The variation and utilization of water resources in the Heihe River basin

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Abstract

The Heihe River basin, draining an area nearly 130,000 km^2, is the second largest inland river basin in China. The upper reach, namely the Qilian mountainous area, is the formation area of runoff and water resources. The method of time series analysis is applied to annual runoff series to analyze the dynamic variation of headstreams. The results show that the variation of the runoff is slightly decreased. The plains in the middle reach are the main consumptive regions of water resources in the basin. The time series analysis method is also applied to the annual runoff series. It shows there is a significant decreasing trend and it indicates an over-consumption of water resources in this area. A historical analysis proves this. Also, the irrational utilization of water resources has caused a series of detrimental environmental effects, which are summarized as water environment change, land desertification and salinization, and vegetation degeneracy. A water consumption model of the mainstream area is established to analyze the characteristics of water consumption in the middle reach. The simulated result shows that water consumption increases by about 1040×10^4 m^3/yr on average.
Keywords: runoff variation, water consumption, time series analysis method, Heihe River basin.

1 Introduction

The Heihe River Basin, located in the northwest China, is the second largest inland river basin in China (Fig. 1). It covers from N 37°41′—42°42′and E 96°42′ — 102° 00′, with an area of 12.83×10^4 km^2. Heihe River originates from Qilian Mountains in the south, flows through the middle basin called as Hexi

Corridor (part of the Ancient Silk Road), reaches the lower reach named as Ejina basin and disappears in the west Juyanhai Lake and east Juyanhai Lake. In history, the Heihe River Basin included 35 river systems flowing towards the mainstream of the Heihe River. Now, with the increase of water consumption, many branches have no surface water connection with the mainstream and the basin is divided into three large unattached water systems (Fig. 1): the east, the middle and the west. Among the three parts, the east includes the mainstream and takes up most of the water resource. This paper mainly discusses the east part.

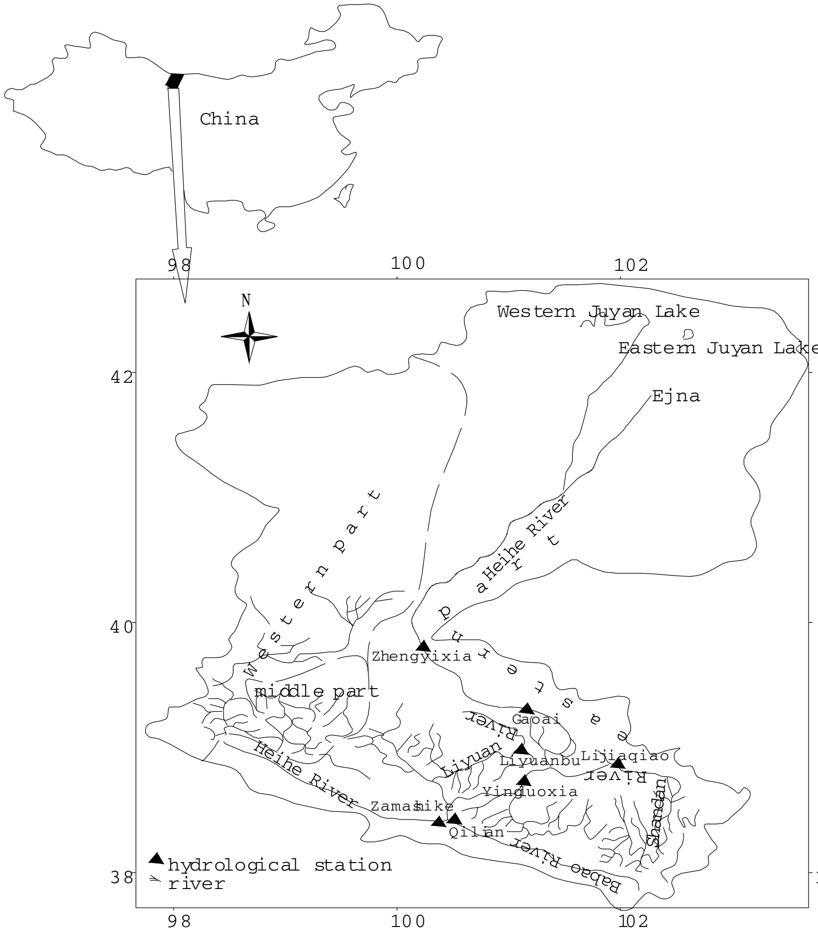

Figure 1: Water systems and some hydrological stations in Heihe River basin.

Irrational exploitation of water and land resource can lead to serious ecological and environmental problems [1]~[2]. Environmental changes caused by mankind's exploitation and development of natural water and soil resources have long been a severe problem in the world, especially in the arid and semiarid areas because of their vulnerability of ecosystems [3]~[4]. During the last 50 years, a series of detrimental environmental effects summarized as water environment change, land desertification and salinization, and vegetation degeneracy have occurred owing to irrational exploitation and development on water resource in Heihe River basin [5] ~ [7], which have invoked society's concerns. Heihe River basin is very typical in arid and semiarid areas in Northwest China. The focus of these problems is the coordination of sustainable development of economy and society with the protection of ecology and environment. Thus it is necessary and significative to study the variation and consumption patterns of the water resource of Heihe River.

2 Runoff trend analysis on Heihe River

2.1 Methodology

Time series analysis method is used to analyze the dynamic variation of runoff [2], [8]. Due to the impact of determinate and indeterminate factors of meteorology and human activities, the variation of annual is very complex. By applying the combined model of time series analysis, the annual runoff series $\{R_t\}$ are decomposed as follows:

$$R_t = N_t + P_t + S_t + \varepsilon_t \tag{1}$$

where $\{N_t\}$ and $\{P_t\}$ are determinate trend and periodic item respectively, and $\{S_t\}$ and $\{\varepsilon_t\}$ are indeterminate steady stochastic item and residual item respectively.

In the analysis, Kendall order test is first used to test if there exists an obvious trend of the annual runoff series. If it exists, the linear trend can be tested and the trend item $\{N_t\}$ can be obtained. Then subtract trend item $\{N_t\}$ from $\{R_t\}$. The new series $\{R_t - N_t\}$ is used to test its periodicity, and the periodic item $\{P_t\}$ is described by Fourier series. The series $\{R_t - N_t - P_t\}$ is described with a p-order autoregression model AR(P) to obtain steady stochastic item $\{S_t\}$. Finally, the residual item $\{\varepsilon_t\}$ should be independent and stochastic.

2.2 Trend analysis on headstreams inflow

Runoff yield areas of the Heihe River are all in a mountainous area named Qilian Mountainous Area [3],[7]. In the analysis of the dynamic variation of water resource of the Heihe River, emphasis is put on the east part because the middle and the west part of Heihe River nearly have no connection with the mainstream. Shandan River and Liyuan River are the most important branches of Heihe River in east part (Fig .1).

Time series analysis method is applied to annual runoff of hydrological stations on headstreams. The trend item N(t), periodic item P(t) and steady stochastic S(t) of AR(2) model are obtained. Table 1 gives the mean runoff and dynamic trend with t=1 for 1957. Table 1 shows annual runoff of rivers originating from the Qianlian Mountains has a slightly variation.

Table 1: Mean annual runoff and dynamic trend of headstreams of Heihe River.

river	Hydrologic station	Mean annual runoff (m^3/s)	Trend item	Variation trend	Notability at significance level α = 5%
Shandan	Lijiaqiao	2.35	N_t= 2.35-0.0001t	Slightly decrease	insignificant
Babaohe	Qilian	14.31	N_t= 14.15+0.0069t	Slightly increase	insignificant
Heihe	Zamashike	22.59	N_t= 23.23-0.026t	Slightly decrease	insignificant
Liyuanhe	Liyuan	7.94	N_t=7.79-0.0021t	Slightly increase	insignificant
total		47.19			

Time series analysis of the total annual runoff of the above four stations shows the total runoff has a slightly decreasing trend with a linear trend item of

$$Nt = 47.49 - 0.020t \quad \text{(t=1 for 1957)} \tag{2}$$

The variation and linear trend of the total annual runoff are shown in fig.2.

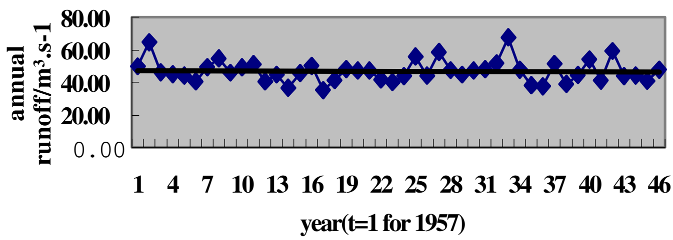

Figure 2: Total annual runoff of four hydrological stations in the headstreams and its linear trend.

Since the runoff mainly comes from precipitation and glacier-snow melt water in the mountainous area. Through the analysis of the precipitation and air temperature data in upper reach of Heihe River, it shows that both the precipitation and air temperature have an increasing trend, that is to say, the runoff in headwaters area should increase. The main reason for runoff decrease is the increase of water consumption (mainly for agriculture).

2.3 Trend analysis of runoff in middle reach of the Heihe River

There are three hydrological stations along the Heihe River in middle reach, namely Yingluoxia, Gaoai and Zhengyixia. Time series analysis method is also applied to annual runoff of these three stations. The results show that the annual runoff of Yingluoxia has an increasing trend:

$$N_t = 47.29 + 0.064t \text{ (t=1 for 1945)} \tag{3}$$

while Gaoai and Zhengyixia have significant decreasing trend

$$N_t = 38.56 - 0.571t \text{ (t=1 for 1981)} \tag{4}$$

$$N_t = 38.37 - 0.0285t \text{ (t=1 for 1957)} \tag{5}$$

Fig.3 shows the annual runoff of Yingluoxia and Zhengyixia and their different trends. Data of Zhengyixia in 1945 to 1956 are prolonged with the data in Yingluoxia in same period.

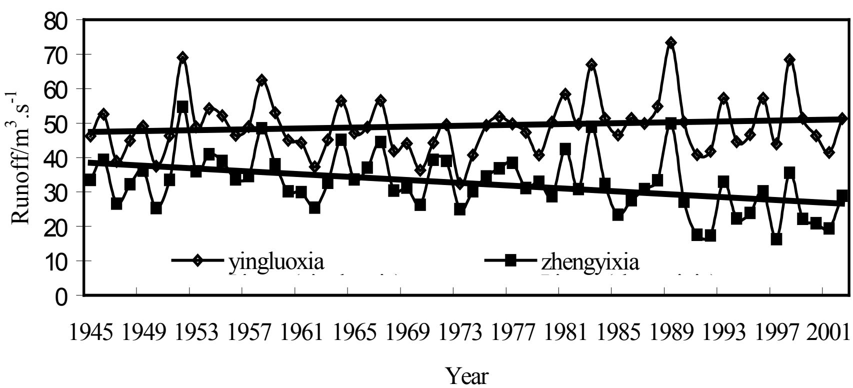

Figure 3: The variation and linear trends of annual runoff of Yingluoxia and Zhengyixia.

3 Analysis on water consumption in the middle reach areas

Besides the mainstream of Heihe River, there are several branches in the middle reach (Fig 1). With the increase of water resource utilization and the reservoirs built in the branches, the branches nearly have no inflow into the mainstream except floodwater in flood season. Therefore, those small branches can be omitted in the analysis of inflow to the mainstream of Heihe River. The difference runoff between Yingluoxia Station (a border of upper and middle reach of Heihe River) and Zhengyixia station (a border of middle and lower reach of Heihe River) will be approximately taken as total water consumption in the middle reach areas.

3.1 General situation of water consumption in the middle reach

The middle reach of the mainstream has an area of 23365.40 km^2, takes up 18.2 % of the whole river basin. In 1995, this area consumes 20.458×10^8 m^3 water resource and in possession of 60.9 % of the whole water consumption in the Basin. [9]. Most of the water is diverted into the channels and consumed on the agricultural irrigation (table 2).

Table 2: The purpose and amount of surface water diversion in the middle reach of Heihe River in 1990-1995.

administrative area	living utilization		Industrial utilization		agricultural irrigation		total	
	Amount /10^8m^3	Percentage /%	Amount /10^8m^3	Percentage /%	Amount /10^8m^3	Percentage /%	Amount /10^8m^3	Percentage /%
Ganzhou district	0.041	0.48	0.060	0.70	8.530	98.82	8.631	100.00
Linze county	0.018	0.33	0.019	0.34	5.480	99.33	5.517	100.00
Gaotai county	0.000	0.00	0.011	0.30	3.680	99.70	3.691	100.00
total	0.059	0.33	0.090	0.50	17.690	99.17	17.839	100.00

3.2 A historical analysis on water consumption in the middle reach areas

In the middle reach of the mainstream of Heihe River, the main factors influencing water consumption include river inflow from the upper reach and human activities. With the increase in population and development of economy, human activities, such as construction of canals and reservoirs and diversion of water for irrigation in recent 30 years, have led to a sharply increase of water consumption.

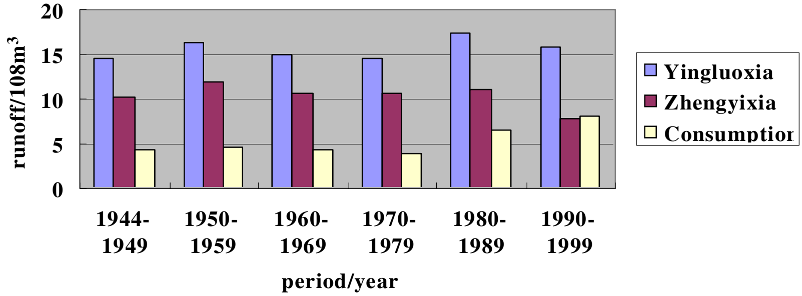

Figure 4: The annual runoff at Yinluoxia and Zhenyixia hydrometric stations and the water consumption in middle reach of mainstream in Heihe River.

Fig 4 shows the historical variation of water consumption in the past 60 years. we can see that in 1940s, 1950s and 1960s, the annual consumption nearly keeps stable, and the value is about $4.40\times10^8m^3$/yr. In 1970s, the annual consumption reach the minimum, 3.95×10^8 m^3/yr. The main reason is the decrease of runoff, and the other reason is the economic decline during this period. Owing to the resumption and great development of economy especially the agriculture, the water amount for irrigation sharply increased in 1980s and reaches 6.44×10^8 m^3/yr. Compared to 1940s to 1970s, increased 1.97×10^8 ~2.49×10^8 m^3/yr. In 1990s,water consumption reaches 8.08×10^8 m^3/yr.

Since 1949 to 1998, the water consumption in the middle reaches area of the basin has increased by 19 times. At the same time, the area of oasis in this area has added by 89.5%. The irrational utilization of water resource in this area has caused a series of detrimental environmental effects: the discharge in the lower reaches of the river has reduced by 51 %; the spring water output has reduced by 22.8 %; mineralization degree of surface water and shallow ground water in the middle and lower reaches have been increasing due to variations of hydrological condition and redistribution of water resources. In the middle section of the river basin some 43.18×10^4 hm^2 of grassland degraded seriously; 0.93×104 hm^2 of forest have been destroyed and the decertified land has increased to 5.35×10^4 hm^2. In the lower reaches of the river basin, degraded vegetation has reached 27.18×10^4 hm^2 and land desertification is expanding at a rate of $(1.1\sim1.3)\times10^4$ hm^2/yr [10].

3.3 Analysis on water consumption in the middle reach areas

Based on the above analysis, the difference runoff between Yingluoxia Station and Zhengyixia station will be approximately taken as total water consumption in the middle reach areas. Annual runoff of Zhengyixia Station can be calculated using the following water balance equation:

$$WZY^* = WYL - WRC \tag{6}$$

where WYL is the inflow of Yinluoxia and WRC is the water consumption in middle reach.

From the historical analysis on the water consumption, with more inflow from the mountainous areas, water diversion to the irrigation area and water consumption will also get more. As a result, WRC is related to WYL. On the other hand, WRC increases with time due to social and economic development and exploitation of water and land resources in middle reach. Considering the above factors, a simple linear model to estimate water consumption in middle reach is established:

$$WRC = k_w WYL + k_t t \tag{7}$$

where k_w and k_t are coefficients which are related to water inflow in Yinluoxia and time respectively.

The following equation can be obtained from (6) and (7)

$$WZY^* = (1 - k_w) WYL - k_t t \tag{8}$$

By adopting the least square method to measured data of WYL and WZY from 1957 to 2002, values of the coefficients are estimated to be k_w =0.21 and k_t =0.32. Therefore, water consumption of the middle reach WRC* and WZY* can be calculated

$$WRC^* = 0.21WYL + 0.32t \quad (\text{ t=1 for year 1957 }) \tag{9}$$

$$WZY^* = 0.79WYL - 0.32t \quad (\text{ t=1 for year 1957 }) \tag{10}$$

Fig.5 shows the calculated annual water consumption of the middle reach with model (9) and comparison with measured data.

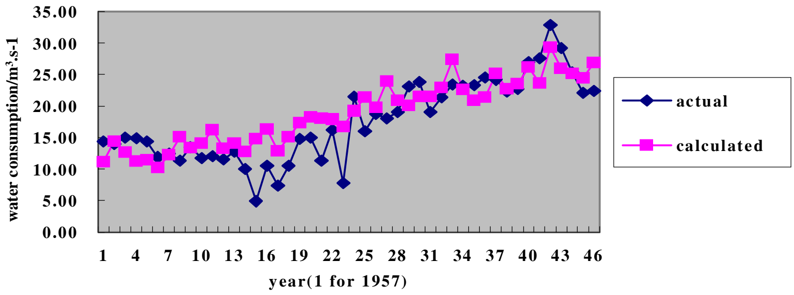

Figure 5: Comparison between measured and calculated annual water consumption of the middle reach.

Deduced from eqs. (3) and (9), the trend item of water consumption of the middle reach expressed as follows:

$$Nt = 9.93 + 0.33t \quad (\text{ t=1 for year 1957 }) \tag{11}$$

The equation (11) indicates that water consumption of the middle reach of the mainstream increases by about 1040×10^4 m^3/yr in average.

4 Conclusion

(1) The method of time series analysis is applied to annual runoff series to analyze the dynamic variation in headstreams and middle reach of mainstream of Heihe River. The results show that the variation of runoff in the headstreams slightly decreases, Yingluoxia has an increasing trend, and Gaoai and Zhengyixia have significant decreasing trend.
(2) Based on a historical analysis on water consumption in the middle reach of mainstream, in 1980s, water consumption in this area increases sharply duo to the resumption and great development of economy especially the agriculture, and in 1990s reaches its peak, 8.08×10^8 m^3/yr. The irrational utilization of water resource in this area has caused a series of detrimental environmental effects

which are summarized as water environment change, land desertification and salinization, and vegetation degeneracy.
(3) A simple water consumption model is established to analyze the variation of water consumption in the middle reach. The simulated result shows that water consumption in the middle reach of the mainstream increases by about 1040×10^4 m^3/yr in average. Regulations of the effective management of water resource are imperative in the current situation.

Acknowledgements

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