Effect of Water Resources Allocation on Groundwater Environment and Soil Salinity Accumulation under Climate Change

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Abstract: The combined surface and groundwater allocation practice by wells and canals had contributed to the safety of groundwater environment and agriculture sustainable production. The typical area in the People's Victory Canal irrigation district was taken as a case, drawing together the irrigation district agriculture water consumption and precipitation from 1954 to 2014 in the People's Victory Canal irrigation district, ratios of surface to groundwater irrigation amount, dynamic of groundwater depth and hydrochemical characteristic of groundwater from 2008 to 2014 in the research area, the relationship between groundwater depth and ratio of surface to groundwater irrigation amount was analyzed, in order to ascertain the influence of precipitation on ratios of surface to groundwater irrigation amount and its effect on soil and groundwater environment. The results indicated that positive correlation between the ratios of surface to groundwater irrigation amount and annual precipitation was appeared, affected by climate change, average irrigation amount from surface in the recent 5 years was 2.90×10^8 cubic meters, accounted for 75.52% of total irrigation amount, on the other hand, decreasing tendency of precipitation was obvious, and groundwater depth dynamic in upstream of the branch canals was more dramatic than downstream because of surface water irrigation infiltration, under the unified condition of water use efficiency, ratio of surface to groundwater irrigation amount was negative correlation with area of the groundwater depth beyond 11 m, meanwhile, groundwater depth demonstrated negative correlation with the ratio of surface to groundwater irrigation amount, moreover, alkaline trend of groundwater hydrochemistry during the normal season in the research area was obvious because of phreatic evaporation and the agricultural irrigation from wells, along with irrigation from surface inflow of Yellow River, quality of groundwater hydrochemistry during the dry season was ameliorative greatly. Consequently, it was very important to the agriculture sustainable production that well-canal combined irrigation patterns alleviated extremely alkaline trend of the groundwater hydrochemistry and played a positive role of root layer soil salinity leaching.

Key words: Well-canal combined irrigation district, irrigation patterns, ratio of surface to groundwater irrigation amount, hydrochemical characteristic.

1. Introduction

Starting from 1952, irrigation from the Yellow River has been developed in the People's Victory canal irrigation district, up to 2012, total irrigation amount from the Yellow River was 360×10^8 m³. It

played a positive role of soil salinity leaching that irrigation water from the Yellow River improved productivity of land of the saline-alkali, low swampy and sandy in the Yellow River old path area accounting for 34.6% of cultivated area in the People's Victory canal irrigation district. Meanwhile, well-canal combined irrigation patterns maintained dynamic balance of irrigation district groundwater,

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regulated spatial and temporal arable distribution of soil salinity and alleviated groundwater salinity, thus, which maintained and increased the yield of irrigation district [1]. With the rapid development of social economy, agricultural water of irrigation district was diverted seriously, only $2.9 \times 10^8 \text{ m}^3$ in the recent 5 years accounting for 75% of average agricultural water consumption in the People's Victory canal irrigation district. In order to ensure food security, groundwater exploitation in the downstream district has become a "New Normal" of local agricultural water resources management [2], the determination of groundwater level in the typical agricultural area indicated that groundwater level decreased year by year in the recent 5 years differing by 0.86 m/a, thus, the management of over exploitation was extremely urgent. Up to now, studies for managing the water-resource problems in well-canal combined irrigation district mainly focused on optimization methods of groundwater under water utilization patterns [3-5], effect of water-saving irrigation area on ecological bearing capacity [6], model for conjunctive use of surface and groundwater [7-9], variation of groundwater salinity and its influence on crops in irrigation area [10], prediction model of farmland water environment after reconstruction of water-saving in the large-scale irrigation district [11-13], adaptation between irrigation intensity and groundwater carrying capacity in North China Plain [14]. However, there was absence of consideration about trend of groundwater hydrochemical and evaluation of environmental effect, meanwhile, there was not completely taken into account combined effect of climate change and water resources management strategies in the above studies.

In this work, attempt was made to ascertain the suitable water resources management pattern by analyzing the relationship between agricultural water utilization, groundwater depth, groundwater hydrochemical and precipitation. Finally, targets were improved scientific management of well-canal

combined irrigation district and maintained the agricultural sustainable production capacity.

2. Materials and Methods

2.1 Study Areas

The People's Victory canal irrigation district is located in the north of Henan province, 113°31' to 114°25' E, 35°0' to 35°30' N, the irrigation district control area is 1,486.84 km², there are mainly distributed 3 kinds of geological unite, the depression area of the old Yellow River, floodplain area of the old Yellow River and Wei river alluvial area, respectively. Hydrogeological condition in the irrigation district is characteristic with heterogeneous, groundwater depth is about 6 m, groundwater and soil salinity are about 1 g/l and 1 ‰ in the floodplain area of the old Yellow River, meanwhile, groundwater depth is about 3 m, groundwater and soil salinity are about 2 g/l in the depression area of the old Yellow River. Groundwater flow in the irrigation district is consistent with ground slope, grade is about 1/4,000. There is the warm temperate zone continental monsoon climate zone, four distinct seasons. Average annual temperature is 14.5 °C, maximum and minimum temperature is 41 and -16 °C, respectively. Frost-free period around 210 d, average annual water surface evaporation about 1,860 mm, average annual precipitation around 600 mm, accounts for 70% to 80% of annual precipitation occurs in June to September.

The research area is typical well-canal combined irrigation area, located in 3rd western main canal belong to the People's Victory canal irrigation district, which is characteristic with equipped foundation and complete system distribution canals (Fig. 1). Three branch canals belong to 3rd western main canal, one of the 1st, 2nd and 3rd, branch canal control irrigation area is 300, 213.3 and 286.7 hm², respectively. There is the same of cropping system, water ways and water table in the research area, and then wheat-maize cropping system, the traditional border irrigation

Fig. 1 The layout of 3rd western main canal in the People's Victory Canal irrigation district.

for 1,200 to 1,800 m³/hm², 3 times irrigation from surface water at wintering, green stage of winter wheat and summer maize seeding stage. Meanwhile, groundwater was exploited for supplementary irrigation in drought year.

2.2 Precipitation of Irrigation District, Typical Irrigation Area and Irrigation Amount

The datum of precipitation, wells and canal irrigation amount were sourced from statics annual report of People's Victory Canal Irrigation district administration and extensive field investigation. The precipitation and irrigation amount of people's Victory Canal irrigation district was from 1952 to 2014, and the precipitation and irrigation amount of typical surface to groundwater irrigation amounts irrigation district was from 2008 to 2014. All the data have been completely analyzed and reliable, which could be used as the base data.

2.3 Soil Sampling and Analysis

Soils were sampled from typical surface to groundwater irrigation amounts irrigation area at seeding stage, post-harvest of winter wheat, post-harvest of summer maize in 2013 and 2014. At each soil sampling point, paired soil samples were taken at depths of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-60 cm, 60-80 cm and 80-100 cm soil auger using a 3.5 cm bucket auger. Each of the paired soil samples was a composite of five sub-samples that were taken randomly from the entire point and stored at room temperature before analyzing for EC and pH.

2.4 Monitoring Interval of Groundwater Depth and Method

Determination of groundwater depth in the typical surface to groundwater irrigation amounts irrigation area was at 20th every month by solinst 102 acousto-optic alarm table feet, distribution of

groundwater monitoring wells showed in Fig. 1. The sampling date of groundwater was same as the survey of groundwater depth, each of the groundwater samples was taken from the long-term monitoring wells and detected in the Key laboratory of high-efficient and safe utilization of agriculture water resources of Chinese Academy of Agricultural Sciences for pH, ECe.

3. Results and Analysis

3.1 Effect of Precipitation on Ratio of Surface to Groundwater Irrigation Amounts Irrigation Amount in the Irrigation District

Relationship between ratio of surface to groundwater irrigation amounts and precipitation was shown in Fig. 2. Precipitation of the research area in 2008 to 2014 was 563.1, 499.7, 608.3, 578.3, 412.2, 486.3 and 554.0 mm, respectively. Average ratio of surface to groundwater irrigation amounts of 1st, 2nd, 3rd branch canal was 1.55:1, 3.64:1, 1.94:1, respectively. Positive correlation between precipitation and ratio of surface to groundwater irrigation amounts irrigation amount, that's to say, more precipitation more the surface inflow, and less groundwater exploration, furthermore less precipitation less the surface inflow, and agricultural irrigation replied more on groundwater exploitation.

Annual precipitation and 5-year moving trend of

precipitation from 1952 to 2014 was shown in Fig. 3. The relationship between irrigation amount and precipitation of typical area was shown in Fig. 4. Annual irrigation amount from surface water of 1952 to 2014 was $3.48 \times 10^8 \text{ m}^3$, furthermore, annual irrigation amount from surface water in the recent 5 years was only $2.90 \times 10^8 \text{ m}^3$, accounting for 75.52% of the annual irrigation amount. The result indicated that precipitation in the People's Victory Canal irrigation district showed a decreasing tendency in the recent year according to the simple linear regression analysis [15], negative correlation between precipitation and irrigation amount, in other words, the less precipitation, the higher the agricultural production dependent on irrigation [16].

3.2 Dynamic of Soil Salinity in Typical Canal-Well Combined Irrigation Area

Dynamic change of soil layers salinity with date in typical area was shown in Fig. 5. Soil salinity accumulation in 0 to 20 cm layer of typical area increased obviously in winter wheat seeding stage irrigation, varied from 0.3308 to 0.4129 ds/m, soil salinity accumulation in 20 to 30 layer of typical area was lower than that of other layers, average soil salinity of the area was 0.2002 ds/m. Soil salinity accumulation in 0-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100 cm layer in 2014 was lower than that of

Fig. 2 Correlation between ratio of surface to groundwater irrigation amount and precipitation in irrigation area.

Fig. 3 Annual precipitation and 5-year moving trend in People's Victory Canal irrigation district from 1952 to 2014.

Fig. 4 Correlation of groundwater hydrochemistry of typical area in well-canal combined irrigation area.

Fig. 5 Dynamics of soil salinity of winter wheat seedlings in typical well-canal combined irrigation area.

2013 by 14.40, 17.21, 9.04, 20.29, 26.18, 24.09 and 21.67% in the winter wheat seeding stage of 1st branch canal area, and by 17.99, 33.28, 9.78, 10.33, 16.83, 15.57 and 26.20% of 2nd branch canal area, and by 17.90, 36.35, 12.66, 4.56, 18.68, 21.95 and 21.49% of 3rd branch canal area, respectively. The accumulation variation of soil salinity (the accumulation variation of soil salinity equal to soil salinity accumulation in 0 to 100 cm layer in 2013 minus soil salinity accumulation in 0 to 100 cm layer in 2014) in 0 to 100 cm layer of 2nd branch canal was lower than that of 1st, 3rd branch canal, by 4.77%, 5.55%, respectively. The result indicated that more surface water irrigation drive the salinity leaching lower layer, decreased the salinity accumulation in 0 to 100 cm layer [11].

3.3 Dynamic of Groundwater Depth with Date in the Typical Well-Canal Combined Irrigation Area

Dynamic change of groundwater depth with date was shown in Fig. 6. Annual average groundwater depth of upstream, downstream area of 1st branch canal was 11.27, 11.91 m, furthermore, variable coefficient of groundwater depth of upstream, downstream area was 0.0378 and 0.0359. Annual average groundwater depth of upstream, downstream area of 2nd branch canal was 10.68, 10.48 m, furthermore, variable coefficient of groundwater depth of upstream, downstream area was 0.0352

and 0.0322. Variable coefficient of upstream groundwater depth of 1st, 2nd branch canal was greater than that of downstream differing by 5.39%, 9.08%, respectively. The result indicated that the fluctuation of upstream underground water level was more intense than that of downstream because of priority for groundwater recharge. Meanwhile, the annual dynamic change of upstream, downstream groundwater depth was the same, that's to say, underground water level was decreased obviously during the winter wheat post-harvest stage by 0.92 m, underground water level was increased obviously during wet season by 0.49 m. Furthermore, annual average underground water level of upstream, downstream of 2nd branch canal was higher than that of 1st branch canal differing by 0.59, 1.43 m, respectively. The result indicated that higher ratio of surface to groundwater irrigation amounts irrigation amount was helpful for the improvement of the groundwater environment [17].

3.4 Spatial Dynamic of Groundwater Depth in Typical Combined Canal-Well Irrigation Area

Spatial dynamic of groundwater depth with date was shown in Fig. 7, such as 20th 12, 2013 and 20th 12, 2014. Compared to the canals downstream, underground water level of canals upstream was higher relatively. In the winter wheat wintering stage of 2013, the area less than 11 m of groundwater

Fig. 6 Dynamics of groundwater depth with date in typical well-canal combined irrigation area.

Fig. 7 Spatial distribution of groundwater depth of typical area in well-canal combined irrigation area.

depth of 1st, 2nd, 3rd branch canal accounted for 40.21, 100, 99.03% of its irrigation range, respectively. At the same stage of 2014, the area less than 11 m of groundwater depth of 1st, 2nd, 3rd branch canal accounted for 8.43, 74.93, 58.22% of its irrigation range, respectively. The result indicated that the area of groundwater depth exceeded 11 m was increased obviously, taking into account the same surface water irrigation amount in 2013 and 2014, moreover, precipitation in 2014 was more than that of 2013 by 13.92%, but compared to 2013, the area greater than 11 m of groundwater depth of 1st, 2nd, 3rd branch canal of 2014 was an obvious increasing trend differing by 31.85, 25.07 and 40.81%, respectively, in other words, suitable ratio of surface to groundwater irrigation amount irrigation amount alleviated tendency increased of groundwater depth [17].

3.5 Dynamic of Groundwater Hydrochemistry of Typical Well-Canal Combined Irrigation Area

Annual dynamic of groundwater hydrochemistry of 1st, 2nd, 3rd branch canal was shown in Fig. 8. According to piper diagram and the classification of the hydrological chemical phase, groundwater chemistry types of 1st, 2nd, 3rd branch canal was $\text{HCO}_3^-/\text{Cl}^-/\text{SO}_4^{2-}-\text{Ca}^{2+}/\text{Na}^+$, $\text{HCO}_3^-/\text{Cl}^-/\text{SO}_4^{2-}-\text{Ca}^{2+}/\text{Na}^+$,

$\text{Cl}^-/\text{SO}_4^{2-}/\text{HCO}_3^- - \text{Ca}^{2+}/\text{Na}^+$ in dry season (average of February to May in 2013 and 2014), respectively. Groundwater chemistry types of 1st, 2nd, 3rd branch canal were same types of $\text{Cl}^-/\text{SO}_4^{2-}/\text{HCO}_3^- - \text{Ca}^{2+}/\text{Na}^+$ in wet season (average of June to September in 2013 and 2014). Groundwater chemistry types of 1st, 2nd, 3rd branch canal were $\text{Cl}^-/\text{SO}_4^{2-}/\text{HCO}_3^- - \text{Na}^+/\text{Ca}^{2+}$, $\text{HCO}_3^-/\text{Cl}^-/\text{SO}_4^{2-} - \text{Na}^+/\text{Ca}^{2+}$, $\text{Cl}^-/\text{SO}_4^{2-}/\text{HCO}_3^- - \text{Na}^+/\text{Ca}^{2+}$ in normal season (average of October to December and January in 2013 and 2014), respectively. The result indicated that groundwater hydrochemistry was obvious alkaline trend because of cation change of $\text{Ca}^{2+}/\text{Na}^+$ in wet season to $\text{Na}^+/\text{Ca}^{2+}$ in normal season [18, 19], especially in general hydrological year, there were mainly agricultural irrigation seasons of wintering stage, green and elongation stage, heading and filling stage (dry season), groundwater hydrochemistry attribute maintained previous types because of recharge from surface inflow irrigation infiltration in dry season, and groundwater hydrochemistry attribute of wet season was ameliorative than that of dry season because of recharge from precipitation, furthermore groundwater hydrochemistry attribute of normal season was trended to alkaline because of phreatic evaporation [20]. Thus, irrigation

Fig. 8 Dynamics of groundwater hydrochemistry of typical well-canal combined irrigation area.

Note: ▲—Normal season of 1st branch canal △—Dry season of 1st branch canal ◐—Wet season of 1st branch canal
 ★—Normal season of 2nd branch canal ☆—Dry season of 2nd branch canal ☆◐—Wet season of 2nd branch canal
 ●—Normal season of 3rd branch canal ○—Dry season of 3rd branch canal ◐—Wet season of 3rd branch canal

Table 1 Dynamics of groundwater hydrochemistry of typical branch canal irrigation area.

Area	Season	Ca ²⁺ (mg/l)	Mg ²⁺ (mg/l)	Na ⁺ (mg/l)	K ⁺ (mg/l)	CO ₃ ²⁻ (mg/l)	HCO ₃ ⁻ (mg/l)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	TDS (mg/l)
Area of 1st branch canal irrigation	Dry season	112.88	11.67	129.25	0.00	0.00	403.72	126.37	131.80	895.63
	Normal season	83.56	23.38	167.18	0.00	0.00	412.91	126.38	156.55	947.41
	Wet season	187.18	43.96	194.63	0.00	0.00	485.28	126.38	145.93	868.49
Area of 2nd branch canal irrigation	Dry season	140.40	28.70	167.70	0.00	0.00	555.78	136.18	178.53	1113.43
	Normal season	82.93	39.98	201.12	0.00	0.00	511.53	126.33	186.85	1009.83
	Wet season	212.19	58.14	230.06	0.00	0.00	576.53	142.73	205.05	838.24
Area of 3rd branch canal irrigation	Dry season	91.20	32.30	162.00	0.00	0.00	373.30	135.10	188.10	981.20
	Normal season	101.87	45.17	259.13	0.00	0.00	519.83	165.57	330.20	1214.30
	Wet season	222.68	75.13	233.50	0.00	0.00	647.05	174.33	234.73	814.67

water from the Yellow River during the dry season and precipitation during the wet season in the well-canal combined irrigation district ameliorated extremely the groundwater hydrochemistry quality, and the degradation of groundwater hydrochemistry during the normal season should be worth attention,

emphasis in the area of groundwater exploitation irrigation.

4. Conclusions and Suggestions

Mesoscale studies and investigation were conducted in the People's Victory Canal irrigation district to

evaluate the effects of ratios of surface to groundwater irrigation amount on soil salinity and groundwater hydrochemistry in typical well-canal combined irrigation area. Our main findings are:

(1) Positive relationship between precipitation and ratio of surface to groundwater irrigation amount was appeared, in other words, the ratio of surface irrigation accounted for total agricultural irrigation amount was positive correlation with precipitation. Furthermore, precipitation in the People's Victory Canal irrigation district showed a decreasing tendency, meanwhile irrigation requirement was negative correlation with precipitation, and compared to 2013, the area greater than 11 m of groundwater depth of 1st, 2nd, 3rd branch canal of 2014 was increased obviously differing by 31.85, 25.07 and 40.81%, respectively.

(2) The average accumulation variation of soil salinity in 0 to 100 cm layer of 1st, 2nd, 3rd branch canal irrigation range was 0.5491, 0.5229, 0.5536 ds/m, respectively, the average accumulation variation in 0 to 100 cm layer of 2nd branch canal was lower than that of 1st, 3rd branch canal by 4.77%, 5.55%, respectively, which showed more surface water irrigation drive the salinity leaching to lower layers and decreased the salinity accumulation in 0 to 100 cm layer.

(3) Cation of groundwater hydrochemistry during the wet season was types of $\text{Ca}^{2+}/\text{Na}^{+}$, along with the phreatic evaporation and the agricultural irrigation from wells, cation of groundwater hydrochemistry in normal season turned into types of $\text{Na}^{+}/\text{Ca}^{2+}$, which showed groundwater hydrochemistry was obvious alkaline trend. Cation of groundwater hydrochemistry in dry season turned into types of $\text{Ca}^{2+}/\text{Na}^{+}$ again because of irrigation from surface inflow of Yellow River. Thus, water resources allocation by wells and canals combined ameliorated extremely the groundwater hydrochemistry quality and played a positive role of root layer soil salinity leaching.

In the well-canal combined irrigation district, precipitation showed a decreasing tendency, in other

words, available water resource of the typical irrigation district was reduced, it was therefore that aggravated the shortage of agricultural water resources. Meanwhile well-canal combined irrigation patterns decreased tendency increased of groundwater depth and alleviated quality of groundwater hydrochemistry.

Acknowledgements

This research was funded by the Agricultural Science and Technology Innovation Program (ASTIP) of Chinese Academy of Agricultural Sciences, the Special Fund for Agro-scientific Research in the Public Interest (2012 03077), National Natural Science Foundation of China (51009141), and the National 863 Plans Project of China (863 Program, 2012 AA101404).

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