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RESEARCH ARTICLE

Changes in major factors affecting the ecosystem health of the Weihe River in Shaanxi Province, China

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Abstract Maintenance of the ecosystem health of a river is of great importance for local sustainable development. On the basis of both qualitative and quantitative analysis of the influence of natural variations and human activities on the ecosystem function of the Weihe River, the changes in major factors affecting its ecosystem health are determined, which include: 1) Deficiency of environment flow: since the 1960s, the incoming stream flow shows an obvious decreasing tendency. Even in the low flow period, 80% of the water in the stream is impounded by dams for agriculture irrigation in the Baoji district. As a result, the water flow maintained in the stream for environmental use is very limited. 2) Deterioration of water quality: the concentrations of typical pollutants like Chemical Oxygen Demand (COD) and NH_3-N are higher than their maximum values of the Chinese environmental quality standard. Very few fish species can survive in the River. 3) Deformation of water channels: the continuous channel sedimentation has resulted in the decrease in stream gradient, shrinkage of riverbed and the decline in the capability for flood discharge. 4) Loss of riparian vegetation: most riparian land has been occupied by urban construction activities, which have caused the loss of riparian vegetation and biodiversity and further weakened flood control and water purification functions.

Keywords influencing factors, ecosystem health, ecological and environmental functions, the Weihe River, Shaanxi Province

1 Introduction

River serves many societal and natural functions [1,2]. A healthy river is sustainable and resilient, maintaining its ecological structure and function over time while continuing to meet societal needs and expectations [3]. The ecosystem health of river expresses that it is not only the ecological component that makes up a sustainable system, but also the ecological qualities should be safeguarded and (re)developed in full accordance with social and economic qualities [1]. In general, there are five categories of threats to river health – overexploitation, water pollution, fragmentation, destruction or degradation of habitat, and invasion of non-native species [4]. They can be exacerbated by the modification of river flows and wetland inundation regimes. Land-use change, river impoundment, surface and groundwater abstraction and artificial inter-/intra-basin transfers profoundly alter natural flow regimes [5,6]. There are a variety of indicators can be used to assess health of river ecosystem. These include water quality; the structure, abundance and condition of aquatic flora and fauna; hydrology; levels of catchment disturbance; the physical form of the channel system; and native riparian vegetation communities. Importantly, no single variable can indicate ecosystem condition unequivocally and a suite of complementary variables is typically required to provide an accurate picture of river ecosystem health [7]. Therefore, assessment of river ecosystem health needs integration of measures of multiple, complementary attributes and analysis in a systematic way. The commonly used approaches for river ecosystem health assessment can be divided into top-down and bottom-up groups. The top-down approach provides a holistic basis for studying river ecosystems focusing on macro-level functional aspects without knowing all the details of internal structure and processes, but rather knowing the primary responses in system performance under stress [8]. The bottom-up approach emphasizes the structural aspects of natural systems and focuses on identifying ecosystem health on the basis of accumulated data on simple stressor-effect (i.e. causal) relationships [9]. Moreover, river ecological health can be assessed using top-down as well as bottom-up by combining indicators of system stress responses (i.e.,

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condition) with indicators identifying the causative stress (i.e., stressor) [1].

The “river invertebrates prediction and classification schemes (RIVPACS)” was released to assess the river health in Britain. Australia used a series of indicators (biologic integrity index IBI, including fish species richness in rivers, indicator species categories, nutrition type, etc) sensitive to changes of environmental conditions, in order to make a comprehensive assessment for the river health [10]. More “River Health Program” has been developed in other countries, such as South Africa [11,12]. In Sweden, the riparian, channel and environmental (RCE) inventory has been developed to assess the physical and biologic conditions of small streams in the lowland, agricultural landscape. It consists of 16 characteristics which define the structure of the riparian zone, stream channel morphology, and the biologic condition of habitats [13]. The Victorian River Health Strategy (2002) outlines the government’s long-term direction for the management of Victoria’s rivers. It provides a clear strategy for protection of native flora and fauna systems in the river and along its banks, maintenance of natural ecosystem processes and major natural habitat features, linkages between river and floodplain and associated wetlands, and sea or terminal lakes [14].

In China, maintenance of a healthy river has been proposed by both the Yellow River Conservancy Commission and the Yangtze Water Resources Commission. More and more researchers have undertaken this kind of research. The frameworks for assessing river health have been proposed, especially in the Yellow River, Yangtze River, Zhujiang River and Liao River [15–19]. However, as the largest tributary of the Yellow River, few studies on the ecosystem health of the Weihe River have been reported. An ecologically healthy Weihe River should have flow regimes, water quality and channel characteristics. These include that: 1) stable developments of streambed are maintained, 2) smooth channel for discharging water and sediment is maintained, 3) necessary amount of stream flow and appropriate proportion of water to sediment are reserved, 4) good water quality for supporting native fish and other fauna, and even societal use and ecosystem function abilities is guaranteed, 5) major natural habitat features are represented and are maintained over time, 6) linkages between river and floodplain and associated estuary are able to maintain ecological processes, especially the Tongguan Elevation needs to be controlled to a rational scale. The Tongguan Elevation is defined as the stage of a flood discharge at 1000 $m^3 \cdot s^{-1}$ at the Tongguan gauging station, which is essentially the datum plane of the bed profile of the Weihe River. The Tongguan Elevation can be used as a reference of channel deposition in the cross section of the Yellow River and the Weihe River. 7) native riparian vegetation communities exist sustainably for the majority of the river’s length [20]. But the current ecosystem functions of the Weihe River have been serious degraded [21].

This paper, therefore, aims: 1) to analyze the changes of ecological and environmental function caused by variation of stream flow, water quality, channel morphology and riparian vegetation; 2) to draw attention to the importance of river health as the context for local sustainable development; and 3) to provide more reasonable safeguard measures to improve the ecological and environmental functions of the Weihe River.

2 Methods

Considered the dominant factors affecting the ecosystem health such as flow regimes, water quality and channel characteristics, the methods for trend test of the hydrological series, assessment of water quality and correlation between stream gradient and cumulative yield of sediment deposition were introduced.

2.1 Hydrological analysis

2.1.1 Spearman rank correlation test

Spearman’s rank correlation provides a distribution free test of independence between two variables. It is, however, insensitive to some types of dependence. Kendall’s rank correlation gives a better measure of correlation and is also a better two-sided test for independence.

Spearman’s rank correlation coefficient (ρ) is calculated as:

$$\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}, \tag{1}$$

where x_i and y_i are the ranks of a pair of variables (x and y), each containing n observations [20].

Tied values are assigned equal to the average of their positions in the ascending order of the values. In applications where ties are known to be absent, a simpler procedure can be used to calculate ρ as [22,23]:

$$\rho = 1 - \frac{6\sum d_i}{n(n^2-1)}, \tag{2}$$

where differences between the ranks of each observation on the two variables, $d_i = x_i - y_i$.

The significance can be tested using the following formula:

$$t = \rho\sqrt{\frac{n-2}{1-r^2}}, \tag{3}$$

which is distributed approximately as student's t distribution with $n-2$ degrees of freedom under the null hypothesis. Usually, the greater the value of $|t|$ is, the more significant the trend will be. $t<0$ indicates an increasing trend and $t > 0$ indicates an decreasing trend.

2.1.2 Mann-Kendall non-parametric statistical test

Let $x_1, x_2, x_3, \ldots, x_n$ be a bivariate random sample of size n. a total number p is given such that

$$p = \text{number}\{x_i,\ x_j\}, \forall j > i, \tag{4}$$

The set $\{x_1, x_2, x_3, \ldots, x_n\}$ can be divided into a series of subset such as $A_1 = \{x_{i=1} x_{j=2,3,\ldots,n}\}$, $A_2 = \{x_{i=2} x_{j=3,4,\ldots,n}\}$, $A_3 = \{x_{i=3} x_{j=4,5,\ldots,n}\} \ldots A_{n-1} = \{x_{i=n-1} x_{j=n}\}$, Then, the p value and the monotonic trend of the set $\{x_1, x_2, x_3, \ldots, x_n\}$ can be determined such that

$$p = \begin{cases} 0.5 \times n \times (n-1) \\ 0 \end{cases}, \tag{5}$$

$x_i > x_j, \forall A_m,\ m = 1,2,\ldots,n-1$, increasing trend, $x_i < x_j$, $\forall A_m,\ m = 1,2,\ldots,n-1$, decreasing trend.

Otherwise, the desired value of p is estimated by the following formula

$$p = 0.25 \times n \times (n-1), \tag{6}$$

And a test statistic U can be defined as:

$$U = \frac{\tau}{\text{var}(\tau)^{0.5}}, \tag{7}$$

where

$$\tau = \frac{4p}{n(n-1)} - 1, \tag{8}$$

$$\text{var}(\tau) = \frac{2(2n+5)}{9n(n-1)}. \tag{9}$$

With an increase in n, the U converges to standard normal distribution. The null hypothesis is no trend, for a given significant level a, the threshold value of $U\alpha/2$ can be read in the standard normal distribution table. If $|U| < U\alpha/2$, the set conforms the null hypothesis, the trend is not significant, on the contrary, the $|U| > U\alpha/2$ indicates the set rejects the null hypothesis and has a significant trend [24–26].

2.2 Water quality assessment

The water quality is assessed by using equivalent standard pollution load method as:

$$P_j = \frac{1}{n}\sum_{i=1}^{n} P_i, \tag{10}$$

$$P_i = \frac{C_i}{C_s}, \tag{11}$$

where P_j is the comprehensive index of water pollution for cross-section j. P_i is the water pollution index of pollutant i. C_i is the annual mean concentration of pollutant i. C_s is the evaluation criteria value of pollutant i.

Moreover, the trend of water quality is determined by using mathematical statistical analysis method.

2.3 Calculation of stream gradient and cumulative yield of sediment deposition

The stream gradient is determined as:

$$J = \frac{E_1 - E_2}{L}, \tag{12}$$

where E_1 and E_2 are the water levels of the upper gauging station and the lower gauging station, respectively, and L is the length from the upper station to the lower one. The total cumulative yield of sediment deposition is estimated by adding up each measured value of deposited sediment during the study period.

3 Study area

The Weihe River, originating from north of the Niaoshu Mountain with an altitude of 3485 m above sea level, is the largest tributary of the Yellow River. It runs 818 km through the provinces of Gansu and Shaanxi and joins the Yellow River from the right bank in the city of Tongguan, from where the Yellow River turns to the east. The drainage area, annual runoff and annual sediment load of the Weihe River account for, respectively, 17.9%, 16.5% and 2.5% of the total amount of the Yellow River basin. The channel length in the confluence area is about 13.1 km [27].

The River flows about 502.4 km with a drainage area of 67100 km^2 in Shaanxi Province where the well-known Guanzhong Plain in North-west China is located. The river basin belongs to arid and semi-arid region, and the mean annual precipitation is $311.63 \times 10^8\ \text{m}^3 \cdot \text{a}^{-1}$, accounting for 22.4% of the total precipitation of Shaanxi Province [28]. The River has been called as the "Mother River" of the Guanzhong region, which plays a great role in the development of the West China and the ecosystem health of the Yellow River (Fig. 1). However, the ecological and environmental problems of the basin have been deteriorating due to human activities and natural changes. Since the 1980s, it has suffered from major problems, such as greatly decrease in the annual river runoff, geologic hazards caused by water projects, high concentration of sediment and severe flood, over-exploration of ground water, as well as heavy water pollution [29,30]. Since the late 1990s, the ecosystem functions in many parts of the river have degraded. These problems have restricted the sustainable social and economic development in the region [28].

4 Changes of ecological and environmental functions

The value of measuring ecosystem functions in regular monitoring programs is increasingly being recognized as a potent tool for assessing river health. An important consideration in river ecosystem health assessment is choosing the indicators that are most likely to response of ecosystem metabolism, organic matter decomposition and strength loss and invertebrate community composition across a gradient of catchment impairment defined by upstream land-use stress [31]. Another integrated assessment of river health is based on water quality, aquatic life and physical habitat [19].

4.1 Deficiency of environmental flow

The hydrological data of 1961–2009 from five gauging stations: Linjiacun, Weijiabao, Xianyang, Lintong and Huaxian (Fig. 1). The hydrological data sources for gauging stations of Linjiacun, Weijiabao and Lintong were measured by monitoring department of Shaanxi Provincial Department of Water Resource, and for the Xianyang and Huaxian gauging stations were measured by monitoring department of the Yellow River Conservancy Commission. Since the 1960s, the incoming stream flow shows an obviously decreasing trend. After the 1990s, the decreasing trend is still significant (Fig. 2). Compared to the 1960s, more than 50% of stream flow has reduced during past two decades (Table 1). The results of spearman rank correlation test show that the significance of the decreasing tendency of runoff slows down from the upper gauging station of Linjiacun to the lower gauging station of Huaxian (Table 2).

The amount- decreasing flow mainly results from the decrease in precipitation and water utilization by human activities. From Mann–Kendall test on monotonic trend for the precipitation time series during the period 1961–2009, the annual precipitation shows an overall decreasing trend (Table 3). In general, stream flow in the basin is mainly generated from precipitation. However, since 1980, the overall decreasing trend for the annual runoff is obviously greater than that of annual precipitation (Figs. 2 and 3, Table 4), which suggests that the decrease in precipitation after 1980 was not the main cause of the decrease in runoff.

Increasing water use for agricultural irrigation, industrial production and domestic life has been the main reason for the decrease in incoming stream flow. There is a long history of water exploitation from the Weihe River in Shaanxi, and eight well-known agricultural irrigation projects have been formed to supply water to irrigate more than 100000 ha of farmland in the Guanzhong region. Agricultural irrigation is the largest water consumer, accounting for 60% of the total amount of water consumption. The ratio of water use volume for domestic, industry and agriculture to the total volume of water resources in the Weihe River basin runs up to 47.9% [30]. Even in the low flow period, 80% of the river flow is impounded by dams for agriculture irrigation in Baoji district (Table 5). At the same time, with the industrial expansion and population growth, water use from the Weihe River to meet the industrial and domestic water requirements increases greatly. Moreover, a large number of groundwater pumping wells have been constructed in the watershed. Most of them are close to the river, which potentially induced the infiltration of river water into the

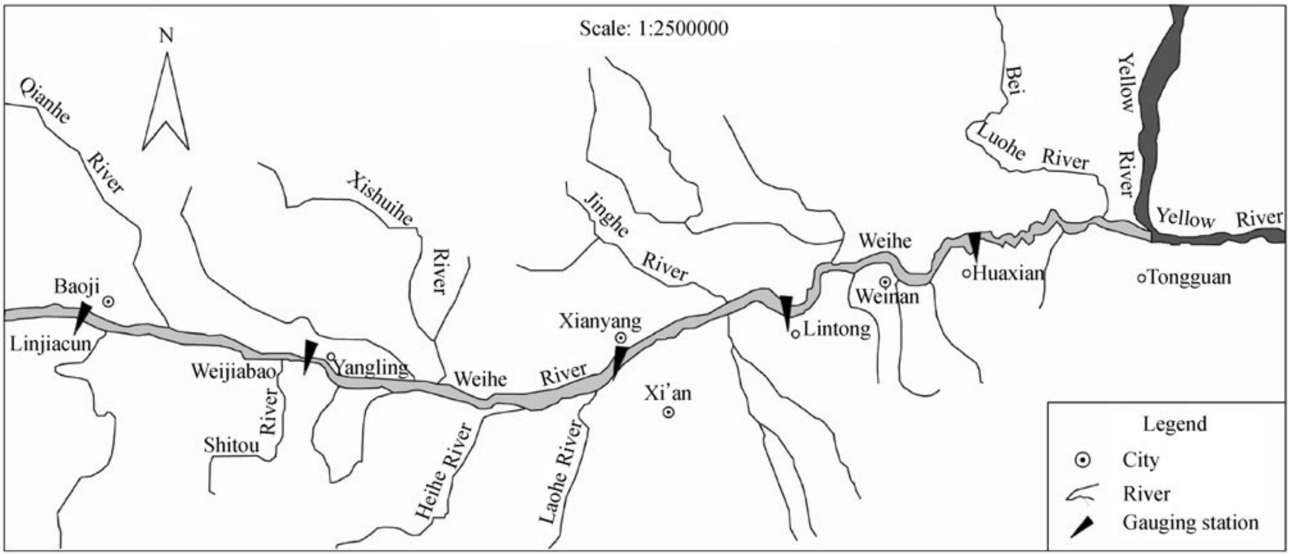
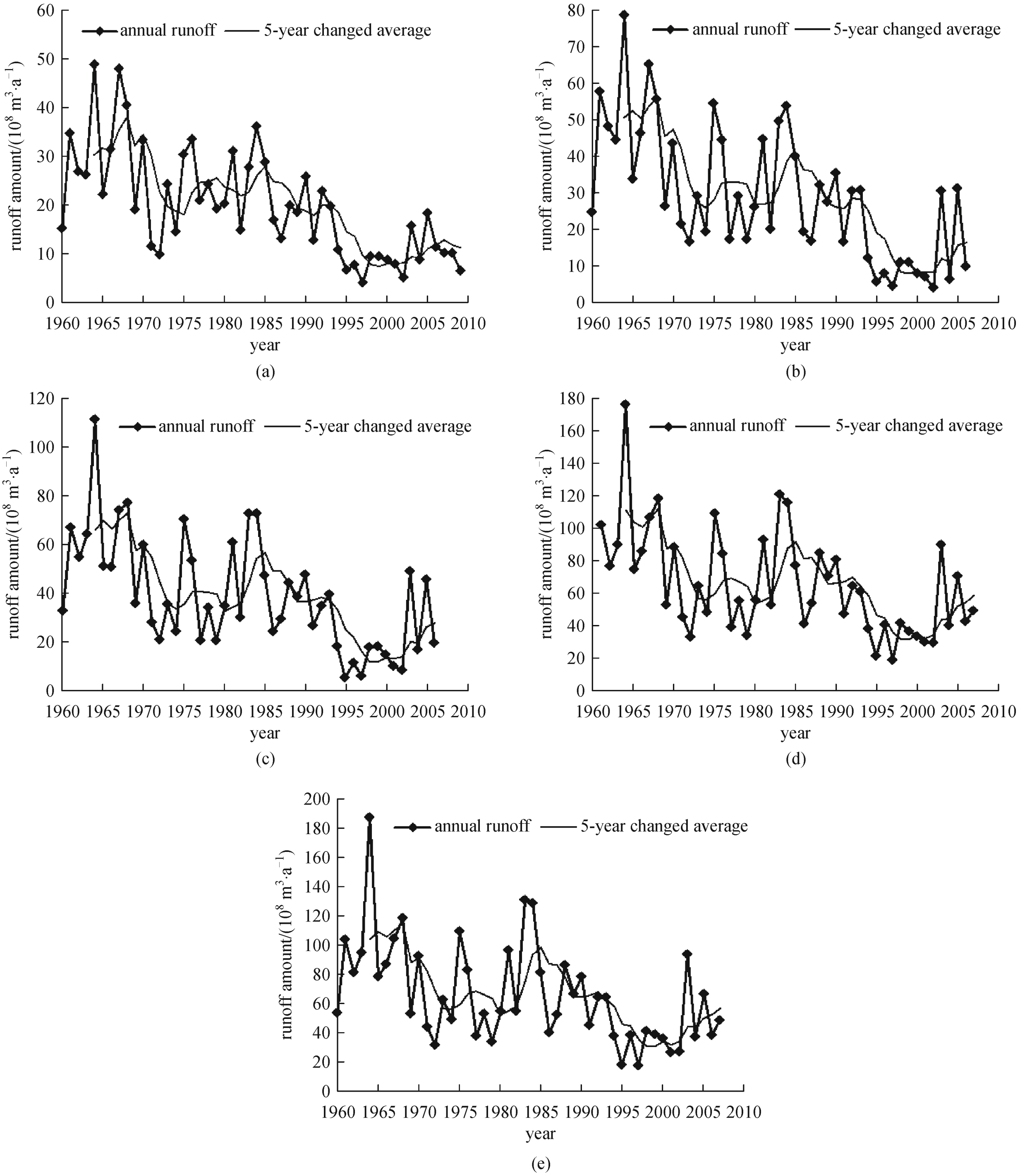


Fig. 1 Study area showing gauging station



(a) (b) (c) (d) (e)

Fig. 2 Tendency of runoff from the five gauging stations in the Weihe River: (a) Linjiacun; (b) Weijiabao; (c) Xianyang; (d) Lintong; (e) Huaxian

adjacent aquifers of the Weihe River. It was estimated that water pumping is 0.62 billion m^3 · a^{-1} [30]. It was suggested that the environment flow requirements in a normal-flow year with occurrence probability of 50% for the fiver gauging stations of Linjiacun, Weijiabao, Xianyang, Lintong and Huaxian are about 50.9, 117.6, 187.8, 274.6 and 285.5 m^3 · s^{-1}, respectively. However, the actual shortages of environmental flow for the five stations were estimated as 2.01, 17.65, 37.18, 41.91 and 42.52 m^3 · s^{-1}, respectively [30,32]. As a result, the water flow maintained in the stream for environmental use is very limited, and the major natural habitat features can not be maintained.

Both human activity and climate change induced a

Table 1 Percentage of annual runoff for each gauging station during different periods

gauging station	1960–1969	1970–1979		1980–1989		1990–1999		2000–2009	
	runoff /(10^8 m^3)	runoff /(10^8 m^3)	variation percentage/%	runoff /(10^8 m^3)	variation percentage/%	runoff /(10^8 m^3)	variation percentage/%	runoff /(10^8 m^3)	variation percentage/%
Linjiacun	31.24	22.13	–29.15	22.70	–27.33	12.90	–58.70	10.22	–67.29
Weijiabao	48.01	29.20	–39.19	32.93	–31.41	16.54	–65.56	13.77	–71.31
Xianyang	61.96	36.67	–40.82	45.46	–26.62	22.48	–63.72	23.38	–62.27
Lintong	98.05	60.06	–38.75	76.48	–22.00	44.69	–54.42	47.91	–51.13
Huaxian	96.20	59.41	–38.24	79.13	–17.74	44.08	–54.18	46.39	–51.78

Note: variation percentage is estimated by the monitoring value of runoff during each period to that of the period 1960–1969

Table 2 Trend test of annual runoff variation for each gauging station during the period 1961–2005

gauging station	t	ρ	threshold value	variation tendency
Linjiacun	5.98	0.67	2.01	decreased significantly
Weijiabao	5.46	0.64	2.01	decreased significantly
Xianyang	5.05	0.61	2.01	decreased significantly
Lintong	4.10	0.53	2.01	decreased significantly
Huaxian	3.93	0.51	2.01	decreased significantly

Table 3 Mann–Kendall test on monotonic trend for annual precipitation time series in the Weihe River basin

year	U	P	τ	var(τ)	trend
1961–2005	–1.75	404	–0.18	0.01	decreasing
2001–2005	1.47	8	0.60	0.17	increasing

Table 4 Variation periods for annual precipitation and annual runoff

factor	dry season	wet season	dry season	wet season	dry season
precipitation	1961–1970	1971–1979	1980–1988	1989–1996	1997–2005
runoff	1961–1971	1972–1979	1980–1991	1992–1997	1998–2005

Table 5 Comparison of impounding water by dams and the runoff in Baoji area

month	impounding water/(10^6 m^3)	runoff/(10^6 m^3)	ratio of impounding water to runoff
Jan	38.0	44.7	0.85
Feb	34.5	40.7	0.85
Mar	38.8	60.6	0.64
Apr	34.0	63.6	0.53
May	31.0	88.2	0.35
Jun	46.2	99.3	0.47
Jul	55.3	166.8	0.33
Aug	81.6	181.5	0.45
Sep	65.9	165.2	0.40
Oct	71.0	184.3	0.39
Nov	47.2	76.7	0.62
Dec	40.1	48.5	0.83

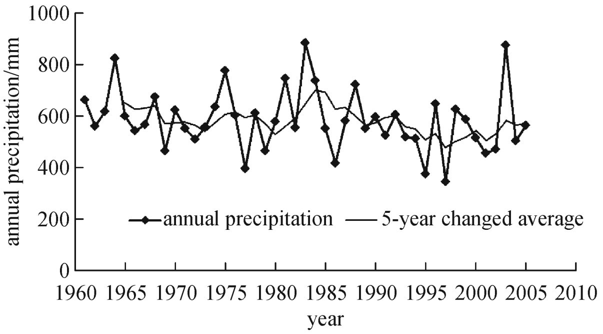


Fig. 3 Trend in annual precipitation in the Weihe River basin of Shaanxi Province

significant decreasing of stream flow. Climate change resulted in hydrological regime variation. Human activity from reservoir irrigation, pumping well seepage, and supply for industrial and domestic water use caused water losses in the river channel. Moreover, land-use and land-cover change induced by human activity resulted in decrease in the river runoff [33]. The degree of the influence of human activity and climate change vary across areas and over time. It was reported that about 55.9% of the decrease in the river flow is due to climate change for the reach above the Xianyang gauaging section, while that was about 56.2% for the reach above the Huaxian gauging section during the past decades [32].

4.2 Deterioration of water quality

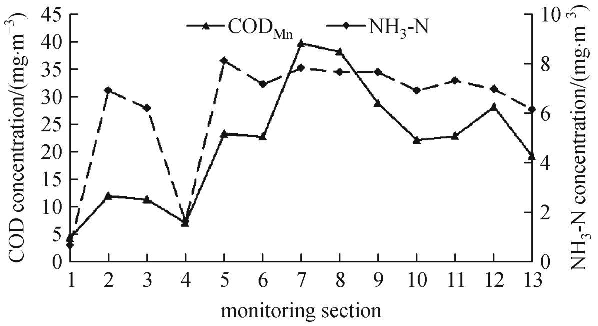


Fig. 4 Annual mean concentrations of COD and NH_3-N for each monitoring section from upstream to downstream. Numbers of horizontal axis expressing monitoring section are as follows: 1-Linjiacun, 2-Wolong temple bridge, 3-Guozhen Bridge, 4-Changxing Bridge, 5-Nanying, 6-Xianyang Iron bridge, 7-Tianjiangrendu, 8-Gengzhen Bridge, 9-Xinfeng Bridge, 9-Sha-wangdu, 10-Tree Park, 11-Tongguan Bridge

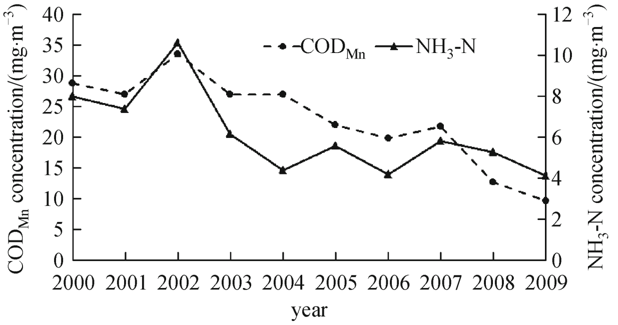


Fig. 5 Annual mean concentration of COD and NH_3-N during the period 2000–2009

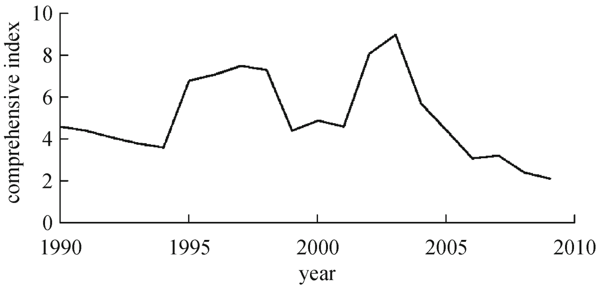


Fig. 6 Variation of comprehensive index of water pollution during the period 1990–2009

The major pollutant in the Weihe River is organic pollution including Chemical Oxygen Demand (COD) and NH_3-N. According to containment concentration data from the Bulletin of Environmental Quality in Shaanxi Province and other related literatures and publications [30,34], the water quality gets increasingly worse for downstream (Fig. 4). Though annual mean concentrations of pollutants show a decreasing trend from 2000 to 2009 (Fig. 5), the concentrations of typical pollutants like chemical oxygen demand (COD_{Cr}), permanganate index (COD_{Mn}), five-day biologic oxygen demand (BOD_5), petroleum hydrocarbon, ammonia-nitrogen (NH_3-N), are still greater than their top threshold values of environmental quality standard on the basis of the surface water functional regionalization of Shaanxi Province proposed in 2004. Since 1990, the annual comprehensive index of water pollution has largely fluctuated, and the water quality has greatly improved in recent several years. However, the index value is still higher than 2.0 (Fig. 6). As the water pollution is very serious, some ecological and environmental functions such as biologic survival, landscaping and agricultural irrigation are disabled. The water can not be directly used for human utilization as well, and even very few fish species can survive in the Weihe River. This intensifies water scarcity and makes it hard for the water supply to meet the growing requirements. The serious water pollution has therefore damaged river health and restricted the local economic and social development. The Weihe River is the major sewage discharge channel in the Guanzhong Region. Large amount of untreated industrial wastewater and domestic sewage is directly discharged into the Weihe River. Also, the non-point source of contaminated stormwater washingoff parking lots, roads and highways, and lawns (containing fertilizers and pesticides) drain into the river. According to the survey, a total number of 245 sewage discharge ports are distributed on both sides of the Weihe River. More than 700 million tons of sewage discharge into it yearly. The maximum volume of sewage discharge comes from Xi'an, which has most of sewage discharge ports (Table 6). The average distance between two neighboring ports for the whole reach in Shaanxi Province is 220 m. But for the sub-reaches of Baoji area, Xianyang area, Xi'an area and Weinan area, the average distances are quite different. The distance in Baoji reach is 2300 m, which is the largest one. For the reaches of Xianyang, Xi'an and Weinan, the distances are 220, 150 and 70 m, respectively. This distribution of sewerage discharge results from inadequate drainage facilities and low wastewater treatment rate.

Based on the statistical analysis of the pollution sources from data recorded in Shaanxi Environmental Protection Bulletin, the annual volume of NH_3-H discharged into the Weihe River is about 37100 t. Of which, 71.20% comes from losses of farm fertilizer. It suggests that the pollutant of NH_3-N mainly results from agriculture non-point source pollution [34]. In 2005, a total number of 3705400 t of fertilizer was used for agriculture, and the average application rate per hectare was 2.52 t. The utilization rate of nitrogen was 30%–50%; about 10% of the nitrogen was washed into the Weihe River. Therefore, effective measures for controlling non-point source pollution especially from farm fertilizer are urgent to be proposed and implemented.

4.3 Deformation of river channel

The most important topographic feature of the Weihe River basin is the Loess Plateau in the north, which is the main source of sediment in the Weihe River [35,36]. The Jinghe River, the Beiluo River and the Shichuan River from the Loess Plateau flow into the Weihe River with hyper-concentrated sediment (Fig. 1). The Weihe River basin has been one of the most serious soil loss areas in the Yellow River basin. The area that suffers from serious soil loss has reached 360000 km^2, about 65% of the total land area in the Weihe River basin. This has not only aggravated the deterioration of the ecosystem, but also resulted in severe sediment deposition in the lower reach of the Weihe River [27,29]. Furthermore, the declined precipitation and increased water diversion for agricultural irrigation, industrial and domestic uses in the upstream area have led to the decrease of water discharge into the lower reach of the Weihe River. For the reach above Huaxian, the average amount of runoff during the period 1950–1969 was $9.1\times10^9\ m^3\cdot a^{-1}$, while it was only $6.5\times10^9\ m^3\cdot a^{-1}$ for the period 1970–1995 [37]. The significant reduction of runoff from upstream has resulted in the shortage of stream flow for sediment transport in the lower Weihe River, leading to a significant increase in annually sediment concentration [30]. Based on the data for the sediment deposition and erosion from the listed measuring stations by monitoring department of the Yellow River Conservancy Commission during the period 1960–2001, the cumulative yield of sediment deposition was $1.30\times10^9\ m^3$ in 2001 with the maximum amount of 1.32 billion m^3 in 1997 (Fig. 7). Heavy channel deposition has caused a rising riverbed and a great increase in front-back difference. So far, the average front-back difference in the reach from Weinan to Huaying is 2–3 m, and the largest one reaches to 4 m. and the average difference in Xi'an reach is about 1 m. The Weihe River has become a second largest "hanging river" after the main stream in the Yellow River basin [32]. The main ecological functions for discharging water and sediment have been damaged.

Channel sediments consist largely of sand and gravel, and floodplain consists mainly of silty sand. Sediment particle becomes smaller with increasing the streambed depth. Sediment deposition affects channel morphology [38], as stream gradient declines with the increasing deposited sediment. The correlation coefficient (R^2) between stream gradient (J) and the accumulated volume of deposited sediment (D) in the reach from Xianyang to Huaxian during the period 1960–2001 is 0.68 (Fig. 8). Channel deposition can result in river bed aggradation. Channel width becomes narrow and stream gradient becomes gentle from Xianyang to the mouth of the lower Weihe River. This declining stream gradient has resulted from the rising of Tongguan Elevation (Fig. 1). It was reported that Tongguan Elevation has risen about 3.67 m during 1960–2001 [39]. Channel deposition accounted for the decline in river bed slope. The change in the Tongguan Elevation can reflect the change in erosion and deposition in the lower reach of the Weihe River [21]. Since the operation of the Sanmenxia Reservoir in 1960, the Tongguan Elevation has kept rising due to high-level sluice from the reservoir for a number of times. The

Table 6 Sewage discharge port distribution and discharged amount in 2007

sewage discharged characteristics	Baoji	Yangling	Xianyang	Xi'an	Weinan	total
sewage discharged amount/(10^8 m^3)	0.94	0.05	0.08	4.46	1.03	6.56
COD/(10^4 t)	1.99	2.52	2.90	9.35	2.52	19.28
NH_3-N/(10^4 t)	0.21	0.01	0.22	0.83	0.17	1.44
sewage discharge port	101	3	11	117	13	245

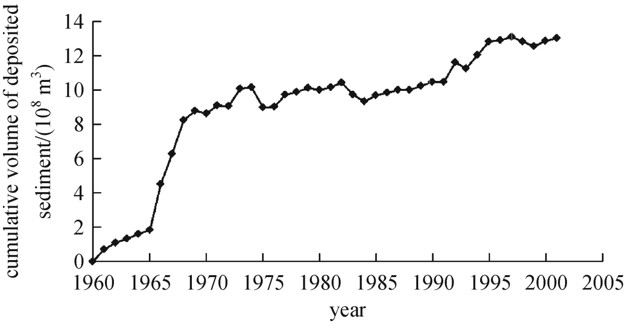


Fig. 7 Cumulative volume of deposited sediment in the channel of the lower Weihe River

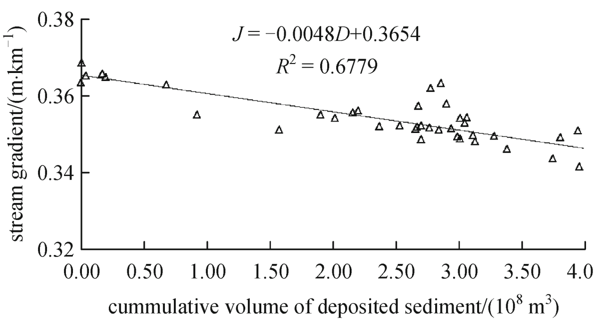


Fig. 8 Correlation between stream gradient and cumulative volume of deposited sediment for the reach from Xianyang to Huaxian during the period 1961–2001

continuous channel sedimentation occurred in the lower Weihe River, which has resulted in the shrinkage of riverbed and the decline of the capability for flood discharge [40]. The capacity of the levees to prevent flood in the lower Weihe River decreased from 50-year to 20-year frequency of flooding, and further decreased to 10-year flood frequency presently [27]. And the channel flood capacity has decreased to 1500 $m^3 \cdot s^{-1}$ by now from 4500 to 5000 $m^3 \cdot s^{-1}$ before 1960 [28]. Even a small flood can wash out the main channel and form floodplain. “S” shaped section increased and the top spot of flood wash constantly changed, which has resulted in the stream flow out of control of hydrological works and directly scoured river bank, and further induced arbitrarily swing of river channel [41]. The river regime has been greatly destroyed and its ecosystem functions have deteriorated. This caused a serious threat to the animal and plant in waterway and even those in catchment.

4.4 Loss of riparian vegetation

Riparian vegetation is extremely important because of the many functions it serves. The roots of riparian trees and shrubs help hold stream banks in place, preventing erosion. Riparian vegetation can traps sediment and pollutants, helping keep the water clean, provides habitat for aquatic insects that sometimes drop into the water for fish food source, shields streams and rivers from summer and winter temperature extremes that may be very stressful, or even fatal, to fish and other aquatic life, and provides food, nesting, and hiding places for wildlife habitat [42,43]. For the Weihe River, riparian vegetation is essential for maintaining high water quality, flood control and biodiversity. However, riparian vegetation remains relatively unprotected from poor agricultural practices, residential and commercial construction, landscaping, and logging. With social-economic development and population growth, most riparian land has been reclaimed. According to analysis of the land use change in Guanzhong region based on data from statistical yearbook of Shaanxi Province, the area of vegetation cover, water and cultivation decreased from 1980 to 2007, especially during the decade of 1990–2000, in which the land for water, vegetation and forest decreased largely. Almost one-third of the water land was lost. Meanwhile, the land for urban construction increased greatly since 1980 (Table 7). The increase of forest land resulted from the government’s grain-to-green policy. Moreover, the decrease of water flow in the Weihe River basin resulted in an increase of water exposed land from formerly water submerge land, and then those land were used for urban construction and other human activities. The native riparian vegetation communities have been destroyed. This unreasonable land-use has caused the loss of riparian vegetation and biodiversity and further resulted in damage of flood control and water purification functions. In recognition of this, the local government requires the preservation of riparian vegetation along streams, around wetlands, and in other sensitive areas in order to protect the water quality and habitat value of the Weihe River basin.

5 Conclusions

In this study, we focus on variations of stream flow, water quality, channel morphology and riparian vegetation and

Table 7 magnitude of changes with Land use in the Weihe River basin of Guanzhong region/%

period	forest/%	vegetation/%	water/%	urban construction/%	cultivation/%
1980–1990	0.93	6.62	0.24	7.76	−4.31
1990–2000	−0.44	−7.22	−29.53	9.55	4.56
2000–2005	1.10	0.31	1.29	1.74	−0.97
2005–2007	3.74	−1.55	−1.79	5.49	−1.69

their effects on ecosystem functions in the Weihe River. With the social-economic development and population growth, the ecosystem health of the Weihe River has been greatly affected by human activities, which poses constraint to the local sustainable development. The ecological and environmental functions of the Weihe River has greatly changed which mainly resulted from deficiency of environment flow, deterioration of water quality, deformation of channel and loss of riparian vegetation. A considerably large amount of water is used for agricultural irrigation, industrial production and domestic life. The water flow remained in the stream for environmental use is limited. Due to the poor water quality, very few aquatic organisms can survive in the river. The rising level of Tongguan Elevation resulted in the continuous channel sedimentation, which further induced the decrease in stream gradient, shrinkage of riverbed and decline in the capability for flood discharge. Most riparian land has been occupied by urban construction and other activities. This inappropriate land use has caused loss of riparian vegetation and biodiversity. The deterioration of ecological and environmental functions in the Weihe River basin has drawn a great attention to both the state and the local governments. More effective safeguard measures for improving the current situation should be developed and put into effect before more harm is done to the ecosystem health of the river.

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