nitrogen loss, building sanitary landfill site for municipal refuse, strengthening the popularization of groundwater contamination prevention knowledge, enhancing environmental protection consciousness, self-conscious protection for water resource and water environment.

This paper is supported by the Major State Basic Research Development Program of China (973 Program) (Grant NO. 2010CB428800).

Jiansheng Shi

Male; born in 1962; Director of institute of hydrogeology and environmental geology, CAGS. He has been researched the regional environmental geological and hydrogeology evaluating, loess deposit for many years. At present, he is responsible for the project “Evolution Mechanism and Regulation of the Groundwater in North China Plain (973)”

References

M. J. Currell, D. Han and Z. Chen et al.
Sustainability of groundwater usage in north

- China: dependence on palaeowaters and effects on water quality, quantity and ecosystem health. Hydrol Process, 2012
- J. Zhao, C. Wang and Z. Jin et al. Seasonal variation in nature and chemical compositions of spring water in Cuihua Mountain, Shaanxi Province, central China. Environ Geol, vol 57, 1753-1760, 2009
- R. Ma, J. Shi and J. Liu. FRFI model application in groundwater non-point source pollution evaluation: a case study in the Luoyang Basin of North Henan Province, China. Environ Earth Sci, Vol 68, 45-56, 2013
- Y. Xue. Present Situation and prospect of groundwater numerical simulation in China. Geological Journal of China University. Vol 16, 1-6, 2010
- China water resource bulletin. The ministry of water resources of the people's republic of china. 2011
- Z. Shen, H. Guo and G. Xu et al. Abnormal groundwater chemistry and endemic disease. Chinese Journal of Nature, vol 32, 2010
- J. Wang, J. Huang and S. Rozelle et al. Agriculture and groundwater development in northern china: trends, institutional responses, and policy options. Water Policy Supplement, Vol 1, 61-74, 2007
- L. R Brown. Could food shortages bring down civilization. Scientific American, Vol 300, 50-57, 2009
- F. Schwartz. China faces up to groundwater crisis. Nature, vol 466, 308-319, 2010
- Q. Guo, Y. Wang and T. Ma et al. Variation of karst spring discharge in the recent five decades as an indicator of global climate change: A case study at Shanxi, northern China. Science in China Ser. D Earth Science, vol 48, 2001-2010, 2005
- China land resources bulletin. The ministry land and resources of the people's republic of china. 2011
- WHO. Guideline for drinking water quality, addendum to vol 1, World Health Organization. ISBN 92 4 154696 4, 2006
- L. Yi, F. Zhang and H. Xu. Land subsidence in Tianjin, China. Environ Earth Sci, Vol 62, 1151-1161, 2011
- R. Hu, S. Wang and C. Lee et al. Characteristics and trends of land subsidence in Tanggu, Tianjin, China. Bulletin of Engineering Geology and the environment, vol 61, 213-225, 2002
- Abbott, G.D, Swain, E.Y, Muhammad, A.B, Allton, K, Belyea, L.R, Laing, C.G, Cowie, G.L. Effect of water table fluctuations on the degradation of Sphagnum phenols in surficial peats. Geochim. et Cosmochim. Acta. Vol 106, 177-191, 2013
- F. Huang, S. Zhang and J. De Leeuw et al. Wetland changes in the middle and lower Wuyuer River, Songnen Plain since the 1970s. Journal of Natural Resources. Vol 21, 949-956, 2006
- S. Feng, Z. Huo and S. Kang et al. Groundwater simulation using a numerical model under different water resources management scenarios in an arid region of China. Environ Earth Sci, Vol 62, 961-971, 2011
- N. Don, N. Hang and H. Araki et al. Groundwater resources management under environmental constraints in Shiroishi of Saga plain, Japan. Environ Geology, Vol 49, 1223-1232, 2006
- J. S. Neal, W. J. Fulkerson and B G Sutton. Differences in water-use efficiency among perennial forages used by the dairy industry under optimum and deficit irrigation. Irrigation Science, Vol 29, 213-232, 2011
- Y. Li, H. Pang and T. Yu. Evaluation of Agricultural Water Use Efficiency and Regional Irrigation Strategies in China Based on GIS. Paddy and Water Environment, vol 115, 473-481, 2012
- K. Nelson, M. Cismaru and R. Cismaru et al. Water management information campaigns and protection motivation theory. International Review on Public and Nonprofit Marketing, vol 8, 163-193, 2011

- Y. Gao, H. Wang and L. Han et al. Consciousness of Water Resources Crisis and the Innovation of the Water Resources Management System in Beijing. Resource Science, vol 32, 274-281, 2010
- X. Liu, X. Ju and F. Zhang et al. Nitrogen dynamics and budgets in a winter wheat-maize cropping system in the North China Plain. Field Crops Research, Vol 83, 114-124, 2003
- Y. Wang, W. He and M. Cai et al. Evaluation model on environmental benefit water saving agriculture in arid continental river basin of northwest China. Journal of China Agricultural University, Vol 11, 65-70, 2006