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Review

Division of the water-saving crop planning system in the Heihe River basin

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Instituting water-saving crop planning (WSCP) is an effective way for the Heihe River basin to reverse its current growing scarcity of water resources and continuing environmental deterioration. However, because different areas of the river basin have different natural resources and diverse social and economic conditions, the planting structure for the region must be divided before the optimal adjustment of WSCP. The influencing factors for this division are chosen based on the analysis of the WSCP system. The appropriate indicators are selected from the overall influencing factors according to the existing hydro-meteorological, socio-economic and agricultural water conservancy conditions in each county in the river basin. Several unrelated main components that reflect most information from the original variables are extracted using factor analysis (FA) with the Statistical Package for the Social Sciences (SPSS) software and are then clustered using the K-means clustering algorithm (KMCA). Based on the clustering results, the basin is divided into six subzones: (1) Forage grass with dry farming, (2) grain and cash crops with rain-fed irrigation, (3) grain and cash crops with irrigation, (4) fruits and vegetables with irrigation, (5) cash crops with irrigation and (6) forage grass and cash crops with irrigation. Suitable development programs for each subzone were then drafted. This method avoids the overlap of related variables, reduces the difficulty of treatment and is convenient for indicator selection and information collection.

Key words: Division of water-saving crop planning, Heihe River basin, factor analysis, K-means clustering algorithm.

INTRODUCTION

The Heihe River basin, located in the middle of Gansu Corridor, is the second largest inland river basin in North-west China and lies roughly between 37°44′ and 42°40′N and 97°37′ and 102°06′E. The Heihe River is 821 km long from its source in the Qilian Mountains to its terminus in Juyan Lake. It flows through three provinces and its basin covers about 1.43×10^5 km^2. As shown in Figure 1, the upper reaches belong to Qilian County of Qinghai Province and Sunan County of Gansu Province, the middle reaches belong to the counties of Shandan, Minle, Ganzhou, Linze, Gaotai, Jiayuguan and Suzhou in Gansu Province, and the lower reaches belong to Jinta County of Gansu Province and Ejina of the Inner Mongolia Autonomous Region. According to modern surface water and groundwater hydraulic links, the Heihe River basin can be divided into eastern, central and western water subsystems. The main rivers in the western water subsystem (with a total watershed area of 2.1×10^4 km^2) are the Hongshui and Taolai rivers, which flow into the Jinta Basin. The central water subsystem (with a total area of 6×10^3 km^2) contains the Maying and Fengle

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Abbreviations: WSCP, Water-saving crop planning; **FA,** factor analysis; **SPSS,** statistical package for the social sciences; **KMCA,** K-means clustering algorithm.

rivers, which flow into the Gaotai Salt Lake and Minghua Depression. The eastern water subsystem (with a total area of 1.16 × 10^5 km^2) includes the main forks of the Heihe and Liyuan rivers as well as more than 20 tributaries. The total surface runoff of the Heihe River basin is 37.28 × 10^8 m^3 and the total groundwater is 4.31 × 10^8 m^3, so the total water in the basin is 41.59 × 10^8 m^3.

The Heihe River basin is located far inland in central Asia and has a dry climate with abundant sunshine, scarce but concentrated precipitation, strong winds, intense evaporation and an extreme shortage of water resources (Ministry of Water Resources, China, 2002). Because of the continuous pressure of population growth and excessive economic development, water consumption has been steadily increasing in the basin for many years, especially in the central portion. Utilization of water resources in 2006 reached 95% (statistical data from the water resources department of Gansu Province), which far exceeds the rational exploitation limit of 40% set by international consensus. This excessive water consumption by humans has resulted in continued environmental deterioration, which has become a serious threat to sustainable social and economic development in the basin. Agricultural water use accounted for about 94% of the total social and economic water consumption in 2006, but the water use efficiency and the benefit thereof were very low. Agricultural water conservation is the key to reversing the current growing water shortage and the continuing environmental deterioration. However, if water use efficiency is enhanced only through improving irrigation facilities or increasing the level of irrigation district management, the cost per cubic meter of water saved will continue to increase (Wang et al., 2010, Sethi et al., 2002, Sarker and Ray, 2009). So, to improve water use efficiency, the planting structure must be adjusted by increasing the input only slightly, reducing the proportion of high-water-consuming crops and coordinating crop planning better with the effective precipitation, incoming river water, available groundwater and crop water demand (Wang et al., 2010, Adeyemo and Otieno, 2010).

The Heihe River basin includes three major types of geomorphologic zones: Mountains, basins and deserts. Therefore, the climate, topography, soil, water and other natural resources are different from region to region. For example, the mean annual precipitation varies from 406.7 mm in Qilian County in the upper basin to 37.0 mm in Ejina County in the lower basin, and the annual evaporation ranges from 1191.9 mm in Qilian County to 3841.5 mm in Ejina County. There is also considerable diversity in market sales, labor, quantity of land, policies and regulations, farmers' culture, investment abilities, cultivation habits and other socio-economic conditions. As an illustration, in 2007, the level of urbanization in Minle County was 12.86%, but in Jiayuguan City, it was 76.71% (Gansu Yearbook Editorial Board, 2007). Both natural and human conditions have a large impact on the local planting structure; so, planting structure division must be implemented before the optimization of water-saving crop planning (WSCP), and then the planting structures of each subzone must be optimized to obtain the desired results (Jolayemi, 1996, Nevo et al., 1994, Pereira, 1982).

THE DIVIDING METHOD

There is little research on specific methods for dividing planting structure; the existing relevant research is more about agricultural economic structure and land-use patterning methods. For example, the agricultural economic structure of different administrative areas was divided by using the fuzzy clustering analysis method and choosing factors that play a leading role in agricultural economic development, such as average annual precipitation, mean annual temperature, per capita grain yield and per capita net income (Hall and Arnberg, 2002; Liu and Samal, 2002, Ma et al., 2000). Programs for optimal soil and water use were determined through the analysis of the regional ecological construction methods and resources, noting the advantages found under different land-use patterns. The programs were then assigned to space unit plots by the Geographic information systems (GIS) (Chambers, 2005, Yule et al., 1996, Yao et al., 2004). The division of wheat cultivation was completed according to the index of different lands' rents under the principle of grain security (Tratnik et al., 2009).

Common dividing methods currently include the following: Decision tree, statistics, nearest neighbor, empirical quality-deciding, indicator, type, overlap, stepwise discrimination analysis, clustering and fuzzy clustering (Dinpashoh et al., 2004, Qiao et al., 2002). This study completely drafts the influencing factors based on the analysis of the WSCP system and then selects the appropriate indicators from the overall influencing factors by using the existing hydro-meteorological, socio-economic and agricultural water conservancy conditions in each county in the Heihe River basin. Next, a few unrelated components that reflect most of the information from the original variables are extracted using factor analysis (FA) with the Statistical Package for the Social Sciences (SPSS) software, and then are clustered using K-means clustering algorithm (KMCA). Based on the clustering results, the basin is divided into six subzones, and suitable development programs for each subzone are drafted. This method avoids the overlap of related variables, reduces the difficulty of treatment, and is convenient for indicator selection and information collection. The calculations can be completed quickly, accurately and conveniently using SPSS.

DIVISION OF WSCP IN THE HEIHE RIVER BASIN

Influencing factors system of division

The selection of dividing factors is a prerequisite and

Table 1. Influencing factors system of WSCP division.

Category	Control layer	Influencing factors
Natural	Heat	Accumulated temperature, mean annual temperature, maximum and minimum temperature, nonfrost period, etc.
	Illumination	Annual and monthly quantity of radiation and annual hours of sunshine, etc.
	Terrain	Macrorelief (mountain, hill, valley, basin, plain, and plateau), microtopography (flat, low-lying land, raised land), altitude, slope, aspect, etc.
	Soil	Type, depth, texture, ph, organic content, nutrient content, moisture, erosion, etc.
	Moisture	Annual and monthly precipitation, drought index, air humidity, source, resource quantity and quality , etc.
	Disasters	Drought, flood, disease, insects, etc.
Human	Water resource use	Exploitation and utilization ratio of surface and ground water, water use structure, etc.
	Land	Land use (farmland, forest and grassland, wasteland, etc.), cultivated area, paddy field area, irrigable and dry land area, per capita area of cultivated farmland, etc.
	Crop cultivation	Species, area, yield, production capability, breed, cultural practices, planting tradition, etc.
	Irrigation level	Irrigation facility, agriculture measure, etc.
	Fertilizer	Type and amount, amount per unit area, nutrient balance, etc.
	Pesticide	Type and amount, amount of spraying per unit area, etc.
	Machines	Tractors and drainage-irrigation machines, etc.
	Vegetation	Trees, bushes and grass, etc.
	Stock breeding	Type and numbers of livestock, etc.
	Output and income	Annual net income per capita, output and income from farming, forestry, husbandary, fishing, etc.
	Market	Public purchases, free market, distant or near, traffic, etc.
	Price	Purchase and market price of farm produce, price of agricultural production means, etc.
	Policy and system	Policy of purchase, awards, commodity circulation , foreign trade, etc.; operating mechanism, etc.
	Science and Technology	Staff level, water-saving irrigation area, facility agriculture, etc.
	Culture	Culture level of farmer, etc.
	Capital input	Input orientation and ability, capital productivity, etc.
	Labor	Population and labor, etc.

basis for WSCP division. If the dividing factors are suitable, the dividing results will be valid and rational. The system of dividing factors of WSCP should be able to scientifically reveal the general and regional differences in agricultural production conditions, characteristics, development trends, production potential and means of development.

It should also adapt to the water shortage situation in the region and completely merge the development of planting with sustainable ecological, economic and social development. The division of WSCP is influenced by both natural and human factors as is shown in Table 1. These factors include:

(1) Natural factors: Natural conditions such as climate, topography, soil, hydrology and natural disasters play a decisive role in the normal growth and distribution of crops; these conditions are difficult or impossible to change. Therefore, natural conditions play a decisive role in the division of WSCP.

(2) Human factors: These include regional population, cultural and educational standards, the technological level of planting operations and management, the organizing capacity of the government and national guidelines and policies. The requirements for the economic development of planting are also related to the division of WSCP, the input capacity of labor, and the financial and material resources for planting development.

Selection and extraction of dividing indicators in the Heihe River basin

According to Table 1, and accounting for the actual situation in the Heihe River basin, we selected twenty-one indicators to constitute the indicator system of WSCP in the Heihe River basin as shown in Table 2. The indicator data are shown in Table 3. To ensure the reasonability of the clustering results, we joined two qualitative variables-irrigation district pattern and administrative area, and

Table 2. Dividing indicator system for WSCP in the Heihe River basin.

Category	Control layer	Index layer	Characteristic reflected by the index function
Natural	Heat	Maximum temperature	Heat state
	Illumination	Annual hours of sunshine	Illumination
	Terrain	Altitude	Mean altitude
		Irrigation region type	The main terrain of irrigation region
	Moisture	Annual precipitation	Mean annual precipitation
		Water resources per capita	Amount of water resources
		Water resources per unit area of arable land	Amount of water resources
Human	Water resources use	Utilization Ratio of surface water	Utilization Degree Of surface water
		Agricultural water proportion	Water consumption proportion
	Output and income	Rural annual net income per capita	Farmers' ability for capital input
		Agricultural output value proportion	Aspiration for capital input
		Output ratio for farming to husbandry	Farmers' activity for planting
	Yield	Grain yield per capita	Grain security
	Urbanization level	Urbanization rate	Economic development level
	Administrative boundaries	Administrative region	Practical operability
	Farmland scale	Rural arable land area per capita	Farmland scale
	Labor	Number of labor per unit area of arable land	Available labor
		Farm machinery power per unit of farmland	Mechanization level
	Science and technology	Fertilizer consumption per unit of farmland	Fertilization level
		Proportion of water-saving irrigation area	Input level of irrigation project
	Planting tradition	Proportion of planting area of grain crops	Planting tradition

used a classification method to quantify them.

The selected dividing indicators in Table 3 are still too much for a subsequent application to a cluster. Selecting a large number of indicators is necessary for complete and clear results, but using too many will invite confusion and will be less likely to show any pattern present. Therefore, FA is required to reject possible overlap between variables and to reduce the data analysis. FA can remove independent and unrelated indicators from those that have been selected by dimension reduction, and then use them as the basis for the next cluster analysis. The basic purpose of FA is to use several factors to describe the link between many indicators; that is, it is used to classify a number of closely related variables in the same category. Each category of variables will then be a factor, allowing the majority of original information to be reflected with fewer factors (Liu and Yin, 2008).

FA in SPSS can output the variables' correlation matrix, which shows the correlation between variables and demonstrates the importance of FA. These correlations show the proportions of extracted information from each variable after the main component is extracted according to selected standard. The total variance explanation lists all the variables' eigenvalues and the percentage of the total variance explained; the scree plot can show these items visually. The component matrix shows which factors can explain the variation of each variable; that is, it gives the factor expressions required in FA. The rotated component matrix makes the main contribution of each variable to the main component more obvious, since it has changed after rotating. The component score coefficient matrix is the final result of the main component analysis, where all the main components can be expressed as the linear combination of each variable.

The total variance explanation is the most important part of the entire output, as shown in Table 4. All the main components are listed in descending order according to eigenvalue. The sixth main component explains 3.835% of the total variation, but the eigenvalue (0.805) is less than 1, indicating that the explaining ability of this main component is less than that of the original variable. Therefore, only five main components are needed to be extracted from the twenty-one variables, because they can explain 93.258% of the total variation; that is, they can cover 93.258% of the information of the twenty-one original variables.

Spatial cluster of dividing indicators

The outputs of KMCA in SPSS include initial cluster

Table 3. Subzone index data for WSCP in the Heihe River basin.

Index	Unit	Upper reaches		Middle reaches							Lower reaches	
		Qilian	Sunan	Shandan	Minle	Ganzhou	Linze	Gaitai	Jiayuguan	Suzhou	Jinta	Egina
		Qinghai	Gansu	Gansu	Gansu	Gansu	Gansu	Gansu	Gansu	Gansu	Gansu	Inner Mongolia
Maximum temperature	℃	30.5	32.4	37.8	32.5	38.6	39.1	38.7	38.7	38.4	39.3	41.6
Annual hours of sunshine	h	2600.0	2800.0	2993.0	2810.0	3085.0	3052.9	2980.0	3000.0	3033.4	3193.2	3400.0
Altitude	m	3169	3200	2997	3308	1482	1785	2200	1600	1765	1270	1000
Irrigation region type		0.2	0.2	0.4	0.4	0.6	0.6	0.6	0.6	0.8	1.0	1.0
Annual precipitation	mm	406.7	257.0	177.0	295.6	114.9	112.3	103.0	80.0	85.3	47.2	37.0
Water resources per capita	m^3/capita	33272.3	46398.9	940.0	1676.4	1600.4	2647.7	2204.0	851.8	2687.4	3455.0	8811.6
Water resources per unit area of arable land	m^3/hm^2	7082.2	7981.4	2981.3	4770.8	15836.0	22534.0	16937.4	26056.3	15888.9	16649.1	25261.0
Utilization ratio of surface water	%	0.4	1.0	89.3	91.6	110.7	139.3	120.1	85.8	103.3	84.8	21.3
Agricultural water proportion	%	88.79	96.16	92.59	97.17	92.69	90.11	97.66	42.77	87.83	96.46	89.48
Rural annual net income per capita	Yuan/capita	2928.00	4754.10	3839.10	3534.32	4132.07	4006.29	3964.63	5315.00	4692.77	4792.81	5315.00
Agricultural output value proportion	%	27.24	24.51	22.69	38.95	25.50	34.19	46.27	1.38	34.60	46.88	5.89
Output ratio for farming to husbandry		0.12	0.54	4.37	3.74	1.84	2.60	4.85	3.68	2.76	3.47	0.13
Grain yield per capita	kg/capita	72.96	218.09	711.59	889.51	615.18	944.55	549.33	34.98	464.64	263.88	164.48
Urbanization rate	%	21.28	30.19	24.88	12.86	37.01	15.00	15.43	76.71	35.80	20.87	75.60
Administrative region		0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.8	0.8	1.0
Rural arable land area per capita	hm^2/capita	0.07	0.19	0.31	0.34	0.17	0.17	0.18	0.06	0.18	0.23	1.43
Number of labor per unit area of arable land	capita/hm^2	7.21	2.57	1.89	1.85	3.07	3.16	3.10	9.33	2.88	2.26	0.51
Farm machinery power per unit of farmland	KW/hm^2	13.05	7.75	5.96	5.20	10.45	13.88	10.48	21.85	12.73	12.01	4.33
Fertilizer consumption per unit of farmland	Kg/hm^2	135.68	170.73	119.32	248.25	730.90	765.75	727.74	594.37	471.32	564.46	229.03
Proportion of water-saving irrigation area	%	0.40	67.11	33.50	62.67	81.31	79.90	77.48	94.13	60.34	57.06	44.91
Proportion of planting area of grain crops	%	50.44	35.83	57.71	57.44	65.36	80.83	59.94	21.63	40.73	14.48	10.79

Table 4. Total variance explanation.

Component	Initial Eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)
1	8.565	40.787	40.787	8.565	40.787	40.787	8.341	39.720	39.720
2	5.058	24.085	64.872	5.058	24.085	64.872	4.471	21.288	61.009
3	3.789	18.044	82.916	3.789	18.044	82.916	3.724	17.735	78.743
4	1.169	5.566	88.482	1.169	5.566	88.482	1.993	9.490	88.233
5	1.003	4.776	93.258	1.003	4.776	93.258	1.055	5.026	93.258

Table 4. Contd..

6	0.805	3.835	97.093						
7	0.247	1.177	98.270						
8	0.194	0.923	99.193						
9	0.124	0.592	99.785						
10	0.045	0.215	100.000						
11	4.4E-16	2.1E-15	100.000						
12	2.9E-16	1.4E-15	100.000						
13	2.2E-16	1.1E-15	100.000						
14	7.1E-17	3.4E-16	100.000						
15	1.61E-17	7.8E-17	100.000						
16	-6.3E-17	-3.0E-16	100.000						
17	-7.7E-17	-3.6E-16	100.000						
18	-1.3E-16	-6.0E-16	100.000						
19	-2.4E-16	-1.2E-15	100.000						
20	-3.8E-16	-1.8E-15	100.000						
21	-8.5E-16	-4.0E-15	100.000						

cases in each cluster. The cluster membership is shown in Table 5.

ANALYSIS OF WSCP SYSTEM'S DIVISION IN THE HEIHE RIVER BASIN

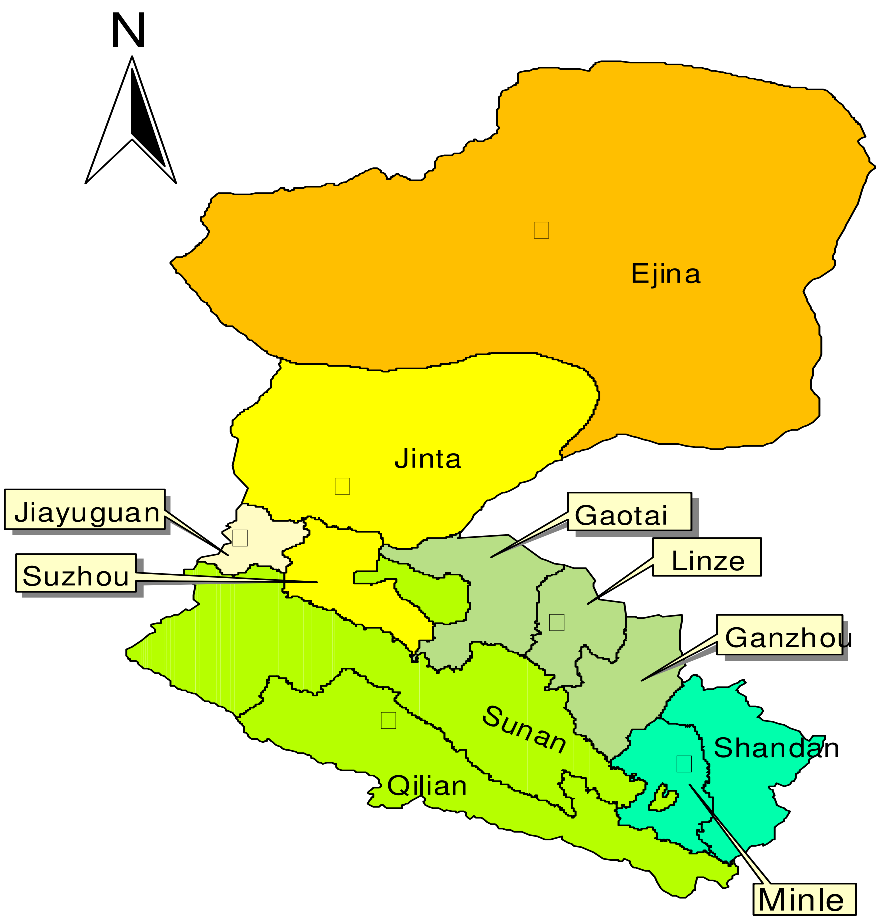
According to the clustering results in Table 5, the WSCP system in the Heihe River basin was divided into six subzones as shown in Figure 1: (1) Forage grass with dry farming (mountain subzone); (2) grain and cash crops with rain-fed irrigation (piedmont subzone); (3) grain and cash crops with irrigation (eastern plain corridor subzone); (4) fruits and vegetables with irrigation (western plain corridor subzone); (5) cash crops with irrigation (central plain corridor subzone); and (6) forage grass and cash crops with irrigation (Gobi Desert oases subzone).

Forage grass with dry farming (mountain subzone)

This subzone is in the upper portion of the Heihe River basin, and is located in the Qilian Mountains at the northern edge of the Qinghai-Tibet Plateau. It includes Qilian County of Haibei Tibetan Autonomous Prefecture in Qinghai Province and Sunan County of Zhangye City in Gansu Province. This subzone belongs to the Qilian Mountains-Qinghai Lake climate zone of the Qinghai-Tibet Plateau and is characterized by high altitude, complex terrain and a cold, damp climate. It is the region with the highest precipitation, the least evaporation, and the lowest temperatures in the entire river basin, and it provides the headwaters for the total basin. There are many rivers in this subzone, so water is very abundant and has little annual variation, but water use is minimal here because of the low level of economic development. This subzone is also rich in mineral and animal resources and has good vegetation, dense forests, vast grasslands, various types of pasture, good quality grass and high grass yield. Animal husbandry is the mainstay of the agricultural economy in the region: the economic output of planting is only about 20 to 30% of that of

Table 5. Cluster membership.

Case number	Cluster	Distance
1	1	0.000
2	1	1.277
3	4	1.023
4	4	0.000
5	6	0.709
6	6	0.000
7	6	1.870
8	3	0.000
9	2	1.627
10	2	0.000
11	5	0.000



I Forage grass with dry farming (mountain subzone)
II Grain and cash crops with rain-fed irrigation (piedmont subzone)
III Grain and cash crops with irrigation (eastern plain corridor subzone)
IV Fruits and vegetables with irrigation (western plain corridor subzone)
V Cash crops with irrigation (central plain corridor subzone)
VI Forage grass and Cash crops with irrigation (Gobi Desert oases subzone)

Figure 1. Subzones for WSCP in the Heihe River basin.

centers, cluster membership, final cluster centers, distances between final cluster centers and number of husbandry. Besides husbandry, there are some small agricultural areas that are dispersed in the edges of valley that can be planted with wheat, Tibetan barley, rapeseed, barley and feed crops. The grain-cash-forage planting structure shows a higher proportion of forage crops, which generally make up more than 50% of the cultivation area. Grain production is low, less than 200 kg per capita.

Planting development in this area should prioritize the conservation and protection of soil, water and forest resources in the Qilian Mountains. Deforestation and grassland reclamation must be banned to protect the stability of water sources in the Heihe River basin. Diversified agriculture should be developed by utilizing mountain resources. Planting development should go hand in hand with animal husbandry, and should include a steady increase in the cultivation of feed grass, while using cultivated grassland to reduce the pressure on natural grassland. Finally, the agricultural skills of minority farmers should be strengthened to improve their current methods of farming and irrigation.

Grain and cash crops with rain-fed irrigation (piedmont subzone)

This subzone includes Minle and Shandan counties of Zhangye City in Gansu Province. It is located in the piedmont proluvial fan, which is the transition zone between the Qilian Mountains and the plains of the Gansu Corridor. The southern portion of this subzone is mountainous; the north-central portion consists of plains. Arable land is mainly above 2000 m in elevation. Planting schemes include both dry farming and irrigation agriculture, with irrigated land accounting for about 60% of the total arable land. This subzone is an important grain- and oil-crop producing area for the Gansu Province. Most of the production consists of wheat, maize, potato, peas, rapeseed, flax and other grain or cash crops. Grain crops account for nearly 60% of the total area, and per capita grain yield reached about 800 kg in 2006. However, water is scarce in the region: in 2006, water resources were only 1 387.9 m^3 per capita, while water resources per unit of arable land were only 4 070.0 $m^3 \cdot hm^{-2}$. Grain-crop yield was negatively influenced in recent years due to a higher proportion of grain crops and a high water demand in summer. Therefore, the industrial structure needs to be further optimized to reverse the trends of declining groundwater and serious desertification.

The production of high-quality grain and oil products should continue to be stabilized in this subzone. There is a need to actively develop water-saving irrigation techniques, adjust crop types, breed drought-resistant varieties and reduce the water requirements of summer irrigation. Development of brewing barley, virus-free potatoes, fibrous flax, Chinese herbal medicines and seed production should be emphasized. In addition, crop patterns and combinations should be adjusted to make full use of the relatively abundant rainfall in the region.

Grain and cash crops with irrigation (eastern plain corridor subzone)

This subzone includes Ganzhou, Linze and Gaotai counties of Zhangye City in Gansu Province and is located in the middle portion of the Heihe River basin, where the terrain is flat and transportation is well developed. The basic conditions of agricultural production are relatively better and the planting level is higher than in subzones I and II, because of abundant light and heat, fertile soil and concentrated arable land. Its irrigated agriculture is developed in the middle portion of the Heihe River, and it is the major water consumer in the Heihe River basin. The main crops are wheat, corn, potato, beans, rapeseed and hemp. Grain crops make up 70% of the total crops; hence, the area is an important grain production center for Gansu Province. However, due to long-term over-exploitation of water resources in this region, water flow has diminished downstream, groundwater levels have continued to decline, and springs have been adversely affected. The amount of available water has been limited in this subzone since 2000, when the national quantitative water division program in the Heihe River basin was implemented. Now, there are serious water shortages for regional planting, especially in late spring and early summer when crop water demand is high but insufficient water is available from the Heihe River.

For planting development in this subzone, crop types and sowing dates need to be properly adjusted to coordinate with the spatial and temporal distribution of the available water; that is, crop water requirements should match the amount of available incoming water in order to reduce the effects of seasonal drought. Under the premise of stable grain production, the industrial and planting structures should be adjusted by properly compressing the irrigation area, developing crop types and varieties with high water use efficiency, restricting the area of high-water-consumption crops, focusing on the protection of oases and their peripheral grasses, shrubs and trees, controlling desertification and soil salinization, optimizing the reallocation of water resources, converting cropland to forest and grassland where it will improve the water supply and establishing a new ecological balance by these means. Advanced water-saving technology should be promoted in order to develop modern water-saving agriculture via suitable intercropping farming models, irrigation methods, and management practices. Green manure crops should be planted and crop rotation should be used to build farmland with high and stable yields. Finally, the ratio of husbandry in agriculture should be increased while also focusing on the development of grain and cash crops.

Fruits and vegetables with irrigation (western plain corridor subzone)

This subzone includes Jiayuguan City in Gansu Province. The Taolai River, the largest river of the western sub-water system, runs through the whole area. In 2006, Jiayuguan City reached the high urbanization level of 77%; therefore, agricultural output accounts for a low proportion of the regional economy, and the area of arable land is only 0.06 hm^2 per capita. Agriculture in Jiayuguan consists mainly of cash crops, with fruits and vegetables accounting for 50% of the total cultivated area. Grain crops are mainly wheat and corn, but they account for only 20% of the total cultivated area; in 2006, grain production was less than 40 kg per capita. In addition, there is a small cultivation area of oil crops.

The planting of this subzone should emphasize the characteristic suburban agriculture: grow high-quality, more expensive fruits and vegetables and also sightseeing agriculture in order to make most of regional advantages (funding and labor force with scarce arable lands). Farmers should be encouraged to adjust their planting structure by offering them services including information, technology, contacting orders and others. Facility agriculture should be actively developed by the use of regional economic and human resource advantages. Finally, the development of the seed industry should be promoted, with seed production been moved from maize to flowers, vegetables and other more profitable commodities.

Cash crops with irrigation (central plain corridor subzone)

This subzone includes Suzhou and Jinta Counties of Jiuquan City in Gansu Province. The main irrigation water source is the Talolai River, but the Heihe River also provides water to the Dingxin irrigation area in Jinta County. The region is mainly agricultural, and has little development in forestry, husbandry or fisheries. It struggles with high soil salinization as well as strong desiccating winds. The cultivated area of grain crops is about 35% of the total area; in 2006, grain production was about 400 kg per capita. The main crops are wheat, corn, cotton, vegetables, and fruits. The region is the second-largest seed production base in China and the largest seed production base that exports to foreign countries.

The development of planting in this subzone should make grain self-sufficiency the goal, focus on the development of facility agricultural as greenhouse and net-type seed production (to ensure the purity of the crop and reduce the number of pests) of high-efficiency cash crops, properly develop vegetables, fruits, cotton, hops, etc. The development patterns of “one town, one industry” and “one village, one product” should gradually be established at a large scale. In addition, crops with high water use efficiency should be developed while simultaneously reducing the planting area of high-water-consumption or low-income crops.

Forage grass and cash crops with irrigation (Gobi Desert oases subzone)

This subzone includes Ejina County in the Inner Mongolia Autonomous Region. It is located in the lower portion of the Heihe River basin. Poor natural conditions such as low precipitation, strong evaporation and fragile ecosystems make this subzone more suitable for animal husbandry than for agriculture. Since 1949, rapid population growth and extensive production have led to large-scale vegetation destruction, and downstream water availability has decreased yearly due to high water consumption farther upstream. In 1961, this led to the river drying up downstream, and in 1992, the terminal lake of West and East Juyan also dried up. In addition, the groundwater level has lowered, water quality has deteriorated, oases have shrunk, grasslands have degenerated, biodiversity has been reduced, desertification and salinization have rapidly increased, and sandstorm damage has been aggravated. This situation began to reverse itself after the implementation of the national quantitative water division program in the Heihe River basin in 2000; since then, the water of the terminal lake has recovered to some degree. The main crops of the area are cotton, honeydew melon, and forage crops. The cultivated area of grain crops is only 10% of the total area, and grain production is only about 160 kg per capita. The output ratio of agriculture to husbandry is about 1:8.

The development of planting in this subzone should prioritize the following actions: construct natural oases and protected areas, implement water-saving reconstruction in existing irrigated areas, strictly prohibit the expansion of irrigated areas, develop eco-efficient agriculture, implement forest protections, transform saline soil, and control desertification. Areas of focus should include the restoration and protection of natural vegetation and terminal wetlands in areas of desertification in the lake delta, the maintenance of natural oases rather than large-scale construction of artificial oases, and strict population control according to the ecological carrying capacity.

The ultimate goals should be to replenish the terminal lake with water, establish a national demonstration zone for ecological protection, and prohibit overgrazing, reclamation, deforestation and indiscriminate digging. In addition, the artificial cultivation of feed grass should be increa-singly developed to reduce pressure on natural grasslands and to increase the output of animal husbandry.

CONCLUSIONS

(1) As a result of differences in natural resources and environmental and socio-economic conditions in different regions of the Heihe River basin, the planting structure must be divided before the optimization of WSCP. Then, the planting structures of each subzone can be optimized to obtain the desired results.

(2) The division of WSCP is influenced by both natural and human factors. Twenty-one indicators were selected from among these factors to divide the eleven counties in the basin. Because the selected indicators are related to some extent, it is difficult to gain insight into any guiding principles. Therefore, FA was used to extract five main components that reflect the majority of the information from the original selected indicators. Then, each county in the Heihe River basin was clustered based on five principal components using KMCA.

(3) Based on the clustering results, the basin was divided into six subzones: a) Forage grass with dry farming (mountain subzone), b) grain and cash crops with rain-fed irrigation (piedmont subzone), c) grain and cash crops with irrigation (eastern plain corridor subzone), d) fruits and vegetables with irrigation (western plain corridor subzone), e) cash crops with irrigation (central plain corridor subzone), and f) forage grass and cash crops with irrigation (Gobi Desert oases subzone). Suitable development programs for each subzone were then drafted.

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REFERENCES

Adeyemo J, Otieno F (2010). Differential evolution algorithm for solving multi-objective crop planning model. Agr. Water Manage. 97: 848-856.

Chambers CP (2005). Allocation rules for land division. J. Econ. Theory, 121: 236-258.

Dinpashoh Y, Fakheri-Fard A, Moghaddam M, Jahanbakhsh S, Mirnia M (2004). Selection of variables for the purpose of regionalization of Iran's precipitation climate using multivariate methods. J. Hydrol. 297(1-4): 109-123.

Gansu Yearbook Editorial Board (2007). Gansu Year Book. China Statistics Press, Beijing, China.

Hall O, Arnberg W (2002). A method for landscape regionalization based on fuzzy membership signatures. Landscape Urban Plan. 59: 227-240.

Jolayemi JK (1996). An integrated model for planning and managing multi-regional mixed-crop farming schemes, Ecol. Model. 84: 63-74.

Liu E, Yin HJ (2008). A Concise Course of SPSS15.0 for WINDOWS. Social Sciences Academic Press, Beijing, China.

Liu MQ, Samal A (2002). A fuzzy clustering approach to delineate agroecozones. Ecol. Model. 149(3): 215-228.

Ma DM, Liang Y, Ma P (2000). The application of fuzzy clustering analysis in classification of agricultural economic types in Ningxia. J. Ningxia Agric. College, 21(4): 52-55.

Ministry of Water Resources, China (2002) Programming of Heihe river basin harnessing in near future. China Waterpower Press, Beijing, China.

Nevo A, Oad R, Podmore TH (1994). An integrated expert system for optimal crop planning. Agric. Syst. 45(1): 73-92.

Pereira AR (1982). Crop planning for different environments. Agric. Meteorol. 27: 71-77.

Qiao YL, Wang Y, Liu JC (2002). Divisional compound hierarchical classification method for regionalization of high, medium and low yield croplands of China. Adv. Space Res. 29(1): 89-96.

Sarker R, Ray T (2009). An improved evolutionary algorithm for solving multi-objective crop planning models. Comput. Elect. Agric. 68: 191-199.

Sethi LN, Kumar DN, Panda SN, Mal BC (2002). Optimal crop planning and conjunctive use of water resources in a coastal river basin. Water Resour. Manage. 16: 145-169.

Tratnik M, Franic R, Svrznjak K, Basic F (2009). Land rents as a criterion for regionalization-the case of wheat growing in Croatia. Land Use Policy, 26(1): 104-111.

Wang YB, Wu PT, Zhao XN, Li JL, Lv L, Shao HB (2010). The optimization for crop planning and some advances for water-saving crop planning in the semiarid Loess Plateau of China. J. Agron. Crop Sci. 196: 55-65.

Yao HR, Wu SH, Cao MM (2004). Optimum allocation of regional land and water resources based on GIS. Transactions of the CSAE 20(2): 31-35.

Yule IJ, Cain PJ, Evans EJ, Venus C (1996). A spatial inventory approach to farm planning. Comput. Electron. Agric. 14: 151-161.