SUSTAINABLE UTILIZATION OF WATER RESOURCES IN EASTERN PART OF NORTH CHINA PLAIN[1]

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ABSTRACT

The eastern part of North China Plain is short of water resources, the deep groundwater has been overdrawn seriously and the eco-environment has deteriorated. For sustainable utilization of water resources, the systems of well irrigation with well drainage and canal irrigation with ditch drainage should be developed. The exploitation and utilization of local shallow groundwater including brackish water and saline water should be regarded as the major water source, and the diversion of available surface water as the supplementary water source. To regulate the groundwater according to a critical dynamics of groundwater depth as the core, take the stratum space of soil and phreatic aquifer as the underground reservoir for regulating atmospheric water, soil water, groundwater and surface water, to transform the natural rainfall unevenly distributed in time and space into sustainable utilized water resources to a maximum.

Keywords: Exploitation and utilization of saline groundwater, Regulation of groundwater depth, Increase of rainfall infiltration, Sustainable utilization of water resources, North China plain.

1 INTRODUCTION

The North China Plain located to the north of Yellow River belongs to a seasonal arid semi-humid continental monsoon climate. The average annual precipitation is 500 – 600 mm. The precipitation varies considerably from year to year, it is unreliable for timely irrigation, it has even been less than 400 mm in a dry year, showing the characteristics of a semi-arid region and even an arid region. The precipitation in a wet year has even more than 800 mm, showing the characteristics of humid region. Besides, the precipitation is concentrated in summer and mainly in July and August, the other months are the dry season. The average annual precipitation is 550 mm in Nanpi County, its summer (June - August) precipitation accounts for 74% of the total annual precipitation. Spring (March – May) and Autumn (September – November) accounts for 11 % and 13% respectively, winter (December-next February) accounts for only 2 %. That causes drought in spring and waterlogging in summer, and then drought in autumn and winter again; drought and waterlogging occurred alternatively. In North China Plain, the precipitation reaching the ground interacts with the underlying surface in North China Plain, a part of it becomes surface water (accounted for 8 %) and a part is infiltrated. Under the action of gravity, a part (accounts for 20.6 %) of water infiltrated becomes groundwater, but most of it (accounts for 71.4 %) is stored in soil as soil water. In the process of the transformation of atmospheric precipitation, the salt in the soil is leached out and moves with water. In the region where with low-lying land and the runoff of surface and groundwater slowly has formed saline-alkali land and mineralized groundwater. In the period of geological history, under the influence of salinization of the continent in dry climate and sea water intrusion, there had formed saline groundwater region of large area in the eastern part of North China Plain. Its total area is 83.9 thousand km^2, in which the area with shallow thin layer of fresh groundwater is 12.8 thousand km^2, the area with wholly saline groundwater is 71.1 thousand km^2 which accounts for 51.1 % of North China Plain. The eastern part of the North China Plain become a region with minimum fresh water resources and the maximum saline groundwater, a region with the lowest water resources per capita (160 – 190 m^3) and the most serious overdrawn of deep groundwater in nation – wide, and the eco-environment there has been seriously deteriorated.

Drought, waterlogging, salinity and saline groundwater are the restraint factors of sustainable development of agriculture, and influenced for each other, caused damage to crops alternatively, caused poorness and backwardness in long term in this region. Till 1985, there were still exist saline-alkali land of 0.47 million hm^2 in Haihe and Luanhe River Plain, the unit yield was only 4050 kg/hm^2 in the eastern part area (Hailonggang region), which was 2400 kg/hm^2 lower than that of the piedmont plain. In order to explore the effective approach of comprehensive control of drought, waterlogging, salinity and saline groundwater and utilization and reclamation of saline-alkali land in large area, in 1984, the Ministry of Agriculture, livestock and Fishery had introduced the IFAD Loan by applying the research results of Hebei Institute of Hydrotechnics on using saline groundwater for irrigation to establish Nanpi Agricultural Development Project Area (NADPA), starting exploitation and utilization of saline groundwater and carrying out comprehensive control. Till 1987, the well irrigation area is increased from that accounted for 22.5 % to 44 %. The groundwater depth before rainy season was kept at 4 – 5 m, when daily rainfall was 189 mm no waterlogging occurred, due to increased of the recharge to groundwater. Utilizing summer rainwater to leach and drain off soil salt, the saline-alkali land had decreased 57 % than that in 1984, the groundwater has been somewhat freshened. Remarkable social-economic and eco-environmental benefits have also been obtained. The grain occupation per capita increased to 521 kg from 294 kg before the project, cotton yields increased by 9- fold. The total agricultural production value was increased by 3.6-fold. The income per capita increased by 3-fold. The forest coverage rate increased from 3 % to 9 %. The research results and experience of NADPA had been applied and popularized extensively in the eastern part of North China Plain. The cycling and blending of saline water with sodic fresh water for irrigation have been widely used in Cangzhou, Hengshui, Xingtai and Tianjin Cities. Now the total volume of brackish water utilized has achieved 0.66 billion m^3 in North China Plain, in which 0.32 billion m^3 was used in Hebei Plain. Scientific experiment and production practice have provided relative technology and scientific accordance on comprehensive control of drought, waterlogging, salinity and saline groundwater and sustainable utilization of water resource in North China Plain.

2 DESTRIBUTION OF WATER RESOURCE IN TIME AND SPACE

2.1 Shallow fresh and saline groundwater

The agricultural water application is takes the local water resources, especially the groundwater resources, as the principal water source. The Hebei Plain belongs to a part of North China subsidence zone. In the Quaternary system, according to the groundwater with mineralization less than 2 g/L is regarded as the fresh water, the boundary of fresh and saline groundwater is approximately located at the line of piedmont plain meeting with alluvial plain, the fresh groundwater region in the west and the saline groundwater region in the east. The area of fresh groundwater and shallow thin layer fresh groundwater in the region with saline groundwater accounted for 67.6 % and the various saline groundwater occupies 32.4 % of the total plain area. But the saline groundwater had not yet been used in the past, it occupies the stratum of shallow groundwater and influences the rainwater and surface fresh water storage. As a result, the water evaporated and the salt accumulated which caused soil salinity. Especially in Heilonggong region and the region to the east of South Grand Canal in Hebei Plain, are short of fresh water and saline groundwater is extensively distributed. Their area and amount of exploitable fresh water account only for 18 % and 14 % respectively, but the area and amount of exploitable brackish water (2 – 3 g/L) all occupy one half in Hebei Plain (Table 1). The saline groundwater region in Hebei Plain is 39471 km^2, the area of brackish water (2 – 3 g/L) and semi-saline water (3 – 5 g/L) accounts for one half of Hebei Plain (Table 2). In NADPA, due to exploiting and utilizing shallow groundwater including brackish water and semi-saline water, the groundwater depth can be kept at 3 m (in dry season) – 6 m (before rainy season), the modulus of exploitable resources is 68 – 73 thousand m^3/km^2.a, it can meet the irrigation requirement for 43 % of farmland.

Table 1 Resources and exploitable resources of fresh and brackish groundwater in Hebei Plain

Region		Fresh water (2 g/L)			BrackishWater (2–3 g/L)	
	Area (km^2)	Resources ($10^8 m^3/a$)	Exp.res. ($10^8 m^3/a$)	Area (km^2)	Resources ($10^8 m^3/a$)	Exp.res. ($10^8 m^3/a$)
Hebei Plain	49486.6	90.45	91.68	14118.1	21.04	15.36
In which:						
Helonggang region	7244.2	11.45	8.95	5616.4	7.90	5.38
East to South Grand Canal	1821.4	2.8	2.03	2042.7	3.1	2.00

2.2 Deep fresh groundwater

The deep fresh groundwater distributed in the 3rd group of aquifers (Q_2, 160 – 360 m) and 4th group of aquifers (Q_1, 360 – 500 m), its mineralization is less than 1 g/L, pH about 8.5, mostly HCO_3 – Na type. The deep groundwater is confined aquifer by overlying and underlying weak permeable layer or water resistance layer (aquitards or aquicludes), that can't receive the supplement from rainfall infiltration, canal seepage and irrigation water. Besides side recharge and cross-flow supplement from neighboring aquifers all the exploited deep groundwater is extracted from unsustainable groundwater storage capacity. From rough estimate, the exploitable deep groundwater is only 0.77 billion m^3 in Heihe River Plain, but the average annual overdrawn amount was 2.6 billion m^3. Due to overdraft an extensive regional cone depression of deep groundwater table in large area in Tianjin, Cangzhou, Henshui, Dezhou and Langfang Cities has been developed. It has caused serious eco-environmental problems, such as: land subsidence, downward movement of the salt-fresh water interface, the worsening of the water quality of deep groundwater etc. For the protection of water resources and rehabilitation of eco-environment, the water supply by the deep confined aquifers it should be gradually replaced by other available water resources and deep groundwater should be strictly forbidden or rigorously controlled. The groundwater in deep confined aquifers should be retained as reserve water source for use in extraordinary year of water shortage.

Table 2 Area of groundwater with different mineralization in saline groundwater region of North China Plain

Mineralization of Groundwater (g/L)	Area (km^2)	Account for (%)	Note
<2	15829	40	Fresh water
2 – 3	14118	36	Brackish water
3 – 5	5154	13	Semi-saline water
> 5	4370	11	Saline water
	39471	100	

2.3 Surface water

There was river flow coming from upper stream to the eastern part of North China Plain from the South Grand Canal in the past, but owing to the water application increased due to the increase of population and the development of economy and society, the river flow of South Grand Canal had been cutoff since 1965. For the supplement of water source to Haihe River Plain, Weilin Canal (from Weishan, Shandong Province to Linqing, Hebei Province) was built for Yellow River Diversion, the water flow diverted in the non irrigation period, i.e. every winter from November to next February, the allowable water diversion amount is 500 million m^3 per year given for Cangzhou, Hengshui and Xintai Cities since 1994. 1997 – 2002, the average annual water diversion was 100 million m^3 to Cangzhou City. Yellow River flow was diverted in winter, stored in canal and ditches, applied for irrigation in spring, and recharging groundwater.

3 INFRASTRUCTURE OF WATER MANAGEMENT AND CONTROL OF WATER AND SALT

3.1 Well irrigation and drainage and combining with canal irrigation

Establishment of well system to exploit and utilize shallow groundwater including brackish water and saline water is the key measure for the regulation of water-salt movement. According to the local hydrogeological conditions, and the layout of the farm canal, well spacing is 200 – 300 m, well depth is 10 – 20 m, output of unit well is 10 – 20 m^3/h, irrigated area served by each well is 2 hm^2. In the place with clay layer above the thin sandy aquifer vacuum well can be used, the well depth is 10 m, the irrigated area per well is 0.6 hm^2. The well water is conveyed by PVC hose pipe to farm canal for irrigation by gravity. The farm canal can also receive the surface water lifted from lateral or branch ditch for irrigation.

Exploiting and utilizing shallow groundwater including brackish water and saline water for irrigation, that enable to regulate water and salt, has also a series of advantages: (a) To meet the water requirement for crops in proper quantity and in time for drought combat and yield increasing. (b) To lift water for irrigation in the mean time to lowered the groundwater table, cutoff or decrease the water-salt of groundwater supplement to surface soil by capillary raise, therefore the salt accumulation can be prevented effectively. (c) To increase water infiltration that changes the process of salt accumulation due to strong evaporation in spring, and has the functions of salt leaching and restricting salt accumulation. (d) Pumping a lot of groundwater for irrigation in spring enable to lowered groundwater table and vacate underground capacity before rainy season, with the benefits of not only reducing the evaporation of phreatic water, capturing available water resources, but also increasing rainfall infiltration, reducing surface runoff, preventing waterlogging and recharging fresh water resources, strengthening the functions of salt leaching by summer rainwater and groundwater freshening.

3.2 Drain off excessive rainwater and salt to the sea by deep drainage ditches

For removing excessive storm water and salt from farmland to main drainage river course and direct to the sea, the NADPA takes the Dalongdian Main Drainage Ditch as the general main drainage ditch and outlet to the sea. The old No. 4 Main Ditch and No.2, No.3, No.4 main ditches (Attached Figure 1) as the main drainage systems (ditch depth 4 – 5 m), are connected together with the newly excavated branch, lateral, farm and field ditches and form a complete farm drainage systems.

The deep ditch drainage system turned the unfavorable factors of inundated farmland by excessive rainwater and salt accumulation after waterlogging in semi-humid monsoon climate region into favorable condition of salt leaching and saline water drainage. In rainy season, when the excessive rainwater is drained off, simultaneously a lot of salt is drained out with drainage water. The increased salt in soil due to irrigation with saline water can be leached and drained off in rainy season. The situation of regional water-salt balance had changed by the deep ditch drainage system, which enables the merging of the local small cycling of water-salt movement into the large cycling of continent and sea. That made the process of desalinization by rainfall leaching stronger than the process of salinization due to evaporation by drought, which lays a foundation for permanent control of soil salinization.

3.3 Water diversion and storage by deep canal and lifting irrigation

The NADPA take Xiaoquan Canal (canal depth 4 – 5 m) as the general main canal to convey diverted water flow of Yellow River by South Grand Canal. The Xiaoquan general main canal is connected with the main ditches (depth 3 – 4 m), irrigation canals and drainage ditches merges into one system. Water is lifted from branch and lateral ditches to farm canal for irrigation. Yellow River flow is diverted and stored in canals and ditches in November to next February, and is lifted for irrigation in spring. For regulating surface water, there were built 14 controlling gates, 4 pumping stations and 346 bridges.

The advantages of deep canal for water diversion, storage and irrigation are: (a) Water can be diverted at any time whenever it is available. (b) All canals and ditches are connected with each other, water flow can be diverted to any where in the controlled range of canals and ditches. (c) The canals and ditches can be taken as regulating reservoir, water stored in winter is used in spring for lifting irrigation with proper water quantity and in time. (d) Through the control of water level in deep canals and ditches, the water table can be controlled below the critical depth of groundwater for prevention of salt accumulation due to water storage. (e) Increase of Groundwater recharge by water storage, it enables to keep the balance between exploitation and supplement of groundwater and freshening of groundwater quality.

4 USING SALINE GROUNDWATER FOR IRRIGATION

4.1 Using brackish and semi-saline groundwater for irrigation

When the crops are irrigation with saline water in dry season, the soil moisture increases and the concentration and osmotic pressure of soil solution decreases which is beneficial to the moisture and nutrient absorption by crops. Since in dry season, the soil moisture during the growing stage of non-irrigated wheat is always less than 10 %, it is a severe limitation to crops growth. The soil moisture content when irrigating with saline water generally is 15 – 20 %, which corresponds to 60 – 80 % of the field moisture capacity and which is conducive to crops growth. During the seedling stage of wheat, soil evaporation is strong and the soil solution becomes concentrated (it may increase from 6 g/L to 14 g/L). However, after the seedling stage, when the wheat is irrigated with saline water, the concentration of soil solution may fall to 6 –10 g/L. According to experimental results, the physiological tolerance of soil solution should not exceed 10 g/L in turn green stage and 20 g/L in jointing stage. Because the concentration of soil solution is kept below their limit, the wheat can grow well.

According to the research in Nanpi Pilot Area by the Hebei Institute of Hydrotechnics during the 1980 – 1989 decade, the crops yield increased significantly by irrigating with saline water as compared with non- irrigation. The yield of wheat irrigated with semi-saline water of 4 – 6 g/L was 2925 kg/hm^2, and for summer corn it was 4036.5 kg/hm^2, so the total was 6961.5 kg/hm^2, which is 1.2 times more than when non-irrigated. The yield of wheat irrigated with brackish water of 2 – 4 g/L was 3630 kg/hm^2 and for summer corn it was 4725 kg/hm^2, the sum being 8355 kg/hm^2 which is an increase of 1.6 times compared with non – irrigation (Table 3).

Table 3 Crop yield (kg/hm^2) irrigated with various qualities of water

Crops	<1 g/L	2-4 g/L	4-6 g/L	Non-irrigation
(1) wheat	4848.0	3630.0	2925.0	840.0
(2) summer corn	5542.5	4725.0	4036.5	2340.0
(1)+(2)	10390.5	8355.0	6961.5	3180.0
(3) spring corn	5883.0	5332.5	4797.0	4882.5
(4)soybean	1704.0	1252.5	960.0	915.0

4.2 Cycling of saline and fresh water

The alternative use of saline water and fresh water, according to the salt tolerance of different crops and salt tolerance in different growth stage, allows to optimize the role and benefits of saline water and fresh water respectively. Saline water is used when irrigating salt tolerant crops in the rotation or when irrigating a salt sensitive crop during a salt tolerant growth stage. The fresh water is used at all other times. Whatever salt build-up occurs in the soil from irrigating with saline water, is leached in a subsequent cropping period when fresh water is applied. The cyclic irrigation scheduling is formulated on basis of the different crops salt tolerances and different salt tolerant stages of the crops. In Nanpi Pilot Area , saline water of 5 – 6 g/L and fresh water of < 1 g/L was used in cyclic irrigation for wheat. Fresh water was used during the seedling stage and saline water was used after the jointing stage, which achieved good harvest. The yield of wheat was 4549.5 kg/hm^2, only 2.2 % less than when irrigating with fresh water (Table 4).

4.3 Blending of saline and fresh water

Blending saline water with fresh water for irrigation, enables to improve the water quality, to enlarge available water resources and to increase the benefits of irrigation. The blending of saline water with sodic fresh water decreases the salinity and sodicity due to the mutual dilution of the two types water, and decreases the residual sodium carbonate (RSC) by the chemical combination of ions in the two types water (Table 5,6). When the sodic water which contains more Na^+ is blended with saline water which contains more Ca^{++}, Mg++, the chemical combination of CO_3^{--}, HCO_3^- and Ca^{++}, Mg^{++} forms harmless salts $CaCO_3$, $MgCO_3$, $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. Also, Na^+ is chemical combined with Cl^-, SO_4^{--} to form NaCl and Na_2SO_4, which are far less harmful than Na_2CO_3 and $NaHCO_3$ and are easy leached by the concentrated rainfall or by irrigating with fresh water. In Nanpi Pilot Area, double cropped wheat and corn was irrigated with shallow saline groundwater (5 – 6 g/L) blended with deep sodic fresh water (< I g/L, pH = 8.5). The average yield during 1980 – 1989 was 8355 kg/hm^2, which was an increase of respectively 163 % and 20 % over non-irrigated with saline water of 4 – 6 g/L (Table 3).

Table 4 Experimental results of cyclic irrigation with saline and fresh water in Nanpi Pilot Area (1989 – 1990)

Growth stages Before seedling	Turn green	jointing	booting	Yield of wheat Kg/hm^2	Relation yield %
Fresh water	Fresh water	Fresh water	Fresh water	4650	100
Fresh water	Fresh water	Saline water	Saline water	4550	97.8
Saline water	saline water	Saline water	Saline water	3660	78.7

Table 5 Chemical properties of irrigation water in Nanpi Pliot Area

Type of water	PH	Mineralization (g/L)	Composition of salt	SSP(%)	SAR	RSC (meq/L)
Deep fresh groundwater	8.3	1.0	HCO_3-Na	90.4	15.2	5.04
Shallow saline groundwater	7.7	5.6	Cl,SO_4-Na,Mg	51.2	9.7	-
Mixture(two kinds as above)	8.1	3.0	Cl,SO_4-Na,Mg	46.4	9.0	-
Shallow fresh groundwater	8.2	1.9	Cl,SO_4-Na,Mg	46.0	4.7	-
River water	8.2	0.3	HCO_3,SO_4-Na,Mg	16.95	0.57	-

Table 6 Chemical properties of saline water, sodic water and mixture in Nanpi Pliot Area

Types	pH	Mineralization (g/L)	Total ions (meq/L)	HCO_3^{--}+ HCO_3^- (meq/L)	RSC (meq/L)	SSP (%)	Na^+/ $Ca^{++}+Mg^{++}$	SAR	$Cl^-+SO_4^{--}$ (meq/L)
Sodic water	8.5	0.88	12.85	6.44	5.34	91.44	10.7	15.84	6.21
Mixture	7.7	2.46	35.69	3.49	-10.71	67.81	1.7	9.16	30.21
Saline water	7.3	6.95	115.2	5.85	-49.55	51.93	1.1	11.37	87.18

4.4 Soil salt control in the root zone

Using saline water for irrigation differs from irrigation with fresh water, because it not only should meet the requirement of moisture of the crops but also control the damage by salt. The principles of salinity control for irrigation with saline water are: (a) The salt accumulated in the soil should not exceed the crops salt tolerance limits. (b) The salt added to the soil by irrigating with saline water should be leached by rain or irrigation water so that the long term balance of soil salinity is maintained. (c) The salt accumulation should not occurred in root zone of soil. The salt balance relationship can be expressed as follow:

$$So + Si - Sd \le Tc$$

Where:
So = original salt content in the soil before irrigation;
Si = addition of salt to the soil due to irrigation with saline water;
Sd = salt leached from soil by rain water or irrigation water;
Tc = threshold value of crops salt tolerance.

Research results indicate that soil salinity does not reduce crop yield measurably until a threshold level is exceeded. Beyond the threshold, yield decrease approximately linearly as salinity increases. The salt tolerance index of crops is expressed as the ratio in yield under saline and non-saline conditions. The crop salt tolerance is evaluated by correlating crop yield and the total amount of soluble salts in the root zone. The equation of crops salt tolerance index can be expressed as follows:

$Yr = 100 \quad \text{for } 0 < C < Ct$
$Yr = 100 - S(C - Ct) \quad \text{for } Ct < C < Co$
$Yr = 0 \quad \text{for } C > Co$

Where:
Yr = relative yield;

C = the average root zone salinity;
Co = the level of soil salinity above which the yield is zero;
Ct = threshold, the maximum soil salinity without yield reduction;
S = slope i.e. the percent yield decrease per unit of salinity above the threshold.

For the Nanpi Pilot Area where saline water is used for irrigation (taking the yields of non – saline soil irrigated with fresh water as 100) the relation between the salinity of root zone (0 – 40 cm) and the relative yield of crops can be expressed by the following equation (see also Figure 1):

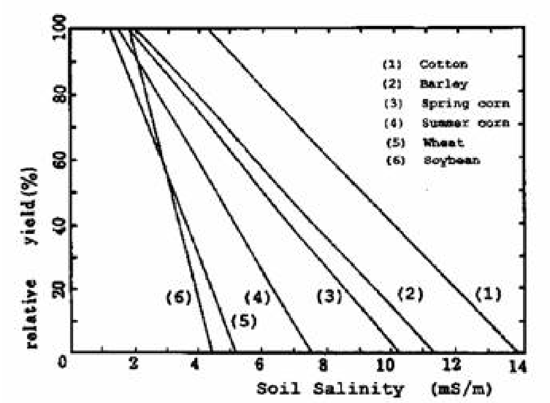

Figure 1 Relationship between soil salinity and crops yield

$Y_{wheat} = 100 - 25.038\ (C - 1.20)$
$Y_{summer\ corn} = 100 - 16.232\ (C - 1.38)$
$Y_{spring\ corn} = 100 - 11.87\ (C - 1.72)$
$Y_{barley} = 100 - 11.975\ (C - 2.02)$
$Y_{soybean} = 100 - 37.722\ (C - 1.80)$
$Y_{cotton} = 100 - 10.3\ (C - 4.2)$
Where
Y = relative crop yield
C = electric conductively (mS/m) of saturatiion extract of root zone (0 – 40 cm) in the growth period of crops.

In Nanpi Pilot Area the regime of the soil salinity in root zone (0 - 40 cm) is such that long term salt accumulation does not occur and that the soil salinity remains controlled within the limit of crop salt tolerance.

5 REGULATING GROUNDWATER DEPTH AT CRITICAL DYNAMICS

The dynamics of groundwater depth is the concentrated reflection of growth, decline and transformations between atmospheric precipitation, soil water, groundwater and surface water. Regulating rational groundwater depth at critical dynamics is the key for comprehensive control of drought, waterlogging, salinity and saline groundwater, regulation of water-salt movement and sustainable utilization of water resources. The required critical dynamics of groundwater depth in different seasons are:

5.1 Critical depth of groundwater for soil salinity control in dry season (2 – 3 m)

That is the shallowest groundwater depth that wouldn't be accumulated salt in soil and not harmed crops by salt in dry season. This is the groundwater index to judge whether salt accumulation occurred in soil or not. Regulating groundwater table at critical depth, can be reduced evaporation of phreatic water as far as possible and prevent salt accumulation. In the region of light loam with different groundwater qualities which salt easily accumulated their critical depth are 1.8 – 2.8 m (Table 7). So that is proper to regulate the groundwater depth at 2 – 3 m in dry season.

5.2 The depth for waterlogging prevention and rainwater storage before rainy season (4 –6 m)

Regulating the groundwater depth before rainy season should beneficial to increase the supplement to groundwater by rainfall infiltration. The precipitation in rainy season from June to September was 434 mm in normal year in Heilonggang region and east to South Grand Canal in North China Plain, the maximum supplement to groundwater by rainfall infiltration, its response groundwater depth was about 4.5 m before rainy season. In the range of groundwater depth at 2.5
– 4.5 m, the water table lowered 1 m, the supplement to groundwater increased 22 – 6 m. When the groundwater depth was more than 4.5 m, the rainfall infiltration decreases with the depth increased. When the groundwater depth at 5.5 and 4 m in wet year and dry year respectively, the supplement of rainfall infiltration is the maximum (Table 8). The proper groundwater depth is at 4 – 6 m before rainy season.

5.3 The depth for subsurface waterlogging control of crops in rainy season (0.5–1m)

The rainy season is the period of soil desalinization, the main disaster to crops is waterlogging.

Table 7 Critical depth of groundwater in the Hebei Plain (m)

Mineralization of groundwater (g/L)	Light loam	Light loam sandwich clay	clay
1 – 3	1.8 – 2.1	1.5 – 1.8	1.0 – 1.2
3 – 5	2.1 – 2.3	1.8 – 2.0	1.0 – 1.2
5 – 8	2.3 – 2.6	2.0 – 2.2	1.2 – 1.4
8 - 10	2.6 – 2.8	2.2 – 2.4	1.2 – 1.4

Table 8 Proper groundwater depth before rainy season and response supplement by infiltration of rainfall

Rainfall frequency (%)	June-Sept. precipitation (mm)	Proper groundwater depth before rainy season (m)	Supplement to groundwater by rainfall infiltration(mm)	Max. exploitable amount of supplement to groundwater by rainfall infiltration (mm)
15	550	5.5	170	150
48	434	4.5	127	105
84	312	4.0	88	65

When ponded water that is drain off, and the groundwater table raised by rainfall infiltration should be lowered to a depth for subsurface waterlogging control (wet resistance depth) in a required time (Table 9). In consideration of the main crops are corn and cotton in rainy season in the area of North China Plain, the proper groundwater depth should be kept at 0.5 – 1 m in rainy season. Summarizing the critical depth of groundwater required in various seasons, the critical dynamics of groundwater depth is as given in Figure 2. This figure can be used as the criteria of water table regulation for keeping water balance between exploitation and supplement and for sustainable utilization of water resources. Transforming natural precipitation distributed unevenly in time and space into sustainable utilized water resources.

Exploiting and utilizing shallow groundwater including brackish and saline water in eastern part of North China Plain have the benefits of lowering groundwater table, vacating underground capacity, regulating groundwater depth at critical dynamics, transforming the natural precipitation distributed unevenly in time and space into sustainable utilized water resources. The exploited amount of groundwater was 6 million m^3 before the establishment of NADPA, and reached 13.8 million m^3 in 1987. The groundwater depths all dropped below 3 m before rainy season (June) in 1988, as compared with the same stage in 1985, the area with depths of 2 – 3 m was reduced by 77 %, the area with depths of 4 – 6 m increased by 53 %. The groundwater depths in 1986 – 1988 were 2.78 – 3.73 m in spring (March), 4.48 – 5.03 m before rainy season (June) and 1.15 – 2.95 m after rainy season (September), which were in accordance to the indices of critical dynamics of groundwater depth (Figure 3). It shows that the project has created the condition for enhance the control and utilization of rainwater.

Table 9 Wet resistance depth of crops

Crops	Growth stage	Dropped to allowable depth (day)	Wet resistance depth (cm)
surghum	Heading Milkage Milky ripeness	12 - 15	30 – 40
corn	Before Heading Heading, milkage	3 – 4	50 – 60
Soybean	Blooming	10 - 12	30 – 40
cotton	Blooming, ball forming	3 - 4	60 - 70

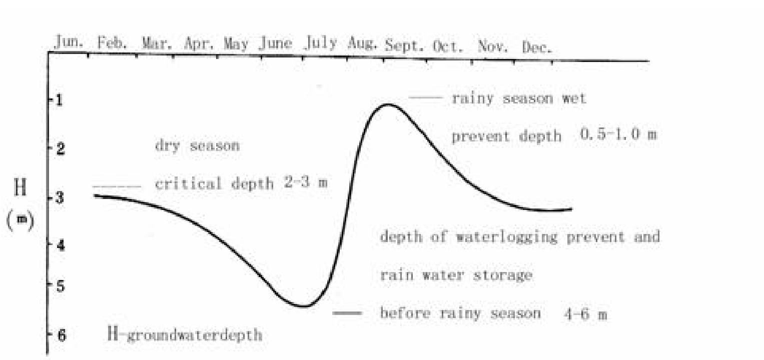

Figure 2 Critical dynamics of groundwater

5.4 To Reduce phreatic water evaporation

The amount of phreatic water evaporation is closely related to the groundwater depth. In the area of light sandy loam, when the groundwater depth is at 1 m, the amount of phreatic water evaporation is 6-times that of the groundwater depth at 2.5 m (Figure 4). In the NADPA according to the average groundwater depth in 1984 – 1986, the calculated exploitable amount of phreatic water was 4.3 million m^3. The groundwater depths in 1986 – 1988, which were regulated at critical dynamics (2.5 – 5 m), the calculated exploitable amount was 13.2 million m^3, that means a total of 8.9 million m^3 of available water resources was taken from phreatic water evaporation.

5.5 To increase rainfall infiltration

After the rainwater has infiltrated into soil, some part of it is stored as soil water, but most is transformed into groundwater and become available water resources. The groundwater depth was in critical dynamic state in NADPA, the rainfall infiltration recharged to groundwater was increased. In October1986 – September 1987 and October 1987 – September 1988, the coefficient of rainfall infiltration reached 25 % and 21 % respectively. Though in 1986 – 1987, drought and a lot of groundwater had been exploited and used, due to the rainwater supplement in rainy season, the groundwater table rose by 1.75 m. After deducting the exploited amount and phreatic water evaporation in that year, the modulus of exploitable amount increased by 85.2 thousand m^3/km^2 per annum, which supplied the groundwater source for combating drought in autumn and next spring.

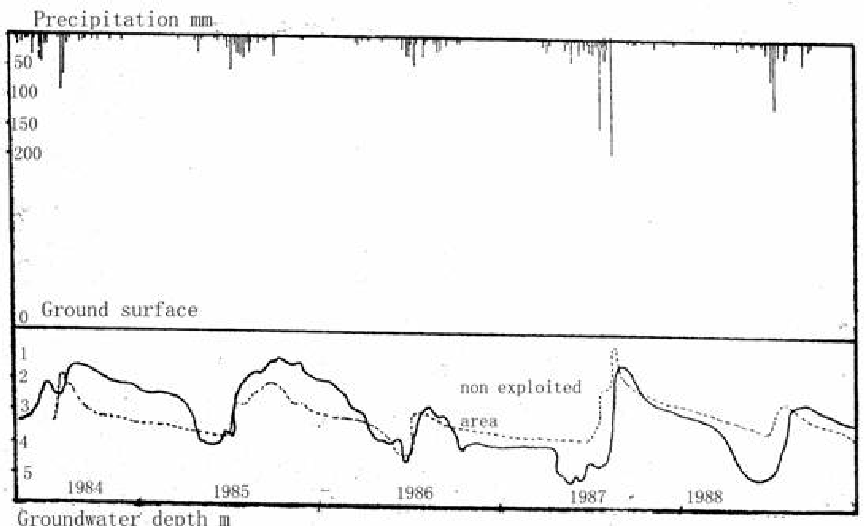

Figure 3 Process of dynamics of groundwater depth in Nanpi Project Area

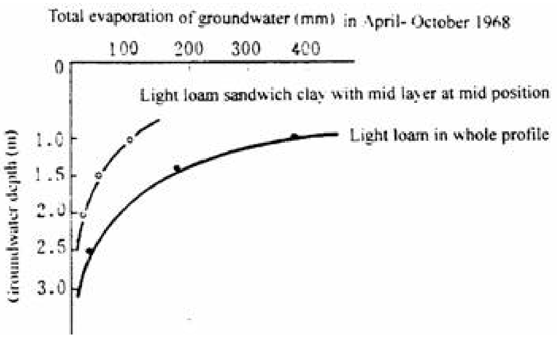

Figure 4 Relationship between evaporation of phreatic water and depth of groundwater ccurred before rainy season.

5.6 To Reduce loss of runoff

While combating drought by irrigation in spring, a lot of shallow groundwater including brackish water had been exploited, that increased the underground reservoir capacity, increased the rainfall infiltration, reduced the surface runoff, and prevented the occurrence of waterlogging. Simultaneously the natural rainfall was transformed into available water resources as far as possible. The observation and research have shown that the runoff decreased with the drop of groundwater table. The groundwater depth was at 1.1 – 2.5 m before rainy season in 1974 – 1977, the individual rain storm and the proceeding rainfall (P+Pa) was 156 – 244 mm, the depth of runoff was 18 – 47 mm. In 1984 – 1987, P+Pa= 88 – 236 mm, the runoff was 0 – 30 mm. As compared with 1980's and 1970's, the groundwater depth increased by 1.6 – 2.0 m, under the condition of P+Pa = 160 – 230 mm, the runoff was reduced by 17 – 24 mm. The groundwater depth was in the range of 1 – 5 m, when it dropped by every 1 m, the runoff decreased by 12 – 25 mm. 1987 was a sub-wet year with a precipitation of 736 mm, in which 509 mm fell down in rainy season, but no waterlogging occurred. The precipitation was 149 mm in Nanpi Pilot Area on August 3,1987, the runoff was only 4 mm, most of the rainfall supplied to groundwater. The individual rainstorm lasting 6 hours was 189 mm on August 26, the depth of runoff was 30 mm, the excessive rainwater was accumulated on surface ground, but the groundwater depth was about 3 m before rainfall. As there are facilities of drainage, the accumulated water was drained off rapidly and infiltrated to underground, the groundwater depth was at 1.73 m 2 days after the rainfall, no waterlogging occurred. In the northern part of Nanpi Pilot Area, the groundwater depth was at 4.62 m before the occurrence of individual rainstorm (189 mm), no runoff occurred (Table 10).

5.7 Salt leaching and drainage by summer rainwater

The precipitation is concentrated in rainy season, mainly in July and August in North China plain. The rainfall is 434 mm in June to September in normal year, which accounts for 73% of the annual precipitation, with a stronger function for leaching salt of soil. Under the condition of deep drainage, the unfavorable factors of inundated by excessive rainwater and salt accumulation after waterlogging can be turned into favorable condition for salt leaching and saline groundwater drainage. Under the situation of groundwater depth regulated at the critical dynamics, the desalinization of soil in large area, mainly depend upon the salt leaching and drainage by summer rainwater. There were 7 times of water and salt drainage in Nanpi Pilot Area from 1974 to 1987, the total salt drainage was 1394.5 t/km^2 (Table 11). Owing to a lot of salt of soil was drained off, the saline-alkali land has reclaimed gradually. The saline-alkali land had reduced by 57 % from 1984 – 1987, till 2001 there was only remained 8 % (Table 12, Attached Figure 1). Owing to a lot of salt of soil was drained off, the soil salt supplement to groundwater was also reduced, which promoted the groundwater freshening gradually.

Table 10 Influence of water table depth on infiltration and runoff of rainfall.

Observed section	Area (km^2)	Date	H (m)	P (mm)	Pa (mm)	P+Pa (mm)	R (mm)	groundwater depth 2 days after the rain (m)
South branch ditch	4.51	1977/7/23	1.10	102.0	54.5	156.4	47.2	0.01
South branch ditch	4.53	1977/5/20	2.05	123.0	121.0	244.0	44.7	0.15
North branch ditch	15.05	1975/7/29	2.36	186.3	8.2	194.5	24.5	0.65
South branch ditch	4.51	1987/8/3	3.20	149.0	12.0	171.0	4.0	1.73
North branch ditch	15.05	1987/8/26	4.62	189.1	47.7	236.8	0	1.92

Note: H=groundwater depth, P=individual rainstorm, Pa=preceding rainfall, R=depth of runoff

Table 11 Amount of rainfall, water and salt drainage in Nanpi Pilot Area

Duration	Drainage area(km^2)	Rainfall (mm)	Water drained 1000 m^3	Average mineral. (g/L)	Salt drained (t)	Unit area salt drained (t/km^2)
1974.7.22-8.30	4.53	570	365.0	3.83	1397.0	308.1
1975.7.29-8.20	4.53	284.5	75.0	4.17	312.5	68.7
1976.7.19-9.27	4.53	384.2	102.0	4.17	422.2	93.2
1977.6.26-8.20	4.53	862.4	1256.0	3.08	3864.3	852.8
1984.8.9-8.16	4.33	179	67.0	1.18	79.8	18.4
1987.8.3-8.4	4.33	149	17.0	1.48	25.6	5.9
1987.8.26-9.3	4.33	189.1	132.0	1.56	205.8	47.5

Table 12 Variation of area (hm^2) of salt-affected soils (SAS) in Nanpi Project Area (1984-2001)

Year	Light SAS	Medium SAS	Heavy SAS	Saline waste land	total
June 1984	959	1011	1866	446	4282
June 1987	1060	472	203	91	1826
June 2001	208	60	72	-	340

5.8 Saline groundwater freshening

Under the monsoon climate and drainage conditions, pumping saline groundwater for irrigation over a long period of time, together with the supplement by rainwater and fresh water, has enhanced the cycling and replacement of saline water and freshwater, and promoted the saline groundwater freshening. Since 1980, the Nanpi experimental field began to pump saline groundwater (5 – 6 g/L) for irrigation by siphon wells, after 8 years, the mineralization of groundwater decreased to 1 - 4 g/L in July 1988. The mineralization of surface groundwater decreased to 1.19 – 2.96 g/L from 4.8 – 5.1 g/L; the mineralization of groundwater at the depth of 5 m decreased to 1.23 – 2.38 g/L from 5.1 – 5.3 g/L; the mineralization of sub-layer (about 10 m) groundwater decreased to 3.06 – 3.83 g/L from 5.2 – 7.8 g/L (Table 13). In Nanpi groundwater monitoring area, the groundwater was freshened obviously in the 15 years from 1974 – 1988. The area of fresh water (<2 g/L) has increased from 20 % to 50 % at the groundwater surface. In some area the groundwater has become fresh water from original saline water from surface to the depth of 8 m (Attached figure 2). The freshwater body increased by 639000 m^3, the modulus of exploitable amount increased by 15000 $m^3/km^2/a$. The rainfall infiltration is the main factor to promote saline groundwater freshening. The precipitation was 736 mm in 1987, the groundwater in every layer was all freshened as compared with the same stage (June and September) of the preceding year. 1985 was a normal year, as compared with the preceding year the groundwater freshened accounted for 72 %. But 1986 was a sub-dry year, as compared with the preceding year, the groundwater mineralized accounted for 78 %. But the general trend was freshening, which accounted for 56 – 72 %, and the mineralized accounted for 23 – 44 %. The key measure for increasing rainfall infiltration is regulating groundwater depth in an appropriate state. The precipitation was 1185 mm in 1977, but the groundwater depth was 1 – 2 m, under such conditions the total rainwater could not be stored, a lot of fresh water was drained off. While in 1987, the groundwater depth was 4.26 m, when an individual rain storm was P+Pa = 236 mm
occurred, no runoff drained off, all infiltrated into underground, the groundwater was freshened more obviously.

Table 13 Variation of mineralization (g/L) of groundwater (1982 – 1988) Nanpi experimental field of Hebei Institute of Hydrotechnics

Date	Ground Water Depth M	Surface	No.12 5 M	Bottom	Surface	No.14 5 M	Bottom	Surface	N0.15 5 M	Bottom	Precipitation (Mm)
1982/6	2.9	5.10	5.3o	7.80	4.80	5.10	5.70	4.80	5.20	6.40	380.4
1982/9	2.0	5.60	5.70	11.5	3.80	3.60	3.60	4.70	5.80	6.90	
1983/6	2.7	4.62	5.06	7.11	2.93	3.27	4.24	5.78	6.26	6.52	405.3
1983/9	2.2	4.05	5.77	6.98	3.66	3.92	4.09	3.67	4.50	11.95	
1984/6	3.0	3.77	3.83	7.25	3.38	3.87	4.05	1.35	4.19	11.73	583.0
1984/9	1.5	3.51	3.23	6.07	1.98	3.77	4.92	2.65	4.00	11.32	
1985/7	1.8	1.98	2.08	2.90	1.98	2.25	4.73	4.98	5.01	10.60	555.2
1985/9	1.0	2.43	3.34	4.05	2.65	3.34	5.05	2.75	3.86	9.06	
1986/6	2.9	4.03	3.93	5.78	2.95	3.23	3.98	4.75	4.81	10.07	396.8
1986/10	3.9	2.98	3.25	5.21	2.71	3.42	4.58	3.78	4.47	12.13	
1987/3	3.5	2.63	2.61	3.93	1.40	2.39	2.38	3.31	3.21	8.56	735.8
1987/8	2.5	0.38	0.57	2.22	1.20	1.44	1.62	0.31	1.01	1.56	
1988/3	2.5	2.46	2.38	3.32	1.19	1.23	2.56	2.12	2.12	2.84	471.4
1988/11	1.5	3.47	3.43	3.83	1.06	1.83	3.83	1.06	1.26	3.06	

The Yellow River diversion for water source supplement is also the important condition for promoting the balance between exploitation and supplement of groundwater and groundwater freshening. The average annual Yellow River diversion was 100 million m^3 in Cangzhou City in which water diverted to Nanpi County was 20.5 million m^3, the area of water storage and irrigation was 6000 hm^2. The annual precipitation was 521 mm in 2001, and from January to May in 2002, the precipitation was only 32 mm, but due to diversion of Yellow River water the groundwater depth still maintained at 4 – 4.5 m in June 2002 after spring irrigation (Attached figure 2), that is it just at critical depth of groundwater before rainy season.

The premise condition to enhance the control and utilization of rainwater is exploiting and utilizing shallow groundwater including brackish and saline water. Owing to exploitation of the storage amount of groundwater, the groundwater table goes down, the underground capacity of groundwater aquifer is vacated, so that the rainfall water can be infiltrated to replenish the groundwater, and the irrigation water extracted from the aquifer can be compensated by rainfall recharge, the salt in the soil can be displaced to a deeper layer and saline water can be desalinized and becomes exploitable resources. The area of brackish and saline water of less than 5 g/L is 36.3 thousand km^2 in North China Plain, in which 20 thousand km^2 is in Hebei Plain. According to rough estimates of the average annual rainfall infiltration 100 mm (100 thousand m^3/km^2), the supplement resources of groundwater in North China Plain and in Hebei Plain are 3.63 and 2 billion m^3 respectively, if exploitation coefficient is 0.8, then the increased exploitable resources due to utilization of saline water will be 2.9 and 1.6 billion m^3 respectively.

6 CONCLUSION

Drought, waterlogging, salinity and saline groundwater are the main restraining factors for sustainable development of agriculture in the eastern part of North China Plain. The area is the region with minimum water resources per capita in nation-wide, most extensive distribution of saline groundwater, and the serious overdrawn of deep groundwater and the eco-environmental deterioration. For the sustainable utilization of water resources should be taken the local shallow groundwater including brackish and saline water as the basic water source, and diverting available surface water resources as the supplementary water source. Setting up infrastructure of wells, canals and ditches, developing well irrigation and drainage in combination with canal irrigation, construction of ditch drainage systems, using deep ditches to drain off excessive rainwater and salt to the sea, diverting and storing surface water by deep canal for irrigation are the comprehensive measures for combating drought, waterlogging, salinity and saline groundwater in this area. Exploiting and utilizing shallow groundwater including brackish and saline groundwater for irrigation can help to increase yield by providing some key waterings for wheat which is the crop that requires most water in dry season, the seedling of corn and cotton may reach full stand by irrigating before seeding in dry spring in every year. It enables to provide one half of farmland with irrigation water, replace the continuous overdrawn of deep groundwater. It can lower the groundwater table and vacate the underground capacity, regulate the groundwater depth at critical dynamics. The stratum space of soil and phreatic water aquifers can be used as the underground reservoir for regulating atmospheric water, soil water, groundwater and surface water, reduce phreatic water evaporation, increase rainfall infiltration, reduce loss of surface runoff, promote salt leaching and drainage by summer rainwater and freshening saline groundwater, thus to transform the natural rainfall unevenly distributed in time and space into available water resources to a maximum. So as to achieve the comprehensive control of drought, waterlogging, salinity and saline groundwater, and the sustainable utilization of water resources as well as the sustainable development of economy and society, and the good cycling of eco-environment can be realized.

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