The Variety of Runoff and Sediment and the Sustainable Development in Fenhe Valley

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Abstract: Fenhe valley located in the region of soil erosion in the middle Yellow River, water resources is always very short. Especially in recent decades, plentiful human activities affected the change of runoff. The negative function brought by the change to Fenhe valley is unexpected. In order to survive and develop, the people destroyed forest and reclaimed wasteland excessively, which made ecological environment breach. Water and soil losses, waterlog, drought disaster, pollution of water quality and soil salinification etc. restricted the development in Fenhe valley.

In recent decades, the days that the observed discharge of Hejin hydrology station in Fenhe less than $1m^3/s$ is up to more than 100 days. It became almost intermittent river due to long time near break-off. Under the condition of same rainfall, runoff decreased largely and concentration of water quality pollution increased. It is very disadvantage to the Yellow River that runoff decreased in Fenhe valley. Owing to excessive population, high degree of water resources exploitation and utilization, and finite local water resources, we must strengthen the management of utilization of exist local water resources, heighten the ratio of water usage, save water usage, and protect water-soil resources for the great development of socio-economic in Fenhe valley.

Keywords: runoff, sediment, water resources, Fenhe

1 Social condition

Fenhe valley, from Ningwu County to Hejin County in Shanxi province, goes through 33 Counties in Xinzhou, Taiyuan, Lvliang, Jinzhong, Linfen and Yuncheng District. Analyzed from development of population in Fenhe valley, the variety of socio-economic is the following: the total population is 9.156 million in 1985, the average increasing ratio in the next every 5 years is 17%, 14.1% and 9.2% respectively, 11.287 million in 1999. Non-agricultural population is 2.4315 million in 1985 and 3.654 million in 1999, the mean increasing percent in every 5 years is 13.8%, 14% and 10.2% respectively. While agricultural population in whole valley is 6.7249 million in 1985 and 7.6336 million in 1999, the mean increasing percent in every 5 years is 6.4%, 4% and 1.9% respectively. The increasing velocity of total population descend, the increasing ratio in 1985 is less 2.6% than that in 1999. The increasing

Table 1 The socio-economic conditions in Fenhe valley

Year	Total population	Non-agricultural	Agricul-tural	GDP	Total industrial product	Agricultu-re and forest product	Pure mean income	Provisi-on output	Oil plants output
	(10^4)	(10^4)	(10^4)	(10^8yuan)	(10^8yuan)	(10^8yuan)	yuan/ren	(10^4ton)	(ton)
1985	915.6	243.1	672.49	90.28	47.32	50.14	384.8	276.05	108,975
1990	1,000.7	282.0	718.63	180.39	94.29	99.84	530.6	332.61	74,234
1995	1,076.5	328.1	748.72	459.81	187.33	207.72	1,209.6	320.79	66,027
1999	1,128.7	365.4	763.37	626.88	840.26	115.10	1,947.2	309.86	87,059

velocity of agricultural population decrease obviously, the increasing ratio of agricultural population is less 2.1% than that of total population. The variety in 1990s is quite apparent. The increasing velocity of non-agricultural population is relatively fast. Based on the above statement, the population structure changed significantly, so the socio-economic also varied obviously.

2 Basic character and variety of water resources

Water resources in Fenhe valley are shortage in the past. The plentiful human activities affected the runoff amount, especially in recent decades. The negative function brought by the effects is unexpected. The yearly runoff and sediment are shown in Table 2.

Table 2 Character of hydrology factor in Fenhe valley

Year	Rainfall	Runoff	Sediment	Sediment runoff modulus
	(mm)	(10^8m^3)	(10^4ton)	(ton/km^2)
1951—1959	501.1	17.57	6,999.2	1,807
1960—1969	517.9	17.86	3,440.6	888
1970—1979	492.4	10.36	1,910.2	484
1980—1989	457.4	6.65	450.6	116
1990—1999	496.5	5.68	316.7	80
1950—1999	491.7	11.42	2,623.5	665

Note: The rainfall data is up to 1995.

2.1 Character of water resources

The runoff in Hejin hydrology station in every decade from 1950s to 1990s is 1.757 billion m^3, 1.786 billion m^3, 1.036 billion m^3, 0.665 billion m^3 and 0.508 billion m^3 respectively. The runoff in 1990s is less than 1/3 of that in 1950s. The runoff in Hejin station in July and October is 60.7% of annual average runoff. The runoff in July and August and in September and October is 54.4%, 45.6% of that in July-October, respectively. The runoff in July-October is 67.7%, 55.3%, 62.1% and 57.3% of the total annual runoff in 1950s, 1960s, 1980s and 1990s, respectively. The runoff in July and August is 59.2%, 54.1%, 55.7% and 55.2% of that in July to October in 1950s, 1960s, 1980s and 1990s respectively.

Table 3 Runoff、Sediment of Hejin station in 1950s, 1960s, 1970s, 1980s and 1990s

year	Runoff（10^8m^3）			
	July to August	September to October	July to October	year
1950—1959	7.04	4.86	11.89	17.57
1960—1969	4.72	5.15	9.87	17.86
1970—1979	3.60	3.05	6.65	10.36
1980—1989	2.30	1.84	4.13	6.65
1990—1999	1.81	1.40	3.20	5.08
1950—1999	3.89	3.26	7.15	11.50
year	Sediment (10^4ton)			
	July to August	September to October	July to October	year
1950—1959	4,826.93	1,777.05	6,603.99	6,999.22
1960—1969	1,698.91	1,207.19	2,906.11	3,440.57
1970—1979	1,271.36	494.29	1,765.65	1,910.21
1980—1989	288.79	114.92	403.71	450.58
1990—1999	181.22	107.65	288.86	316.74
1950—1999	1,653.44	740.22	2,393.66	2,623.46

The yearly average sediment in Hejin station is 26.23 million tons. The sediment in 1950s, 1960s, 1970s, 1980s and 1990s is 69.99 million tons, 34.4 million tons, 19.1 million tons, 4.5 million tons and 3.16 million tons respectively. With respect to the spatial distribution, the sediment in Fenhe valley comes mainly from two regions. One is Zhaishang in upper reaches, where the yearly mean sediment is 7.53 million tons; the other is between Yitang and Chaizhuang in middle reaches, the sediment is 15.44 million tons. Uneven timely distribution of sediment existed. Sediment amounting to 91.2% of the normal annual sediment concentrates in July to October. Among them, 69.1% of sediment focus in July and August, 30.9% occur in September and October.

The distribution of soil in Fenhe valley is complex. Most regions of upper and middle reaches are hilly regions, water and soil erosion of which is serious. The area of Loess region in the upper Zhaishang is about 3,194 km^2, sediment runoff modulus is 52.42 million tons/km^2. The area of Loess region between Yitang and Chaizhuang is about 3,929 km^2, sediment runoff modulus is 45.7 million tons/km^2.

2.2 Variety of runoff and sediment

The runoff in Fenhe valley reduced. The rainfall, underlying and human activity are different in upper, middle and lower reaches of Fenhe valley. The runoff in July and August in upper of Zhaishang varied noticeable before 1970s than that after 1970s. The runoff in July to August in upper of Yitang varied with the same level. The variety of runoff in Chaizhuang and Yitang is very similar. The runoff in Chaizhuang, Yitang and Hejin occur a relative large value in every 10 years. The variety of runoff in September to October in the upper of Zhaishang keeps basically a same level. The runoff between Yitang and Chaizhuang in September-October decreased. The maximum value in 1960s, 1970s and 1980s is about 100 thousand m^3, 70 thousand m^3 and 50 thousand m^3 respectively. The runoff in Hejin in September-October decreased step by step. The maximum runoff in 1950s, 1960s, 1970s, 1980s and 1990s is about 160 thousand m^3, 110 thousand m^3, 70 thousand m^3, 50 thousand m^3 and 40 thousand m^3, respectively. The runoff in July to October and in whole year decreased year by year.

Sediment from upper reach to lower reach reduced. The maximum sediment in Zhaishang in 1950s, 1960s, 1970s and 1980s is near 67.23 million tons, 16.27 million tons, 6.5 million tons, and 4.72 million tons respectively. The maximum sediment in Chaizhuang in 1950s, 1960s, 1970s and 1980s is 109.9 million tons, 62.47 million tons, 43.1 million tons, and 28.87 million tons respectively. The maximum sediment in Fenhe valley in 1950s, 1960s, 1970s, 1980s and 1990s is 176.28 million tons, 64.99 million tons, 51.58 million tons, 14.21 million tons, and 7.41 million tons respectively. The variety of sediment in July to August and September to October give a cycle of 9—12 years, 5—7 years. The variety of sediment in year and flood-season is consistent.

3 Rainfall and flood

3.1 Variety of rainfall

The range of precipitation variety in Fenhe valley is between 300 and 800 mm. The yearly difference of rainfall in upper of Zhaishang is noticeable. The maximum annual precipitation occurred in 1950s and 1960s. The annual rainfall more than 600 mm didn't occur after 1980s. The annual rainfall between Yitang and Chaizhuang is consistent with the upper reaches before 1970s, obviously different in latter 1970s and increasing in 1990s. The annual rainfall Chaizhuang and Hejin is over 800mm in 1958, and range from 650 to 350mm in other years, the yearly change of which is smaller than that of the upper. After consecutive middle-rainfall years, occurred a dry year, and then changed to rainy year, especially from the latter of 1960s to the beginning of 1970s and from the latter of 1980s to the former of 1990s.

3.2 Variety of flood

We analyze the variety of flood, according to statistics of days that every level discharge occurred in Hejin station. There are 63 days that the mean discharge of a day is more than 500 m^3/s, which include 32 days in 1950s, 19 days in 1960s, 6 days in 1970s, 5 days in 1980s and 1 day in 1990s. There are 1,808

days that the mean discharge of a day is between 50 and 100 m^3/s, which include 462 days in 1950s, 802 days in 1960s, 299 days in 1970s, 182 days in 1980s and 63 days in 1990s. There are none day that the mean discharge of a day is between 1 and 50 m^3/s in 1950s, 3 days in 1960s, 505 days in 1970s, 496 days in 1980s and 415 days in 1990s. The large flood in Fenhe reduced. the days in 1950s is the most and in 1990s is the least. The days of small discharge increased, especially in recent decades, the days that the observed discharge less than $1m^3/s$ was up to 100 days. It became almost intermittent river.

3.3 Relation of variety between flood and rainfall

Compared with the variety of flood and rainfall, the shortest flood duration is 2 days, and the longest is 20 days. The flood occurred due to concentration of rainfall days. Plotted the correlation of dayly precipitation and flood discharge, it is shown that discharge after 1970 is more than that before 1970 in the same precipitation. Therefore, the reduction of flood isn't caused by didn't result in precipitation.

4 Reason of variety

The obvious variety is occurred in the runoff and sediment in Fenhe valley. Although runoff and sediment decreased with large degree, the mean precipitation process isn't changed.

4.1 Correlation of precipitation, runoff and sediment

The most runoff yields in Fenhe valley due to storm. The percent of runoff and sediment in flood-season covering that of the whole year is high, so we first consider the storm when analyzing the correlation between rainfall, runoff and sediment. In the upper of Hejin station, there are several rainy years that precipitation is 1.5 times of average value, while in 1990s which is below the average value. Compared with runoff, it is reason of runoff veducing but not.

4.2 Correlation of storm and runoff

In order to analyze the variety of hydrologic elements in each flood, the maximum flood in every decade is found out. The flood occurring in 1958, 1964, 1977, 1982 and 1990 are analyzed. In 1958 and 1960, the largest peak discharge is $1530m^3/s$ and 1060 m^3/s, the second flood volume covers 9.2% and 16% of annual runoff. The former precipitation is 35.3% of annual precipitation, the latter is 28.5%, The second flood volume in 1964 is 1 times larger than that in 1958, the second rainfall is 10% less, and the largest peak discharge is 1/3 less. The rainfall is large and duration is short in 1958, while they are opposite in 1964. The largest peak discharge is $837m^3/s$ in 1977, the second flood volume is 20.4% of annual runoff, and the second rainfall covers 21.7% of the whole year. In 1982, the 3 elements are $473m^3/s$, 33.1% and 41.3%, respectively. In 1990, these are $396m^3/s$, 4.5% and 18.9%, respectively. The above factors show that the more the percent of second rainfall covers the whole year, the more the ratio of second flood volume covers the annual, but the peak did not vary with them. The largest peak discharge decreased decade by decade.

4.3 Effects of water conservancy and water conservation to runoff and sediment

The project of water conservancy and water conservation and the degree of harness affected the runoff in Fenhe valley. There are reservoir and project of water-soil conservation in irrigation region etc. in Fenhe valley. The two large reservoirs of Fenhe and Wenyuhe are built in 1958, and reservoir capacity is 837 million m^3. In addition, there are 13 middle, 72 small (Ⅰ) and 147 small (Ⅱ) reservoirs. The storage of them is 476 million m^3, 191 million m^3 and 46 million m^3, respectively. The total number of reservoir is 234, and the total storage is 1550 million m^3. Reservoir plays an important role in local water supply of industry and agriculture, and makes contribution to reduce the sediment into the Yellow River. The control area of reservoir covers 39% of total area. The sediment blocked by reservoir is 549 million m^3, which covers 35.4% of the total storage. In general, we consider the potential of exploitation in Fenhe

valley is high.

There are not only many reservoirs in Fenhe valley, but also large-scale irrigation regions. In history, from Zhou and Qin dynasty in 220 B.C., spring water has been used for irrigation. Now, there are 100 medium-small irrigation regions. The irrigation modes include artesian well, and pumped well etc. There are 33 artesian irrigation regions and 25 pumped irrigation regions. The irrigation area is up to 3×10^4 ha, which include artesian 35.8×10^4 ha and pumped 4.53×10^4 ha.

Water and soil erosion make the fertile soil decreasing, which resulted soil sterile and gully yielding. The water-soil erosion resulted scouring in upper reach and deposition in lower reach. The silting in lower reach caused the flood disaster. The losses of water and soil destroyed the balance of natural ecology, deteriorated the soil, physiognomy and climate. The harness measures are carried out since 1950s in Fenhe valley, which include terrace, check dam, beach, artificial forest, grass and forestation.

The harness conditions of all kinds of water and soil conservation in Fenhe valley are given in Table 4. The area of terrace is 16.37×10^4 ha, dam 3.94×10^4 ha, beach 2.87×10^4ha, forestation of water conservation 57.8×10^4 ha grass 11.98×10^4 ha. The measures of water-soil conservation are mostly in the middle and lower reach. The increasing ratio of terrace in 1960s, 1970s and 1980s is 15%—17%, 6%—7% and 1%—4%, respectively. The annual increasing ratio of check dam in upper reach in 1960s is 6.7%, in 1970s and 1980s is 3.5%—4%, while in middle and lower reach in 1960s, 1970s and 1980s is 18%—20%, 7%—8% and 1.6%—3% respectively. The increasing ratio of grass in upper reach in 1960s, 1970s and 1980s is 17%, 3% and 16.5%, respectively, which in middle reach is 24%, 6.5% and 4%, and which in lower reach is 5.5%, 7.6% and 0.3%. The forestation is mainly in upper reach, the increasing ratio in 1960s and 1970s is 1.75% and in1980s is 10%. While in middle reach is 3%, 2.4% and 0%, in lower reach is 0.9%—1.2% in 1960s and 1970s, in 1980s and 1990s is negative.

Table 4 Area and increasing ratio of harness of water and soil conservation in Fenhe valley

	Year	Terrace		Dam		Beach		Forestation		Grass	
		10^4 ha	%	10^4 ha	%	10^4 ha	%	10^4 ha	%	10^4 ha	%
Total basin	1959	1.13		0.28		0.16		3.35		0.51	
	1969	5.37	16.91	1.34	16.95	1.41	24.28	12.00	13.60	1.20	9.00
	1979	10.03	6.44	2.69	7.23	2.73	6.84	23.33	6.88	2.33	6.85
	1989	11.94	1.76	3.43	2.44	4.04	4.01	34.85	4.09	3.40	3.87
	1999	16.37	3.20	3.94	1.40	2.87	–3.37	57.84	5.20	11.98	13.42

5 Conclusions and Suggestions

The area of Fenhe valley is large. It goes through the complex physiognomy region of water and soil erosion in middle Yellow River. The human activity affected the runoff. The research in the past and present showed this opinion. In order to survive and develop, the people destroyed forest and reclaimed wasteland excessively, which made ecological environment breach. Water and soil losses, waterlog, drought disaster, pollution of water quality and soil salinification etc. restricted the development in Fenhe valley.

(1) The annual rainfall from 1950s to 1990s in Fenhe valley keeps the same level. Uneven seasonal distribution of annual precipitation existed. The maximum month rainfall covers 20%—30% of that in whole year, which in Julyand August covers 40%—50%, and which in Septembe and October covers 13%—23%. The precipitation in Julyand August is 49%—53% of that in whole year before 1970s, and 40% in 1980s and 1990s. The largest precipitation in a month, between Yitang and Chaizhuang, covers 21%—28% of that in whole year before 1970s, and 18%—21% in 1980s and 1990s.

(2) Runoff and sediment reduced, and the reducing amount is large. The flood discharge is small. In recent decades, the days that the observed discharge of Hejin station in Fenhe less than $1m^3/s$ is up to more than 100 days. It became almost intermittent river due to long time near break-off. It is very disadvantage that flood carrying capacity in Fenhe estuary decreased.

(3) Runoff decreased noticeable in the same precipitation. It indicated the high extent of comprehensive harness on the one hand, serious shortage of water resources and pollution of water quality on the other hand. The decreasing of runoff increased the concentration of pollution of water quality. The pollution of water quality is mainly due to the drainage of sewage. The annual mean drainage of sewage of living and industrial water usage in Taiyuan is $22{,}000\times10^4 m^3$. There are about 1000 enterprises of industry and mining in upper and middle reaches, drainage sewage of which in every day is up to $130\times10^4 m^3$. The drainage of sewage per day is $15\times10^4 m^3$. The drainage of sewage in whole valley in a year is $52{,}500\times10^4 m^3$.

(4) The correlation coefficient between runoff and sediment is good. With runoff decreased, the sediment also decreased. The particle size became thin.

(5) It is very disadvantage to Yellow River that runoff decreased in Fenhe valley. Because of excessive population, finite water resources, and high extent of water resources exploitation and utilization in Fenhe valley, we must strengthen the management of utilization of existing local water resources, heighten the ratio of water usage, save water usage, and protect water-soil resources for the great development of socio-economic in Fenhe valley.

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