Rational Development and Utilization of Water Resources Related to Prevention of Desertification in Arid Area of Northwest China

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[Abstract] The enormous inland basins in northwest China, mainly consisting of Zhungeer basin, Talimu basin, Chaitamu basin and Hexi Corridor, are known as typical Gobi Desert area occupying a dimension nearly 25% of the whole territory. All the streams draining from the mountain area flow into the piedmont plain and become as the main water resources of the cultivated area so called "Oasis" like a green island in the central part of the basin. However, since 1950's, the hydrologic situation is already strongly affected by human activities, resulting in serious deterioration of the ecologic environment. This paper focuses on the variation of the hydrologic system due to the impact of human activities in relation to ecologic environments with special reference to the evolution of desertification in the arid area.

[Key words] hydrologic system; surface runoff; groundwater; oasis; desertification; basin system; hydrogeologic zonation; eco-environment
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0 Introduction

The definition of "desertification" is made out in United Nations Conference on Environment and Development held 1992: "Desertification means land degradation in arid semi-arid and dry sub-humid areas, resulting from various factors, including climatic variations and human activities". According to a lot of research works during past 50 years it is already illustrated that the irrational utilization of the water resources in arid area is a predominant factor influenced the changes of hydrologic conditions caused the rapid extension of desertification. For instance, many reservoirs had been built during that time, these have resulted in the drastic changes of water allocation, declination of groundwater level, depletion of spring outflows, deterioration of water quality, even the interruption of streams and extinction of the terminal lakes. These tremendous changes in the water environment by human activities have seriously affected the ecologic system of the whole region especially displayed by the drastic extension of desertification. How to prevent the harmful ecologic effects of such irrational water development is the most pressing hydro-environmental problems in arid area of Northwest China.

1 Analysis of the hydrologic system

1.1 Origin of the surface runoff

As mentioned above, the inland basin in

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Northwest China are known as typical arid Gobi Desert region, where the precipitation is only 50~200 mm and usually below 50 mm in desert area, while the strong potential evaporation reaches 2 000~3 000 mm, that is the rainfall within the basin almost entirely diminished by evaporation.

On the other hand, all the basins are surrounded by high mountain ranges, such as Qilianshan mt., Tianshan mt. and Kunlunshan mt. generally with an elevation of 4 000~6 000 m, where is widely covered with glaciers and snows. In contrast with the piedmont plain, the amount of precipitation in mountain area is comparatively plentiful and increased with the rising of elevation (Table 1) showing a rule of zonal distribution of precipitation from the high mountains to the desert area of the basin (Table 2).

Table 1 Variation of the Precipitation Related with the Elevation of the Mountain Ranges

Elevation /m	Precipitation /mm	Elevation /m	Precipitation/mm
>4 000	600~800	2 000~1 000	100~200
4 000~3 000	400~600	<1 000	<100
3 000~2 000	200~400		

Table 2 Zonal Distribution of the Precipitation /mm

High mountain	Low mountain	Piedmont plain	Desert land
600~200	200~100	50~100	20~50

Therefore, the surface runoff in mountain area mainly comprises of rainfall, melt water and the discharged fissure water (Table 3). According to the different proportion of these 3 major constituents, 3 types of the surface runoff can be classified:

(1) melt water type (melt water>60%), the stream flow is comparatively stable.

(2) rainfall type (rainfall > 60%), the stream flow is comparatively less stable.

(3) mixed type. In which the rainfall type is most predominant and the melt water type is mainly distributed in Talimu basin.

1.2 Transformation of surface water and underground water in piedmont plain

All the streams that originate from the rainfall and melting snows including dischargedgroundwater in high mountains form a large volume of runoff flowing into the piedmont plain and usually passing through two or three basins separated by rock gorges, finally flowing enter a terminal lake. The surface water and groundwater transform into each other repeatedly in the entire catchment area. Almost 60% to 80% of the runoff penetrates into the ground when passing through the gravel beds in the Gobi area. It emerges in the form of spring clusters on the frontal part of the alluvial fan and flows into the main cultivated land so called Oasis to become the chief water source for irrigation (Fig. 1).

Table 3 Component of Surface Runoff in Mountainous Region of Northwest China

Name of the basin	Name of the drainage	component of surface runoff/%		
		Meltwater	Rainfall	Groundwater
Hexi Corridor	Shiyanghe	4.5	65.4	30.1
	Heihe	11.5	54.1	34.4
	Sulehe	37.6	22.9	39.5
Zhungeer Basin	Urumqi	10.0	66.7	23.3
	Toutunhe	6.1	73.8	20.1
	Manus'he	34.6	40.8	24.6
Talimu Basin	Muzhatihe	81.1		18.9
	Wetakhe	65.7	14.2	20.1
	Chilehe	61.3	26.2	12.5

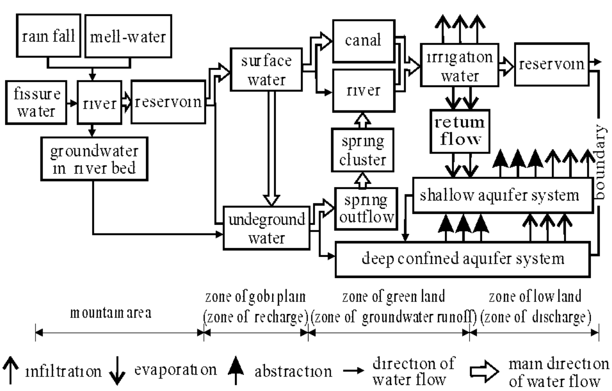


Fig. 1 A Shcematie Diagram Showing the Configuration of the Hydrologic System in An Inland Basin of Arid Area

A hydrologic system in a basin is formed by the combination of the surface water system and the groundwater system intertransforming into a unified body. The surface water system is usually consisting of streams, canals, spring clusters, lakes and reservoirs, in which they are closely connected with each other; while the groundwater system in piedmont plain can be classified into 3 sub-systems:

(1) local groundwater system.

(2) sub-regional shallow aquifer system.

(3) regional deep aquifer system.

The mutual transformation of the surface water system and the groundwater system is actually very complicated as shown in Fig 2.

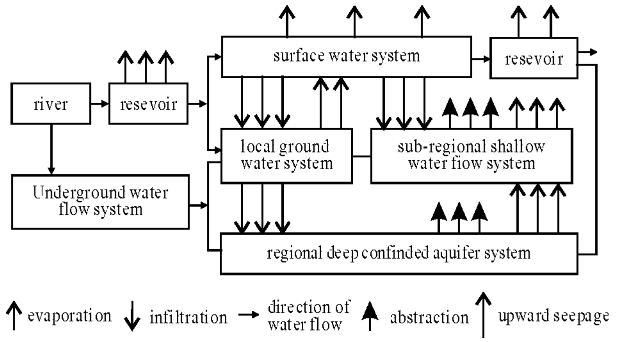


Fig. 2 A Shcematie Diagram Showing the Relationships Between the Surface Water System and the Groundwater Flow System

1.3 Hydrogeologic zonation in piedmont plain

All the basin can be divided into 3 distinct zones based on either geological or hydrological aspects, which are (Table 4):

Table 4 Hydrogeologic Zonation in Piedmont Plain

Geomorphic zonation	zone of gobi plain	zone of Oasis	zone of low land
Quaternary geology	great thickness of gravel beds	medium to fine grained sediments intermedded	Mostly fine grained sediments
aquifer system	mono aquifer with deep water level	multi aquifer both of confined and unconfined with shallow water level	multi aquifer with very shallow water level
water quality	fresh water	fresh water combined with brackish water	Brackish water combined with saline water, fresh water can be found in deep aquifer
groundwater system	zone of recharge, vertical infiltration of surface water	zone of ground water runoff	zone of discharge mainly by evaporation

(1) zone of Gobi plain, also can be called zone of infiltration or zone of recharge.

(2) zone of green land (Oasis), also can be called zone of underground runoff.

(3) zone of low land, also can be called zone of evaporation or zone of discharge.

In zone of Gobi plain, about 80% ~ 90% of the running water penetrates into the underground. The groundwater is deeply buried with a high hydraulic gradient and strong permeability to serve as a large natural subsurface reservoir. In zone of Oasis, there is the main cultivated land in the basin. The water-bearing beds become medium to fine grained sediments to form multi-aquifers including both of the confined and unconfined aquifer.

In zone of low land, the groundwater level becomes very shallow, showing strong evaporation both of the shallow aquifer and the surface water. The water quality gradually worsens from fresh to brackish accompanied with saline water. Fresh water can be found in the lower part of confined aquifer. Swamps and sand dunes are usually spread here and there.

2 Relationships between basin system and water resource system

As mentioned above, a complete hydrologic system usually comprises of 2 or 3 sub-systems represented by the connected basins of a drainage system, where each sub-system formed by the combination of the surface water system and the groundwater system inter-transforming into a united body. These basins from upper reach to lower reach closely connected to each other by a river drainage can be also called a basin system usually comprised the upper basin (Table 5), middle basin and lower basin, in which the total amount of water resources of the these basins are more or less equivalent to the total surface runoff originating from the mountain area. Therefore a basin system is also representing a water resources system, the total inflow of the surface runoff from the mountain area is allocated by these separated basins to form a natural balance with each other depending on historical development.

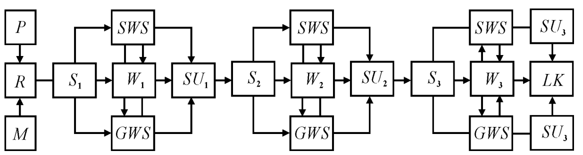
Table 5 Division of A Basin System

sub system	upper basin in upper reach	middle basin in middle reach	lower basin in lower reach
structure type	intra montane depression	fore depression type	fore depression type
neo tectonic	very strong	strong	moderate
scope of the basin	moderate	large	very large
very large	zone of oasis very narrow	zone of oasis well developed	zone of low land more developed
water balance	$I-Sp=W$	$I-(Sp+Z+E)=W$	$I-(Z+E)=W$

In short, the amount of outflow from mountain area is nearly equivalent to the total water resources of the whole basin system. The inflow of the first basin is approximately equal to the total water resources of the whole drainage, while the inflow of the second basin is the corresponding the surplus of the first basin, and the inflow of the third basin is corresponding the surplus of the second basin. Therefore the high consumption of water resources in the upper basin has caused rapid decrease of the inflow into the middle or lower basin, even caused the interruption of the streams or depletion of the lakes.

A water resource system in a drainage basin can be illustrated by following simplified equations:

$$W(\text{total water resources}) \approx R \approx W_1+W_2+W_3$$
$$W_1 \approx S_1-SV_1 \approx W-(W_2+W_3)$$
$$W_2 \approx S_2-SU_2 \approx W-(W_1+W_3)$$
$$W_3 \approx S_3 \approx W-(W_1+W_2)$$



R: surface runoff; P: precipitation; M: melt water; LK: terminal lake; S_1, S_2, S_3: inflow of each basin; SU_1, SU_2, SU_3: outflow of each basin; SWS: surface water system; GWS: ground water system; W_1, W_2, W_3: water resource of each basin

Fig. 3 A Schematic Diagram Showing the Close Relation Between the Water Resources System and the Basin System

3 Hydrologic effect due to human activities

3.1 Changes of irrigation system

During the past 50 years, many reservoirs and irrigation channels have been built for developing new cultivated land known as the man made new oasis. These developments have resulted in the reduction of groundwater recharge that has caused the drastic depletion of spring outflows and the regional declination of groundwater table. In consequence, the original spring irrigation in natural oasis is now mostly replaced by well irrigation, while the original land of stream irrigation mostly replaced by channel irrigation (Table 6, Table 7).

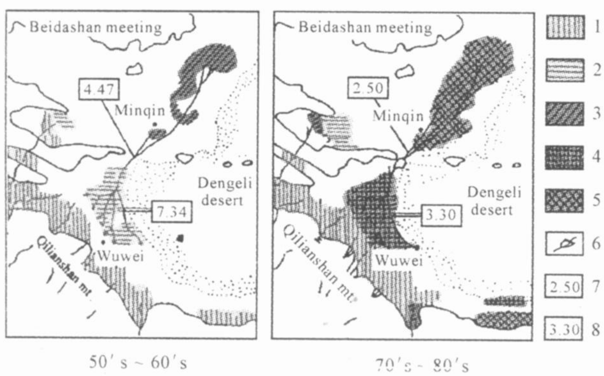
Table 6 Comparison Between Spring Outflow and Infiltration of Stream Flow in Wuwei Basin

item	1956	1961	1986	1971	1978	1980's	1900's
infiltration	10.73	8.83	7.18	5.86	5.35	1~2	<1
spring outflow	8.63	7.10	5.78	4.74	2.12	0.69	0.3
%	80.4	80.4	80.7	80.8	39.56		

Table 7 Changes of the Inflow in Minqin Basin 1950's~1990's

years	1950's	1960's	1970's	1980's	1990's
inflow	5.74	4.31	3.15	2.29	1.7

For example, in the Shiyanghe river basin, all the surface runoff from mountain area is almost entirely obstructed by the reservoirs in mountain valley and diverted by cemented channels flowing into new oasis in piedmont plain for irrigation. Because of the spring outflow is already nearly exhausted, thus the original spring irrigation in natural oasis is entirely replaced by well irrigation, while the original irrigation system of stream flow in Minqin county of lower reach is also replaced by well irrigation and partly of channel irrigation. Because of the shortage of recharge, the highly over exploitation of groundwater hastened the declination of the groundwater level and seriously resulting in the deterioration of eco environment.



1 Surface w. Irrig. Area; 2 Spring w. Irrig. Area; 3 Springs and streams Irrig. Area; 4, 5 Well irrigation area; 6 Reservoir; 7 Inflow of stream; 8 Spring outflow (10^8 m^3/a)

Fig. 4　Changes of Irrigation System in Shiyanghe Drainage Basin

3.2　Extension of salinization

Because a lot of reservoirs had been constructed, a large volume of water is diverted into the barren land of the piedmond plain for reclamation of new Oasis, however the flood irrigation has caused the rising of groundwater level immediately and resulting rapid extension of soil salinization over vast area. According to statistics of the secondary salinizatin in arid area of N. W. China reaches 1.13×10^6 hm^2. The cultivated land in Xinjiang Autonomous Region has a dimension of 3.15×10^6 hm^2, including more than 1/3 with salinazation to various degrees, in which more than 6.67×10^5 hm^2 of salinazed land was abandoned and desertified.

Table 8　Secondary Salinization in Some Inland River Basin

river	Salinized soil area/km^2	ration to total land/%	Cultivation salisoil/km^2	ratio to total cultivated soil/%
Shiyanghe	2049.81	4.98	295.37	11.54
Heihe	1584.21	2.27	256.73	1 075.00
Shule	4713.64	4.57	273.21	21.70
Urumuqi	796.80	5.65	275.02	19.24

3.3　Changes of water allocation

Because of the rapid development of economic construction, the high consumption of water resources in upper or middle reaches of a river, has caused the drastic decrease of the inflow in lower reaches due to the change of water allocation between upper and lower basins seriously influenced the deterioration of ecologic environment.

For example, the inflow of Minqin basin in the lower reach of Shiyanghe River is decreased from 5.47×10^8 m^3 to $(1\sim2)\times10^8$ m^3 during past 50 years. As result, the groundwater table drops down 3~10 m, groundwater strongly over exploited more than 3×10^8 m^3/a, the mineral concentration of groundwater increased from 0.5 g/L to 1.77 g/L in south area and 0.41 g/L to 5.57 g/L in north area, salinized soil increased from 20×10^4 mu of 1970's to 40×10^4 mu of 1980's, the abandoned cultivated land reaches nearly 40×10^4 mu about 40% of the total farm land, the river course interrupted and mostly covered by sands, the terminal lake disappeared, 50% of pasture or vegetation degenerated or desertified.

The similar condition can be observed in Heihe river, in which the inflow of the lower reach known as Ejina basin is reduced abruptly from 8×10^8 m^3/a to $(2\sim3)\times10^8$ m^3/a in 1980's

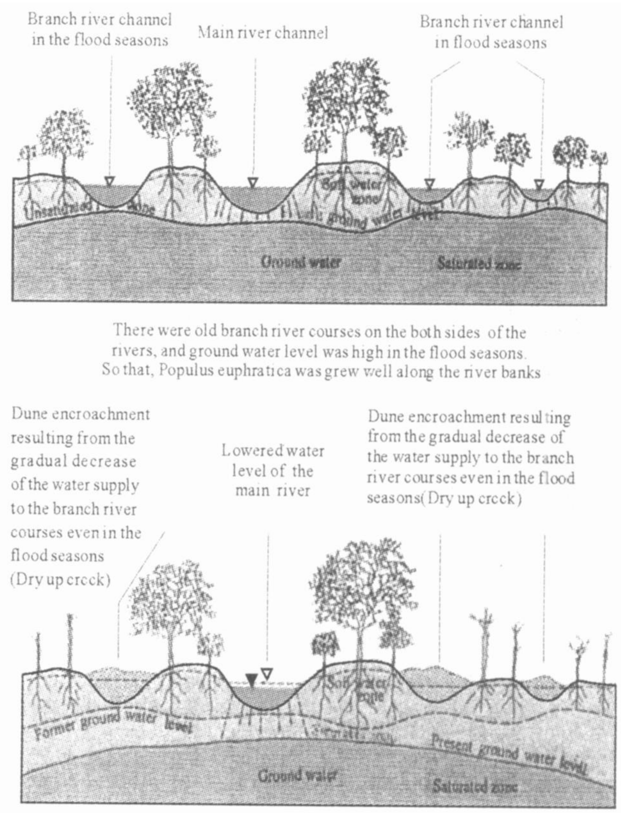


Fig. 5　Figure Showing the Decay of Woods and Vegetation Along the Bank of Talimu River Due to the Drop Down of the Groundwater Level

due to the rapid increasing of water consumption in Zhangyi basin of the middle and upper reach. In compare with 1950's, about 80% of the vegetation seriously degenerated and 30%~50% of the forests or bushes diminished and replaced by desert.

Talimu River, the biggest inland river in northwest China, had an annual flow 49.8× 10^8 m^3 for the last 20 years, a great quantity of water has been diverted into the fields along the upper reaches so that the surplus of annual flow on middle reaches is only 9.5× 10^8 m^3, i.e. decreased by 81%; the lower reaches of the river dried up, the groundwater level decreased by 8 m, and the salt content in groundwater increased dramatically. The forest of diversiform-leaved poplar and red willow withered; more than 2× 10^4 hm^2 of grassland disappeared, and more than 6.67× 10^3 hm^2 of cultivated land was abandoned and was followed by desertification. A great part of the previous "green corridor", with a length of 300 km, was reduced to wilderness.

3.4 Contraction or depletion of lakes

Lakes at the terminus of many rivers have become depleted and even dry up. For example, the famous Luobupo Lake on the lower reaches of the Kongque River at the southeast edge of the Talimu basin had an area of 1990 km^2 in 1943, decreased to 530 km^2 in 1962 and is dry at 1972. The Manas Lake at the terminus of the Manas River in Zhungeer basin had an area of 550 km^2 in 1968 and is also dry at present. The area of the Aibi Lake in the west part of the Zhungeer basin decreased from 1 070 km^2 in 1958 to 570 km^2 at present. Most of the above examples have been replaced by desert. The Juyanhai lake in the lower reach of Heihe had a dimension over 120 km^2 before 1940's and depleted in 1980's.

Table 9 Contraction or Depletion of Lakes

Name of lakes	1940's	1960's	1980's
Juyanhai/km^3	267	35	0
Luobupo/km^3	1 900	530	0
Manas/km^3		550	0
Aibi/km^3	1 070		570

Table 10 Variation of Dimension and Quality of the Lake Juyanhai

Years	Dimension of the lake/km^2	Average concentration/(g/L)	Chemical composition
1940's	>120	<1	HCO_3^- – $SO_4^=$ – Na^+ – Ca^{2+}
1950's	75	1~2	$SO_4^=$ – HCO_3^- – Na^+ – Ca^{2+}
1960's	35(1966)	2.3(1960)	$SO_4^=$ – Cl^- – Na^+ – Mg^{2+}
1970's	23(1980)	7.4(1979)	$SO_4^=$ – Cl^- – Na^+ – Mg^{2+}
1980's	43(1982)	9.7~34.5	$SO_4^=$ – Cl^- – Na^+ – Mg^{2+}

4 Evolution of desertification

The variation of eco-environment in arid area is closely related with the changes of the hydrologic environment due to human activities. Especially as the changes of regional water allocation or changes of irrigation system are usually as an important factor related to the changes of water environment and finally with a result of rapid extension of desertification.

The evolution of desertification can be summarized in following schematic diagram (Fig. 6):

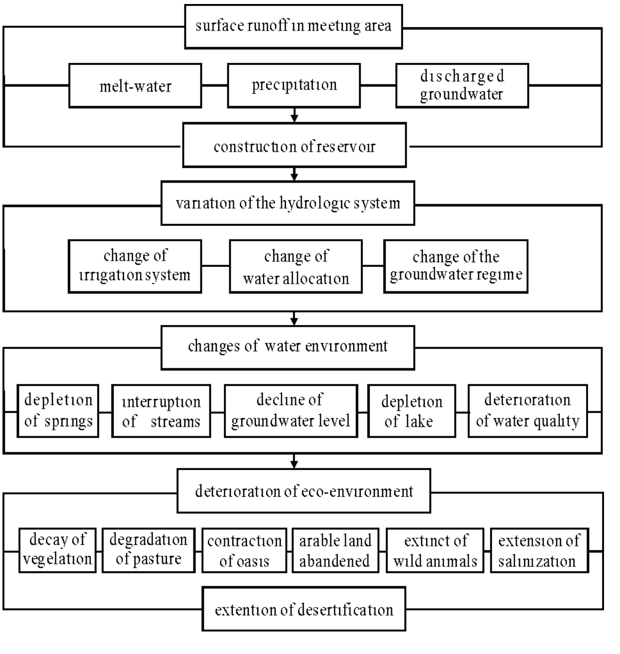


Fig. 6 Evolution of Desertification in Arid Area of Northwest China

During the past 50 years, the desertified land in N.W. China reaches to an area of 262.2× 10^4

km^2 occupying about 27.3% of the whole territory. Since 1980's, the expanding of desert area has increased from 1 520 m^2/a to 2 600 km^2/a. In Xinjiang Autonomous Region, the desert area has increased by 3.4×10^6 km^2, resulting in a lose of 3.4×10^6 hm^2 of arable land. In the Talimu Basin, 857 000 hm^2 of lands have been dasertified during the last century especially in the bank region of the river, 38 000 hm^2 of land have been dasertified. In Hexi Corridor, the desert area is increased from 4.5×10^4 km^2 to 5.31×10^4 km^2 with a rate of 158 km^2/a.

5 Conclusions

(1) Optimal water allocation between upper and lower basin is an important problem in a hydrologic system. The main principle is to guarantee that the water surplus of the upper basin ie. the inflow to the lower basin can satisfy the water requirement without any harmful effects to the ecologic environment in the lower basin. The total water consumption of each basin must keep balance with the total amount of inflow of surface runoff from mountainous area.

(2) Depending on the rule of hydrogeologic zonation, an irrational irrigation system must include channels, streams, springs, and water wells to integrate as an united system to adopt different approaches in different zone. The main purpose is to obtain not only economic value but also the eco-environments effect.

(3) As to the law of repeated transformation between surface water and subsurface water in the piedmont plain, the most important things is to work out a unified program of rational utilization for both surface and subsurface water.

(4) Strictly to control the groundwater level in a optimal condition for more favorable to the growth of vegetation in order to protect the ecologic environment.

(5) To apply remote-sensing technique for monitoring the development of the desertification is the most effective measure to prevent the extension of desertification.

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西北干旱区水资源的合理开发利用与荒漠化防治

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[摘要] 西北干旱区分布的巨大内陆盆地, 如准噶尔、塔里木、柴达木盆地和河西走廊等, 被认为是典型的戈壁沙漠地区, 约占国土总面积的25%。由冰雪融水与降水补给形成的山区河流, 流入山前平原, 在戈壁带入渗地下, 转化为地下水, 并在绿洲带溢出地表, 成为绿洲耕地的主要灌溉水源。自20世纪50年代以来, 由于大规模的水利化建设, 导致水资源条件发生巨大变化, 生态环境严重恶化, 最终导致大片土地荒漠化。因此, 重点论述干旱区在人类经济活动影响下, 水文系统的演变及其与水环境和生态环境之间的相互影响、相互制约关系。

[关键词] 水文系统; 地表径流; 地下水; 绿洲; 荒漠化; 盆地系统; 水文地质分带; 生态环境