A new framework to evaluate ecosystem health: a case study in the Wei River basin, China

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Abstract Due to the rapid growth of the population and the development of economies in the Guanzhong district, central China, the river ecosystem is gradually deteriorating, which makes it important to assess the aquatic ecosystem health and take measures to restore the damaged ecosystem. An index of catchment ecosystem health has been developed to assist large-scale management of watersheds by providing an integrated measure of ecosystem health, including aquatic and terrestrial ecosystem. Most researches focus on aquatic ecosystem or terrestrial ecosystem, but little research integrates both of them to assess the catchment ecosystem health. In this paper, we combine these two aspects into catchment ecosystem health. Ecosystem indicators derived from field samples and modeling are identified to integrate into ecosystem health. These included

indicators of ecological landscape pattern (based on normalized difference vegetation index (NDVI), vegetation cover, dominance index, Shannon's diversity index, Shannon's evenness index, and fragmentation index), hydrology regime (based on 33 hydrological parameters), physical form condition (based on substrate, habitat complexity, velocity/depth regimes, bank stability, channel alteration), water quality (based on electrical conductivity (Cond), dissolved oxygen (DO), $\text{NH}_3\text{-N}$, total nitrogen (TN), total phosphorus (TP), chemical oxygen demand–permanganate (COD_{Mn})), and biological quality (based on fish abundance). The index of ecosystem health is applied in the Guanzhong district, and the ecosystem health was fair. The ecosystem health in the upstream to Linjiacun (U-L) and Linjiacun to Weijiabao (L-W) reaches was in good situation, while that in Weijiabao to Xianyang (W-X), Xianyang-Weijiabao (X-W), and Weijiabao to Tongguan (W-T) reaches was in fair situation. There is a trend that the ecosystem health in the upstream was better than that in the downstream. The ecosystem health assessment is expected to play a key role in future water and watershed management of the Wei River basin, or even the Yellow River basin.

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Introduction

Damage to ecosystems caused by human activities means that the ecosystem health of rivers and streams

is a fundamental and increasingly important water management issue around the world, especially in Australia (Davies et al. 2010; Bunn et al. 2010), USA (Barbour et al. 1999), and Europe (Hering et al. 2010). There are two controversial concepts about ecosystem health recently. The first aspect (Ladson et al. 1999) focus on ecological integrity, and it is usually composed of a set of protocols dealing with different aspects of river quality, including water quality, hydrology, and indicators of biotic integrity based on fish, macroinvertebrate, algae, or macrophyte assemblages (Hering et al. 2006). For example, the objective of the federal Clean Water Act in the USA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. While many have argued that a healthy stream is an ecosystem that is sustainable and resilient, maintaining its ecological structure and function over time while continuing to meet societal needs and expectations (Meyer 1997; Norris and Thoms 1999; Davies et al. 2010). The second concept of river health is incorporating both ecological integrity (maintaining structure and function) and human values (what society values in the ecosystem) (Meyer 1997; Karr 1999). Although inclusion of the human dimension gives the concept of stream health part of its novelty and may provide some impetus for advances in river ecology (Meyer 1997), it is difficult to identify the important ecological assets and services such as clean drinking water or fisheries production, and the human effect on this aspect. Therefore, the first point, only considering ecological integrity is evaluated in this paper.

Ecosystem health in rivers or streams cannot be measured directly. Instead, it is determined through a holistic appraisal of streams and their surrounds, which can be named as aquatic ecosystem, including hydrology, water quality, physical form, riparian zone, and aquatic life (e.g., fish and macroinvertebrate assemblages). Fish assemblages have been regarded as an effective biological indicator of environmental quality and anthropogenic stress in aquatic ecosystems since they are relatively easy to identify and their position at the top of the food chain helps to provide an integrative view of the watershed environment (Karr 1981; Simon and Lyons 1995). Then, fish are considered as the indicators of biological integrity. However, terrestrial ecosystem, as an important part of catchment ecosystem, is separated from ecosystem health in rivers (Hemstrom et al. 2001). The riparian zone has an important effect on water quality (Daniels and Gilliam 1996) or aquatic life

such as fish and macroinvertebrate (Pinto et al. 2006). Therefore, it is often considered as an important component in aquatic ecosystem health. Terrestrial ecosystem, such as land use and land cover changes, encompasses some of the most important human alterations affecting the surface of the earth. Land use impact on runoff generation of a river basin is presented in several researches (Niehoff et al. 2002; Hundedcha and Bárdossy 2004). Landscape health has a high relationship with hydrology. Little research integrates aquatic with terrestrial ecosystem to assess the catchment ecosystem health. In this paper, we combine these two aspects into catchment ecosystem health.

The Wei River is the biggest tributary of the Yellow River, and Guanzhong district is the fastest growing and developed economy region in this basin with several big cities widely distributed, such as Baoji, Xianyang, Xi'an, and Weinan. Human activity has left a significant ecological footprint with agricultural area as the main land use, increasing urban area and serious landscape fragmentation in this region (Zhan et al. 2011). Thirty-two water diversion projects were build up along the Wei River in Guanzhong Region, and the water yield is $6.17 \times 10^8 \text{ m}^3 \text{ a}^{-1}$ (Song et al. 2007). The Wei River in Guanzhong Region is heavily polluted, especially with organic pollutant, such as chemical oxygen demand (COD), total nitrogen (TN), and ammonia nitrogen ($\text{NH}_3\text{-N}$) (Lu et al. 2010; Li et al. 2011; Zhang et al. 2007). The hydrological regime has been substantially altered, not only from interception by dams and weirs but also because of changes in land use and vegetation that have resulted in altered runoff responses to rainfall events and flashing stream flows (Wu et al. 2012a, b). The economic development of Guanzhong district has been limited because of the degraded ecosystem. It is urgent and important to identify the ecosystem health in this area. Previous studies on ecosystem health assessment in this region have only focused on single perspective assessment, such as water quality methods (Li et al. 2011; Wu et al. 2013), hydrological regime alteration (Wu et al. 2012a, b), ecological landscape pattern (Zhan et al. 2011), and biological integrity of periphyton communities (Yin et al. 2013). There is an urgent need for more comprehensive and holistic assessment of ecosystem health. In this paper, we describe the conceptual framework of assessment of ecosystem health and future development and try to report the ecosystem health of the Guanzhong district by comprising of ecological landscape pattern, hydrology regime, physical form

condition, water quality, and biological quality. This work will be a great reference for catchment managers to identify the primary component for catchment restoration.

Methods

Study area

The Wei River originates from Niaoshu Mountain and flows through Gansu, Ningxia, and Shaanxi province with a watershed area of 134,800 km². The Wei River is the largest tributary of the Yellow River, where the annual flow flux and annual sediment discharge account for 16.5 and 2.5 % of the total amount of the Yellow River basin (Song et al. 2010). The majority of rainfall occurs in the summer months from July to October, which accounts for 60 % of annual precipitation. The flow regime of this river is in a high inter-annual variation and seasonal variation: Maximum annual runoff (with annual runoff of 21.8 billion m³ in 1964) was more than five times the minimum one (with annual runoff of 4.3 billion m³ in 1995), and the runoff from July to October accounted for 60 % of annual runoff. Length of the main stem is 818 km, which flows into the Shaanxi province at Fenggeling and runs into the Yellow River at Tongguan with a length of 502.4 km,

known as Guanzhong Plain. It has a semi-arid climate with an annual mean precipitation of 648.3 mm, and an annual average atmospheric temperature of 13.6 °C (Zheng et al. 2002). The Guanzhong district is divided into five reaches, including the reach from upstream to Linjiacun (denoted as U-L), reach from Linjiacun to Weijiabao (denoted as L-W), reach from Weijiabao to Xianyang (denoted as W-X), reach from Xianyang to Lintong (denoted as X-L), and reach from Lintong to Tongguan (denoted as L-T). Five sites, i.e., Linjiacun, Weijiabao, Xianyang, Lintong, and Huaxian, are selected at stream gauging stations so that a record of hydrology regime is available for each sites. In addition, another ten sites were sampled in this district, including physical form condition, water quality, and fish. The location of these sites for each reach can be seen in Fig. 1 and Table 1.

Conceptual framework

Ecosystem health can be determined through a holistic appraisal of streams and their surrounds (Ladson et al. 1999). Catchment ecosystems are divided into two components: terrestrial ecosystem and aquatic ecosystem. Terrestrial ecosystem is evaluated by changes of vegetation cover and ecological landscape pattern, which reflect broad-scale geophysical patterns, more or less modified by human disturbance. Therefore, the

Fig. 1 Location of hydrological stations and sample sites in the Guanzhong district

Table 1 Hydrological stations and sample sites distribution in the five reaches

Reach	U-L	L-W	W-X	X-L	L-T
Hydrological station	Linjiacun	Weijiabao	Xianyang	Lintong	Huanxian
Sample sites	W11, W36	W37, W15	W38, W39, W18	W21	W23, W40

parameters are calculated on the reach scale. The first one is quantified by changes of vegetation cover, using normalized difference vegetation index (NDVI) and vegetation cover as parameters. The second one is ecological landscape pattern, which is measured by the heterogeneity and complexity of landscape types, including dominance index, Shannon's diversity index, Shannon's evenness index, and fragmentation index. Aquatic ecosystem, emphasized in this paper, contains biotic components, including indicator based on fish assemblages, and abiotic components, such as hydrology, water quality, and physical form condition. Hydrology and physical form condition provide information of physical integrity, while water quality is a reflection of chemical integrity. Compared with vegetation and landscape pattern, these four components are identified on the site scale. The list of parameters belonging to five components are shown in Table 2. The index of ecosystem health (IEH) incorporates sets of parameters that are sensitive to human disturbance, and it can represent the holistic ecological situation over a range of spatial and temporal scales. The current values of these parameters, derived from field sampling and historical data, are

compared with that in the expected natural condition, i.e., reference condition. Reference condition or best attainable condition indicates the natural condition without human disturbance or with least disturbance. The choice of an appropriate reference condition is a major problem in ecological assessments (Hughes 1995). The methods used to identify reference condition vary among these components, depending on the availability of data from sites with historical data, expert knowledge, previous research, and modeling (Table 2).

Indicators and methods for data collection

Vegetation and landscape pattern

Terrestrial ecosystem in this paper is only focused on two groups, i.e., ecological landscape pattern and changes of vegetation cover. Ecological landscape pattern is integrated by four parameters, i.e., dominance index (D), Shannon's diversity index (H), Shannon's evenness index (E), and fragmentation index (F). The calculated method see from study of Zhan et al. (2011). Ecological landscape type in Guanzhong district is categorized as

Table 2 The index of ecosystem health includes five components each consisting of various parameters

Components	Parameters	Assessment method	Reference condition method
Vegetation and landscape pattern	6 parameters, describing 2 key components of terrestrial system (changes of vegetation cover and ecological landscape heterogeneity)	GIS and FRAGSTATS (Qiao et al. 2011; Zhan et al. 2011)	1990's vegetation cover (Qiao et al. 2011)
Hydrology	33 parameters, describing 5 key components of the flow regime (magnitude, frequency, duration, timing, and rate of change)	Indicators of Hydrologic Alteration (IHA) (Richter et al. 1996; Wu et al. 2012a)	Before hydrologic impacts, determined using change point analysis of long term flow record (Wu et al. 2012a)
Physical form condition	Substrate; habitat complexity; velocity/depth regimes; bank stability; channel alteration	Visual observation	Based on expert assessment. See Table 3
Water quality	Cond, DO, NH ₃ _N, TN, TP, COD _{Mn}	Comprehensive water quality identification index (Xu 2005a, b)	Based on water quality guidelines (2nd class). See Table 4
Biological quality	Fish (species abundance, biomass and diversity)	Modified index of Well-Being (Barbour et al. 1999)	Based on application in the USA, see report from EPA (1987)

paddy field, dry land, forest, grassland, water, urban, and bareland, and these parameters are only calculated in landscape scale. Changes of vegetation cover is identified by NDVI and vegetation cover, and the calculated method is the same as research from Qiao et al. (2011). According to former research about dynamic changes of vegetation in Guanzhong district of Wei River in recent 30 years (Qiao et al. 2011), vegetation type and coverage are best in 1990, which is as reference condition. Data for extracting NDVI are from Landsat satellite MSS/TM/ETM imagery in 1990 and 2007, and land use data with resolution of 1:50,000 is obtained in the Chinese Academy of Sciences.

The alteration factor (AF) is used as a measure to quantify the deviation of the current condition from the reference condition, which is expressed as follows:

$$AF = \frac{|E-O|}{E} \quad (1)$$

Expected value (E) is calculated from reference condition, while observed value (O) is calculated from the current state. And, greater value means bigger alteration for each parameter. AF was averaged within each group, and the final alteration factor for vegetation and landscape pattern was the worst rank of the two groups. We designate that AF bigger than 0.8 as 0 (very poor), and lower than 0.2 as 100 (excellent). AF between these threshold is scored by continuous scale method.

Hydrology regime

Daily streamflow data from 1958 to 2008 in five stations are used to identify the alteration degree of hydrological regime. It is identified by Indicators of Hydrologic Alteration (IHA), which is widely used to evaluate the alteration degree of hydrologic regime for regulated rivers since it is developed by Richter et al. (1996). It quantifies the alteration degree of hydrology regime on the basis of the 33 IHA parameters, organized into five groups, including the magnitude, timing, frequency, duration, and rate of changes. The description of IHA parameters were shown from the study of Wu et al. (2012a, b). It uses the pre-impact natural variation of IHA parameter values as a reference condition for defining the extent to which natural flow regimes have been altered. The reference condition, i.e., pre-impact period, is defined by change point analysis, and the details of hydrological alteration factors could see from

Wu et al. (2012a, b). The hydrologic alteration factors were averaged within each group, and the overall hydrologic alteration factor was the worst rank of the five groups. We designate alteration factor bigger than 0.8 as 0 (very poor), and lower than 0.2 as 100 (excellent). Alteration factor between these threshold is scored by continuous scale method.

Physical form condition

Physical form condition of each sample site was assessed based on visual observation, including ten sites (W11, W36, W37, W15, W38, W39, W18, W21, W23, W40) in October 2012. Given the ecosystem situation of the Wei River, physical form parameters, i.e., substrate, habitat complexity, velocity/depth regimes, bank stability, and channel alteration in this study, were modified based on that given by Ohio's EPA (Barbour et al. 1999; Zheng et al. 2007). They were rated as 0–20 from four classes of “optimal,” “suboptimal,” “marginal,” and “poor” conditions (Table 3). The physical form condition was got by the sum of five parameters, and the value is high with better physical form condition. The average of sites in every reach was the final scores. We designate sub-index bigger than 80 as 100 (excellent), and lower than 10 as 0 (very poor). The sub-index between these threshold is scored by continuous scale method.

Water quality

Water quality variables of ten sites (W11, W36, W37, W15, W38, W39, W18, W21, W23, W40) were collected two times: once in October 2012 and once in April 2013. Some water quality variables, including dissolved oxygen (DO) and electrical conductivity (Cond), were measured by YSI ProPlus 85 in the field. Other water quality variables, including permanganate index (COD_{Mn}), ammonia nitrogen ($\text{NH}_3\text{-N}$), total nitrogen (TN), and total phosphorus (TP), were tested in the laboratory according to environmental quality standards for surface water (GB 3838–2002).

Referring to water quality researches in Guanzhong District (Lu et al. 2010; Li et al. 2011; Zhang et al. 2007), DO, $\text{NH}_3\text{-N}$, TN, TP, and COD_{Mn} are selected as the indicators of water quality. The water quality variables were scored by single-factor water quality identification index (SWQI) based on environmental quality standards for surface water (GB 3838–2002) (Table 4) and then averaged to get the comprehensive water quality

Table 3 Physical form parameters utilized in the collection of physical form condition

Parameters	Condition category			
	Optimal	Suboptimal	Marginal	Poor
Substrate	Greater than 75 % of substrate is gravel, cobble, and boulder particles	50–75 % of substrate is gravel, cobble, and boulder particles	25–50 % of substrate is gravel, cobble, and boulder particles	Less than 25 % of substrate is gravel, cobble, and boulder particles
Habitat complexity	Mixture of microhabitat (i.e., aquatic vegetation, litter layer, fallen log, down concave bank, and boulder)	Mixture of microhabitat (i.e., aquatic vegetation, litter layer, and down concave bank)	Only 1 or 2 microhabitats	Only one microhabitat, all mud or clay or sand bottom
Velocity/depth regimes	All 4 velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (slow is <0.3 m/s, deep is >0.5 m)	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes)	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low)	Dominated by 1 velocity/depth regime (usually slow-deep)
Bank stability	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5 % of bank affected	Moderately stable; infrequent, small areas of erosion mostly healed over. 5–30 % of bank in reach has areas of erosion	Moderately unstable; 30–60 % of bank in reach has areas of erosion; high erosion potential during floods	Unstable; many eroded areas; obvious bank sloughing; 60–100 % of bank has erosional scars
Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 year) may be present, but recent channelization is not present	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80 % of stream reach channelized and disrupted	Banks shored with gabion or cement; over 80 % of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely
	20,19,18,17,16	15,14,13,12,11	10,9,8,7,6	5,4,3,2,1

Table 4 Scoring criteria of water quality variables in five classes

Primary environmental variables	1	2	3	4	5
DO	7.5	6	5	3	2
NH ₃ _N	0.15	0.5	1.0	1.5	2.0
TN	0.2	0.5	1.0	1.5	2.0
TP	0.02	0.1	0.2	0.3	0.4
COD _{Mn}	2	4	6	10	15

Variable abbreviations are used in the following tables and figures. Scoring criteria of DO, NH₃_N, TN, TP, and COD_{Mn} referred to environmental quality standards for surface water (GB 3838–2002)

identification index (CWQI) (Xu 2005a, b) for each site. The lower CWQI displays better water quality, whereas larger than 7 means very poor water quality (rated as 100), and lower than 3 means excellent water quality (rated as 0). CWQI between these threshold is scored by continuous scale method as the sub-index. The sub-index for every reach are calculated by average of sites in this reach, and then averaged in two seasons (Table 5).

Biological quality using fish as indicator

Ten sites (W11, W36, W37, W15, W38, W39, W18, W21, W23, W40) in the Guanzhong district were sampled two times: once in October 2012 and once in April 2013. Fishes were collected in three habitats (i.e., pools, riffles, and runs) within 200- to 300-m reach of all sites, and individuals in three habitats were combined to represent each site. For the unwadeable sites such as W38, W39, W18, W21, W23, and W40, seines (mesh size of 30 and 40 mm) were used for fish sampling by boat for at least 1 h, and backpack electrofishing was employed to insure the representative of fish at the site. For the wadeable sites such as W11, W36, W37, and W15, backpack electrofishing was employed for at least

30 min. The fish collection was performed by a two-person fish collection team, i.e., one individual used the backpack electrofisher with two handheld electrodes and one was responsible for netting fish with dip nets (Barbour et al. 1999). All the individuals (longer than 20 mm of total length) collected were identified to species, counted, and recorded on field data sheets. Moreover, individuals shorter than 20 mm of total length should be released. Specimens that cannot be identified in the field were preserved in a 10 % formalin solution and stored in labeled jars for subsequent laboratory identification. The fish were identified according to Fishes in Qinling mountain area (Chen et al. 1987).

The biological quality is assessed by Modified Index of Well-Being (MIWB), which were modified by Gammon(1976) based on the Index of Well-Being (IWB). It integrates species richness with diversity (fish abundance and biomass) except for tolerant species, hybrid species, and invasive species. This modification increases the sensitivity of the index to a wider array of environmental disturbances. The high MIWB indicates high fish abundance and biomass distributed across most species, whereas low index means low fish abundance and biomass belonging to one or two species. According to the application in USA (Ohio 1987), it is expected to be 8.9 in excellent condition for wadeable rivers, while 9.1 was the expected value for unwadeable rivers. MIWB bigger than this threshold is rated as 100 (excellent). Values between 0 and this threshold is scored by continuous scale method. The sub-index for every reach are calculated by average of sites in this reach and then averaged in two seasons.

Integration and reporting of ecosystem health

Before integration, each of the components is first standardized (0–100), where 100 means the best quality. Continuous scaling method is employed, which needs

Table 5 Details of scoring method for each sub-index

Sub-index	Range	Upper threshold	Lower threshold
Vegetation and landscape pattern	0–1	0.8	0.1
Hydrology regime	0–1	0.8	0.1
Physical form condition	0–100	80	20
Water quality	>=1	7	3
Biological quality	>0	8.9 (for wadeable sites) 9.1 (for unwadeable sites)	0

to set upper and lower threshold. Values between thresholds are scored on a continuous scale (Table 5). Upper and lower threshold of vegetation and landscape pattern, hydrology, physical form condition and water quality were depended on expert knowledge, and that of biological quality see from Ohio (1987).

For sub-index in that high value means better condition, i.e., physical form condition and biological quality,

$$\text{Sub-index} = (\text{Observed} - \text{Lower threshold}) / (\text{Upper threshold} - \text{Lower threshold}) * 100 \quad (2)$$

For sub-index in that low value means better condition, i.e., vegetation and landscape pattern, hydrology regime, and water quality,

$$\text{Sub-index} = (\text{Upper threshold} - \text{Observed value}) / (\text{Upper threshold} - \text{Lower threshold}) * 100 \quad (3)$$

Five sub-indices are then averaged to determine an index of ecosystem health. Assessment of catchment ecosystem health is presented as scores and conditions (Table 6).

Results

The vegetation and landscape pattern showed better condition comparison with other components, with good condition in W-X reach and excellent condition in the other four reaches. Reference condition for hydrology regime was the period from 1958 to 1985, with little changes of flow regime. Reach of U-L, X-L, and L-T displayed poor condition of hydrologic regime. The other two reaches displayed fair condition. The physical form of U-L and L-W was in good condition. The other three reaches were in poor condition.

Table 6 Final scores and condition to assessment of ecosystem health

Score range	Condition	Difference from reference condition
80<IEH<=100	Excellent	Nearly no alteration
60<IEH<=80	Good	Little alteration
40<IEH<=60	Fair	Moderate alteration
20<IEH<=40	Poor	high alteration
0<IEH<=20	Very poor	Severe alteration

IEH-index of ecosystem health

The water quality in wet season was better than that in dry season. In this period, water quality in L-W and W-X reaches displayed good condition, whereas that in the U-L was in fair condition. Water quality in X-L and L-T reaches are in poor and very poor condition, respectively. The water quality in dry season was much worse, U-L reach was in fair condition, and the other four reaches were in very poor condition. TN and TP were the main pollution variables in Guanzhong district not only in dry season but also in wet season (Fig. 2). There was a tendency for deteriorating water quality downstream with higher TN, TP, COD_{Mn}, and DO which was obvious in wet season than in the dry season. DO in the W21, W23, and W40 was lowest with wider and deeper river. In the dry season, SWQI of TN at site W15 was up to 42.69. Every water quality variable showed worse situation in the dry season.

The MIWB in wet season was higher than that in dry season (Table 7 and Fig. 3), which meant that the biological condition in wet season was better. The L-W reach was in excellent condition in wet season, while the X-L reach was in fair condition, and the other three reaches were in good condition. In the dry season, the U-L and L-W reaches were in good condition, and the other three reaches were in poor condition (Table 8). According to the index of ecosystem health, in the Guanzhong district, reaches of U-L and L-W were in low alteration, while the other three reaches were in moderate alteration (Fig. 4).

Discussion

Catchment ecosystem is a complicated system with their living and non-living constituents, which determine the complex of assessing the health. A lot of studies only focused on stream health, like hydrology regime (Wu et al. 2012a, b), water quality (Li et al. 2011; Wu et al. 2013), fish assemblages (Wu et al. 2014), or terrestrial system, like land use structure (Zhan et al. 2011). In this paper, we try to combine this into an index of ecosystem health, and results show that different responses are shown for different indicator. Several reasons lead to this phenomenon, which are the main components in the following sub-section.

Ecological landscape pattern

Numerous metrics can be calculated to monitor landscape condition in terms of land use pattern and structure, but many of them are closely related (Riitters et al.

Fig. 2 SWQI of six water quality variables in the wet season (a) and dry season (b). Dashed line represents the threshold of V class, SWQI larger than 6 means water quality worse than V class. Solid line is the threshold of reference condition with SWQI=3

Table 7 Index of water quality and biological quality in different seasons

Reach	Water quality		Biological quality	
	Dry season	Wet season	Dry season	Wet season
U-L	46.88	59.23	60.30	66.60
L-W	0	61.11	62.88	81.56
W-X	18.19	64.61	47.44	70.13
X-L	0	30.74	22.68	58.51
L-T	6.50	15.45	41.72	68.38

U-L, L-W, W-X, X-L, and L-T means the reach from upstream to Linjiacun, from Linjiacun to Weijiabao, from Weijiabao to Xianyang, from Xianyang to Lintong, and from Lintong to Tongguan

1995). The landscape metrics are sensitive to scale (Li et al. 2001), and we want to analyze landscape condition in the whole basin, and then metrics at the landscape level were calculated in this paper. According to research from Zhan et al. (2011), seven metrics (fractal fragmentation, fractal dimension, isolation, dominance index, Shannon's diversity index, Shannon's evenness index, and fragmentation index) were calculated, and the four metrics (dominance index, Shannon's diversity index, Shannon's evenness index, and fragmentation index) in the landscape were remained in this paper. The NDVI and vegetation cover have already been successfully applied to research on temporal and spatial trends and variation in vegetation distribution, productivity, and dynamics, to monitor habitat degradation and fragmentation, and the ecological effects of climatic disasters such as drought or fire (Pettorelli et al. 2005).

Fig. 3 MIWB in the wet season and dry season

According to the wide research, these two metrics were used to assess ecological responses to environmental change. No alteration of vegetation and landscape pattern was shown in U-L reach locating in the Qinling mountains with little human disturbance.

Hydrology regime

IHA was integrated with magnitude of monthly flow and characteristics of timing, duration, frequency, and rate of change, which was considered as an effective method to evaluate impact of dam construction or other hydraulic facilities on hydrology regime (Houston and Black 2013) or environmental flow setting (Mathews and

Richter 2007). Flow regime was of central importance in sustaining the ecological integrity of flowing water systems (Poff et al. 1997); then, evaluation of hydrology regime was an important part of ecosystem health assessment. The hydrology regime of U-L was in high alteration because of the operation of Baojixia diversion project. This was similar with research from Zhang et al. (2010), which concluded the huge impact of Baojixia diversion project on hydrology regime and ecosystem, especially for the high frequency of low flow. Among the hydrology parameters, annual multiday minimum flows and monthly mean flows in the dry season altered moderately or highly, indicating that the low-flow regime was easily influenced by the flow diversion (Shiau

Fig. 4 Five sub-indices in every reach

Table 8 Index of ecosystem health in the five reaches

Reach	Ecosystem landscape pattern	Hydrology	Physical form	Water quality	Biological quality	Ecosystem health
U-L	100	20.7	75	53.05	63.45	62.44
L-W	90.48	42.27	69.16	30.55	72.22	60.94
W-X	76.68	40.99	28.88	41.40	58.79	49.35
X-L	91.58	23.76	40	15.37	40.60	42.26
L-T	99.23	29.40	24.16	10.98	55.05	43.76

U-L, *L-W*, *W-X*, *X-L*, and *L-T* means the reach from upstream to Linjiacun, from Linjiacun to Weijiabao, from Weijiabao to Xianyang, from Xianyang to Lintong, and from Lintong to Tongguan

and Wu 2004). Baoji Xia diversion project had significant impacts on hydrology regime, but these effects generally attenuate with distance downstream toward Tongguan except for X-L reach, which was in accordance with the results from Richter et al. (1998). Urbanization had a number of important effects on hydrology (Bobbi et al. 2013). The X-L reach altered highly because of the high demand of industrial and domestic water from Xianyang and Xi'an. Xi'an and Xianyang were the capital and third city of Shaanxi province with high population density and developed industrial production; the high demand of water for urban and industrial uses influenced the hydrology regime in this reach.

Physical form condition

Physical form condition was used to characterize the condition of stream drainage units in terms of both changes in form condition (habitat complexity, velocity/depth regimes, bank stability, and channel alteration) and in substrate dynamics to indicate changes in geomorphic condition. These five parameters were similar with previous researches (Ladson et al. 1999; Davies et al. 2010) (Fig. 4). These parameters were hard to be identified quantitatively, and then they were visually assessed by the same person to reduce the subjective error. The U-L was in extremely low alteration because this was in the mountain with little human disturbance, and the alteration was worse downstream.

Water quality

The water quality of five reaches were in high and extremely high alteration with higher TN and TP and lower DO. There is a trend of worse water quality downstream of the main stem. It was common that lower DO and higher TN and TP were measured in five

reaches, which were located downstream of the main stem in the Wei River. From Fenggeling to confluence of the Wei River and Yellow River, big cities with large population density, such as Baoji, Xianyang, Xi'an, Weinan, were distributed from the upstream to the downstream, which caused great nutrient and organic pollution, such as industrial wastewater effluents and domestic disposal plant effluents, which brought much stressors to environment (Hawkins et al. 2010). A similar result was found in the Taizi River (Wan et al. 2012). In addition, nearly half of land use was agricultural area in the Guanzhong district (Zhan et al. 2011), which means that a lot of nitrogen fertilizer for crops was the main reason for high pollution of TN. Water quality of five reaches in the dry season was worse than that in the wet season, especially for Cond, TN, TP, and COD_{Mn}, which indicated that point source pollution from industrial and domestic wastewater was the main contribution to the water pollution. Li et al. (2011) got similar results in Xianyang and Lintong station by partitioning the point source pollution and non-point source pollution in the dry season and wet season of 2009, dry year. But, this result only displays the water quality pollution in 2013 and cannot explain the whole water quality situation in Guanzhong district. For example, water quality analysis in the dry season and wet season of 2012 (Wu et al. 2013) showed that the water quality in the wet season was worse than that in the dry season, which indicated that non-point pollution was the main contribution to the water quality. That was because different years were assessed, and hydrological year, including October in 2012, wet season, and April in 2013, dry season, was assessed in this paper, whereas calendar year, April and October in 2012, was in the research from Wu et al. (2013). According to the field work, discharge in the river was decreasing in these three times, which may lead to the worse pollution.

Biological quality

The MIWB was applied in many ecoregions of the USA, which was identified to be a useful tool for assessing fish assemblages in large rivers (Yoder and Rankin 1995). In larger (e.g., non-wadeable) rivers, sizes of fish may vary in orders of magnitude. It was necessary to establish different criteria for wadeable and non-wadeable rivers, which will be more accurate to reflect the fish integrity. Using the application in several ecoregions of the USA (Ohio 1987) for reference, 8.9 and 9.1 were identified to be excellent conditions for wadeable and unwadeable rivers. Besides, index of biotic integrity (IBI) was considered to be an effective tool with a wide application in the world (Karr et al. 1986; Simon and Lyons 1995; Siligato and Böhmer 2001; Ohio 1987). Because the IBI is an adaptable index, the choice of metrics and scoring criteria is best developed on a regional basin, such as the USA and Germany. There were several limits about applying the IBI method in the Wei River: (1) it was hard to select the reference condition for serious human disturbance. Over the past 30 years, intensified human activities have made a huge negative impact on the Wei River basin, which is characterized by decreasing annual runoff, heavy pollution, and a high sediment concentration (Song et al. 2007). (2) The scarcity of published biological community data from the Wei River made it hard to assign fish species to trophic, reproductive, and tolerance guilds. Little historical information is available to understand the fish information in the Wei River. The most recent investigation of fish assemblages in the Wei River basin was conducted in the 1980s (Xu and Li 1984), but only fish presence and absence data were listed. The lack of ecological and life history information on most fishes of the Wei River basin, such as their uncertain functional role in the fish community, has made it difficult to develop an IBI for the Wei River. While MIWB was based on fish abundance and biomass, it was easy to calculate and widely used in the USA. Hughes and Gammon (Hughes and Gammon 1987) suggested that the IBI and MIWB were applicable to a large western river in the USA. Therefore, it was effective to assess the biological condition in the Wei River. The biological condition in the wet season was better than that in the dry season, which may be related to better water quality and high water flow in the river. This was supported by study from EspíRito-Santo et al. (2009), who found most of the species that showed large seasonal variations in density occupy temporary ponds

during the rainy season, when much of the valley is inundated and pond networks form adjacent to streams. Fish display a strong association to season, especially with regard to their breeding strategies, with young fish often being produced when environmental conditions are most favorable (Bowden et al. 2007). Seasonal changes in species density, biomass, and diversity were also significant on the Cretan continental shelf and slope (Kallianiotis et al. 2000).

Ecosystem health

The index of ecosystem health was not only for river ecosystem assessment but also for evaluation of changes of ecological landscape in the region. Recent research studies most focused on these two aspects separately, whereas a few integrated them together. It is variable to evaluate the ecosystem health by only one subject. Water quality indicated the extreme high alteration, and hydrology regime was in high alteration, while ecological landscape pattern displayed little alteration. Biological condition based on fish assemblages and physical form condition were in mediate alteration. This was kindly related to their different temporal and spatial scale to environmental changes. Water quality and hydrology regime were the most sensitive factor to environmental changes, which was the essential aspect of water resource, and are widely applied in the world (Richter et al. 1996; Magilligan and Nislow 2005; Lai et al. 2013). Fish assemblages were an effective indicator on environmental changes, including hydrology regime, water quality, and habitat. Fish were at the top of the aquatic food web in relation to diatoms and invertebrates, which helps to provide an integrative view of the watershed environment (Karr 1981). Meanwhile, fish lag behind the environmental changes. Ecological landscape pattern was an assessment of land use and vegetation changes. It was analyzed at the landscape scale, whereas stream pollution or the replacement of native wildlife with introduced species may cause little or no change in landscapes that can be detected in remote imagery (Riitters et al. 1995). Physical form condition, a reflection of geomorphic condition, was a cost-consuming and time-consuming assessment to quantitative measure physical parameters; thus, the more rapid visual-based physical form assessment was applied according to USEPA's RBP (Barbour et al. 1999). It can reflect the human disturbance directly but is affected by the person who assesses the condition. Assessment of the relative

performance of the various indicators groups can be used to interpret probable causal processes (Bunn et al. 2010), knowing that some indicators (e.g., water quality) respond more closely to riparian zone, while others appear to respond to land use activities at the broader catchment scale (e.g., fish). Key processes link the five groups at various scales (Davies et al. 2010). It is reliable to reflect ecosystem health by integrating them.

The ecosystem health in the Guanzhong district was fair, with the U-L and L-W reaches in good situation, and the other three reaches in fair situation. There was a clear trend that the ecosystem health in the upstream was better than that in the downstream health. There are large cities with large population density, such as Tianshui, Baoji, Xianyang, Xi'an, and Weinan, located downstream of the Guanzhong district, which caused serious human disturbance. This displayed as bad water quality, changes in hydrological regime, decreasing fish abundance, etc., which were perspectives of ecosystem health. In total, the problems in five reaches were different, and this will be a great reference to restore the ecosystem health in the Guanzhong district. In the U-L reach, hydrological regimes were in high alteration, caused by the Baojixia water diversion works (Wu et al. 2012b). Therefore, restoring the natural hydrological regime was the first mission to restore the damaged ecosystem health. Water quality in the L-W reach displayed the highest alteration, which displayed that taking measures to control the pollution. Physical form condition altered highest in the W-X reach. The alteration in the X-L reach focused on hydrological regime and water quality. The ecosystem health in the L-T reach was the worst, with severe alteration of water quality and high alteration of physical form and hydrology. Ecological landscape pattern was altered little in five reaches, which was mainly calculated in the catchment scale, while the water quality was in the site scale. This will be a great reference to restore the damaged catchment in the Guanzhong district.

Conclusions

The index of ecosystem health is comprised of five components, such as ecological landscape pattern, hydrology regime, physical form condition, water quality, and biological quality. Incorporating ecological landscape pattern into the index provides a very different perspective from that provided by evaluating ecosystem

condition based on aquatic ecosystem. It has been developed as a tool to help the watershed managers select and evaluate strategies for restoring the damaged ecosystem.

Our analysis has also revealed problems that may limit the wider application of techniques in China. One problem is the rating rule, and expert rules approach to data integration requires judgments of the relative contribution of each metric, indicator or index to the result. There are some relationships between these five subjects, and any two of them may be related, and it is necessary to identify these links before assessments of ecosystem health. In our review, the five subjects react differently to environmental changes not only to the reflection time but the reflection extent. Application of different indicators to ecosystem health in the different dates will be a great reference to ecosystem restoration and management.

Another problem is using fish assemblage as the indicator of biological condition is incomplete. Biological assemblages respond to many types of disturbance, and assessments of biological condition would be based on multiple biological assemblages, thereby providing insight into the overall biological condition of an ecosystem (Carlisle et al. 2008). Also, some papers (Davies et al. 2010) pointed out that ecosystem health is currently determined primarily on the basis of fish and macroinvertebrate condition, and recommend to include condition of vegetation in future. Thus, macroinvertebrate and diatom condition will be added to assess ecosystem health in the future research.

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