RESEARCH ARTICLE

Community characteristics of macroinvertebrates and ecosystem health assessment in Qin River, a main tributary of the Yellow River in China

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Abstract

To know well the ecosystem health status of Qin River, a main tributary of the Yellow River and the largest river in Jincheng region, macroinvertebrates from 49 sampling sites in the Qin River and its largest tributary, the Dan River, were investigated, and community characteristics were analyzed in the autumn of 2020; a Benthic index of Biotic Integrity (B-IBI) was established based on four metrics by a series of steps. The results showed that a total of 38 species of macroinvertebrates were collected and identified, belonging to 6 orders and 19 families, consisting of 17 Insecta species, 13 Gastropoda species, and 4 Oligochaeta species. Four species in Insecta belonged to EPT (E, Ephemeroptera; P, Plecoptera; T, Trichoptera); 10 species in Insecta belonged to Chironomidae and Tipulidae families. All species in Gastropoda belonged to Basematophora order, and, especially, *Bellamya aeruginosa* is highly tolerant to nutrients. All species in Oligochaetes belonged to Tubificidae family, which indicates eutrophication and low-dissolved oxygen. The dominant species in the study were *Ephemera orientalis*, *Chironomus riparius Meigen*, and *Limnodrilus claparedianus*. The final B-IBI scores varied from 0.75 to 3.75, with 5 sites in "excellent," 10 sites in "good," 10 sites in "normal" status, 12 sites in "poor" status, 12 sites in "very poor." "Very poor" and "poor" sites were mainly located in the middle reach of the Qin River and upper-middle reach of the Dan River in Jincheng region. B-IBI strongly differentiated the reference sites and impaired sites, suggesting the suitability of the B-IBI in the Qin River basin. Significantly negative correlations between NH_4^+–N, TN, and B-IBI indicated the B-IBI characterized well the influence of nitrogen pollution.

Keywords Index based on Benthic macroinvertebrate · River health · Reference sites · Qin River

Introduction

As a main tributary of the Yellow River and the largest river in Jincheng region (Li 2019), the ecological condition in the Qin River basin is very important to human life and production in the Jincheng region. However, in recent years, human activities such as overexploitation of water

resources, industrial and agricultural sewage discharge, and sand extraction have led to changes of water quality in the Qin River in Jincheng region, which affected ecosystem health level of the Qin River. Thus, assessing ecosystem health in Qin River in Jincheng region is an important task.

Benthic macroinvertebrates, mainly composed of Oligochaeta, Hirudinea, Gastropoda, Insecta, and Malacostraca, are one of the most diverse and abundant taxa (Cai et al. 2017; Krajenbrink et al. 2019). Functionally, they play an important role in many ecosystem processes such as detritus decomposition and food supply to vertebrate consumers (De la Fuente et al. 2018; Schneid et al. 2017; Silva et al. 2018; Slimani et al. 2019). They are widely used in assessing ecosystem health due to their bottom-dwelling lifestyle, through which they contact closely with both bottom sediments and columns and reflect riverine ecological conditions. Due to short life cycles and stationary characteristic, changes of riverine ecological

conditions can be reflected through changes in their composition and community structure (Calapez et al. 2017; Pan et al. 2015c; Su et al. 2019). Lastly, their vast species diversity shows broad environmental responses (Arman et al. 2019; Fierro et al. 2018; Karaouzas et al. 2019; Kefford et al. 2020; Larson et al. 2019; You et al. 2021; Zhang et al. 2019). To date, several indices including simple metrics (Shannon–Wiener, Simpson, Margalef), rapid biological assessment (BMWP, SIGNAL, ASPT, HBI, BI), multi-metric (MMI, IBI) (Arman et al. 2019; Chen et al. 2014; Su et al. 2019; Zhang et al. 2019) and functional feeding group methods (Fierro et al. 2018; Mangadze et al. 2019) based on macroinvertebrates have been used in assessment of river health. Among these indices, the index of biotic integrity based on macroinvertebrates (B-IBI) is very popular. It integrates the selected biological metrics into a single index, taking a premise that the biological metrics in least-disturbed sites should differ from those in most-disturbed sites (Hughes et al. 1990; Ruaro and Gubiani 2013).

To explore the effect of anthropogenic activity on river ecosystem, an ecological survey based on benthic macroinvertebrates was carried out in the Qin River and its largest tributary, the Dan River, in 2020. This study aimed to (1) describe variability in macroinvertebrate community structure; (2) assess ecosystem health condition of the Qin River and the Dan River in the Jincheng region, Shanxi Province, China, using an index based on macroinvertebrates.

Materials and methods

Study area

As a main tributary, the Yellow River, Qin River has a length of 485 km and a drainage area of 1.35×10^4 km². It starts from Erlang Shengou in Qinyuan county, Shanxi Province, China, and flows through Jincheng City, Shanxi Province, and flows into the Yellow River in Wuzhi county, Henan Province. The Qin River in the Jincheng region flows through Qinshui, Yangcheng, and Zezhou Counties, with a length of 168 km and a drainage area of 4858 km². As the second largest river in the Jincheng region and the largest tributary of the Qin River, Dan River (DR) originates from Danzhuling in Gaoping County and flows through Gaoping and Zezhou Counties, with a total length of 121.5 km and a drainage area of 2949 km². Qin River basin is in the warm temperate terrestrial monsoon region, with annual average precipitation of 626 to 750 mm. Apart from Jincheng City, Gao Ping has the highest level of urbanization with 53.24% (Li 2019). The land use includes farm land, forest land, grass

land, urban land, rural land, construction land, and water body, accounting for 41.6%, 39.2%, 12.1%, 1.4%, 4.1%, 1.2%, and 0.4% of the total areas of Qin River basin in Jincheng region, respectively.

Sampling and biota identification

In this investigation, 49 sites were sampled in the QR in October to November 2020, corresponding to the dry season (Fig. 1), with 26 sites (1–26) in the main stream of Qin River, and 23 sites in the Dan River. Among them, 15 sites (1–15) were in Qinshui County, 11 sites (16–26) were in Yangcheng County, 13 sites (27–39) were in Gaoping County, and 10 sites (40–49) were in Zezhou County (Fig. 1). The Qin and Dan River depth in our study ranges from 0.2 to 1.8 m; the velocity ranges from 0 to 0.8 m/s, with an average of 0.24 m/s.

Macroinvertebrate samples were collected using a multi-habitat sampling procedure. The types of habitats included riffles (shallow/fast flow), runs (deep/moderate fast), glides (shallow/slow moving), and pools (deep/low flow or no flow). Firstly, three subsamples at every site in a 100-m-long stream reach were collected using a 0.09 m² surber net with a 500-µm mesh and were combined to a synthetic sample for a specific site. Then, the samples were moved to 300-mL plastic bottles using a 60-mesh sieve and were preserved by 90% ethanol. Lastly, the macroinvertebrates were moved to 100-mL plastic bottles and were preserved by 95% ethanol for laboratory analysis (Merritt et al. 2008). The average number, biomass, and density were calculated.

Environmental variables

Physicochemical variables

The location and altitude of sampling sites were recorded by GPS (eTrex-301, Garmin, USA). Total phosphorus (TP), total nitrogen (TN), nitrate (NO_3^-), ammonium–N (NH_4^+–N), chloride (Cl^-), sulfate (SO_4^{2-}), permanganate index (COD_{Cr}) were determined according to environmental quality standards for surface water in China (2002).

Landscape characterization

Buffer delineation was performed 1000 m upstream of the sampling sites using ArcGIS10.1 based on sampling sites, stream networks, and elevation models. Percentage of land cover in the 300-m buffer along 1000 m upstream of the sampling sites was determined by overlaying 300-m buffer boundary on digital land-use maps of Qin River from 2018. Seven land-use types were included: forest, grass, farm land, urban land, rural land, construction land, and water body (Fig. 2).
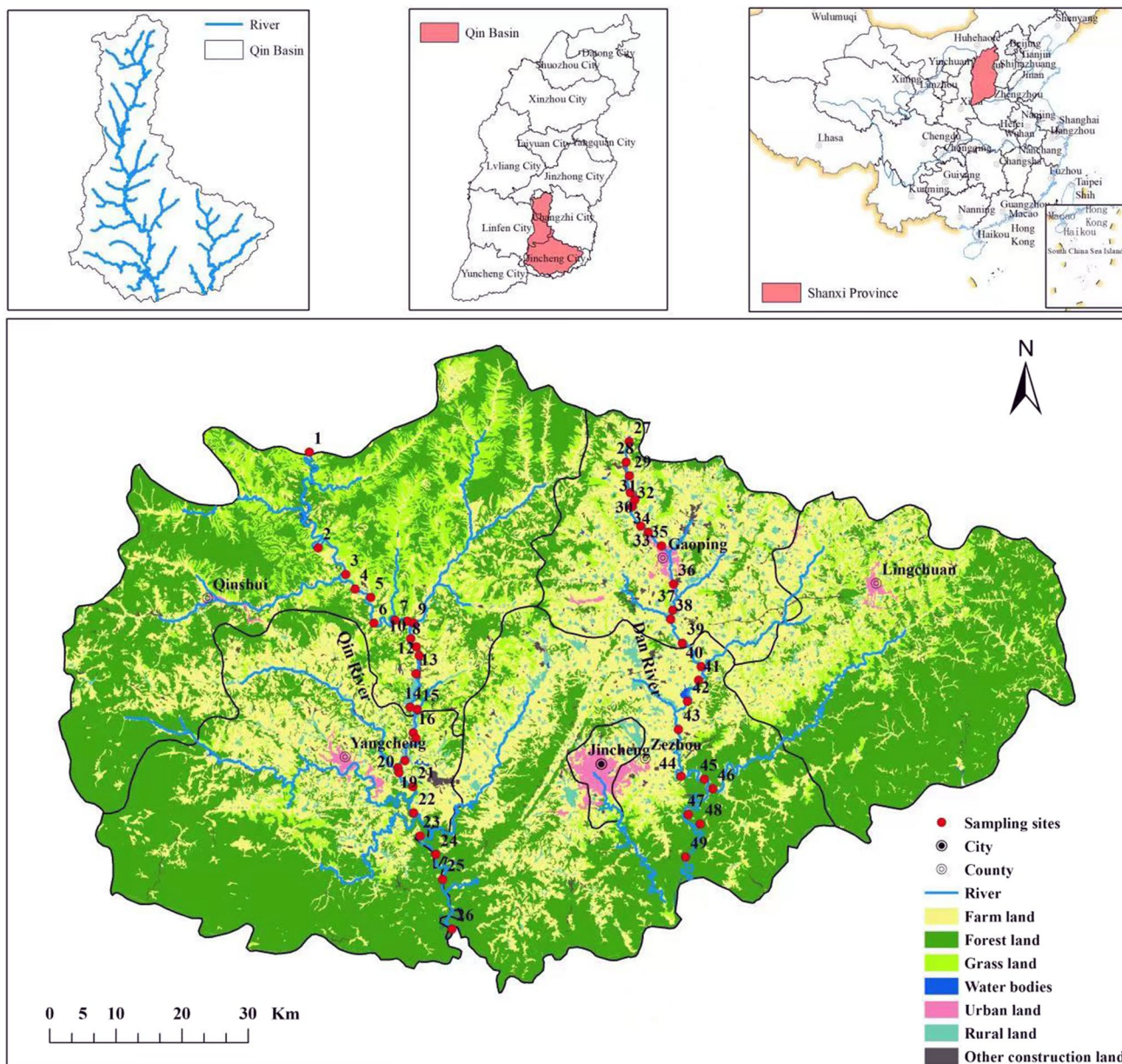
Fig. 1 Location and land use of all sampling sites in the Qin River basin in the Jincheng region, China

B-IBI construction for assessment of river health

Selection of reference sites and impaired sites

The core biological metrics were selected by significant distinction of those potential metrics between the reference sites and the impaired sites (Steedman 1994; Schmidt et al. 2009). Thus, the reference sites and impaired sites are critical for the selection of the core metrics. Ideally, only those non-disturbed sites can be selected as the reference sites. However, non-disturbed sites are non-existent in the Qin River in the Jincheng section. Thus, we determined

least-disturbed sites as the reference sites and most-disturbed sites as the impaired sites. In our study, the ILWQ (index of land use and water quality) integrating the information of land use percentage at a 300-m buffer and water quality was constructed to determine the reference and impaired sites. A low value of ILWQ means low anthropogenic disturbances, and a high value of ILWQ means high anthropogenic disturbances. Therefore, those sites with the lowest ILWQ were chosen as the reference sites, and those sites with the highest ILWQ were chosen as the impaired sites.

A land use index (LDI), by multiplying land use percentage at 300-m buffer by a weighting factor, was
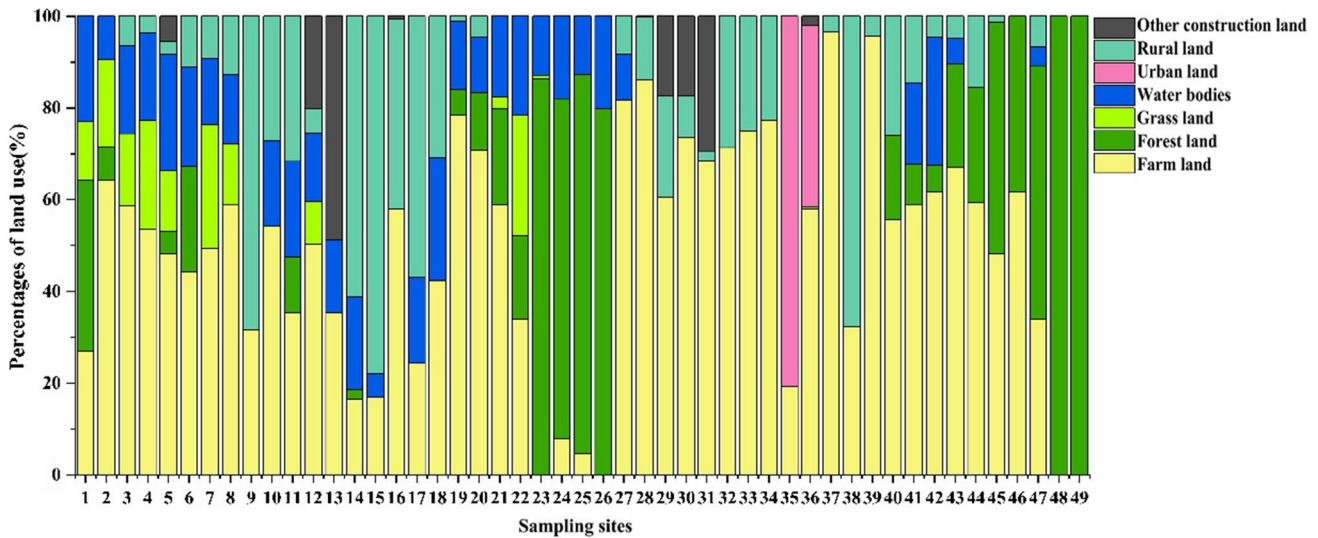
Fig. 2 The percentages of land use at a 300-m buffer of the sampling sites in Qin and Dan rivers in the Jincheng region, China

established to quantitatively reflect human disturbances (Luo et al. 2013; You et al. 2021; Wu et al. 2014). The weighting factors of the land use types were defined according to the amount of carbon emitted from them: forest, grass, and water = 1.00, farmland = 4.54; urban and construction land = 9.42; rural land = 8.66 (You et al. 2021). Physicochemical variables were selected by principal components analysis (PCA) and Pearson correlation (PC) using SPSS 22.0. TN, NH_4^+–N, and Cl − were selected to construct ILWQ after PCA and PC analysis. TN, NH_4^+–N, Cl$^-$ concentrations and the LDI increased with increasing human disturbances; their scores were calculated as follows:

$$ILWQ_i = \begin{cases} 1 & C_i \leq S_{i,1} \\ j + \dfrac{C_i - S_{i,j-1}}{S_{i,j} - S_{i,j-1}} & S_{i,j-1} \leq C_i \leq S_{i,j} \quad j = 2,3,4,5 \\ 6 + \dfrac{C_i - S_{i,5}}{S_{i,5}} & C_i \geq S_{i,5} \end{cases}$$

where $ILWQ_i$ is the normalized values of variable i (TN, NH_4^+–N, Cl$^-$, LDI), C_i is the observed value of variable i (I = 1, 2, 3,4). $S_{i,j}$ (j = 1,2,3,4,5) represents the j class value of variable i (the 5th, 25th, 50th, 75th, 95th percentile values for Cl$^-$ and LDI; the values of class 1, 2, 3, 4 and 5 according to the environmental quality standard for surface water of China for TN and NH_4^+–N.

The final ILWQ is calculated as the average of the normalized values of these four variables. Human disturbance is classified into three levels: least disturbed (ILWQ ≤ 2), moderately disturbed (2 < ILWQ ≤ 4), and highly disturbed (ILWQ > 4). The sites with less than 2 of ILWQ were selected as the reference sites, and those with more than 4 were selected as the impaired sites.

B-IBI construction

As shown in Table 1, 40 candidate metrics were included in our study according to previous studies (Arman et al. 2019; Fierro et al. 2018; Shi et al. 2017). These metrics represent the composition, structure, and function of macroinvertebrate communities and were classified into five groups of attributes: (1) richness; (2) tolerance to pollution; (3) functional feeding groups; (4) habitat quality; (5) diversity. First, core metrics for B-IBI were selected by a series of steps. Step one: the metric is eliminated if the median value is zero. Step two: the metrics were retained if they significantly distinguished between least-disturbed sites and impaired sites (Li et al. 2016). Significant distinction was defined using the box and whisker plots. If the metrics show no or little overlap between reference and impaired sites, they should be retained according to the box (25th–75th percentiles) and whisker plots. The 50th percentile of the metrics at the reference sites is out of its box at the impaired sites, or the 50th percentile of the metrics at the impaired sites is out of its box at the reference sites, indicating that it showed little overlap between reference and impaired sites. Finally, redundancy tests are performed by Pearson's correlation using SPSS 22.0. Then, the scores of core metrics were acquired by the ratio score method after determining core metrics (Shi et al. 2017), with each ranging from 0 to 1, which unifies metric dimension by using the 5th or 95th percentile value as the best expected value. Finally, the score of B-IBI at each site is calculated based on the average score of the core metrics. The five categories including "excellent, good, fair, poor,

Table 1 Candidate metrics for B-IBI

Categories	Metrics	Abbreviation	Categories	Metrics	Abbreviation
Taxa	Number of total taxa	M1	Tolerance	Number of intolerant taxa	M25
	Number of Ephemeroptera taxa	M2		number of tolerant taxa	M26
	Number of Trichoptera taxa	M3		Proportion of individuals of intolerant taxa	M27
	Number of Diptera taxa	M4		Proportion of individuals of tolerant taxa	M28
	Number of Ephemeroptera, Plecoptera and Trichoptera taxa	M5	Functional Feeding groups	Proportion of individuals of collector-filterers	M29
	Number of Chironomidae taxa	M6		Proportion of individuals of collector-gatherers	M30
	Number of Insecta taxa	M7		Proportion of individuals of scrapers	M31
	Number of (Crustacea + Mollusca) taxa	M8		Proportion of individuals of predators	M32
	Number of (Amphipoda + Mollusca) taxa	M9		Proportions of individuals of shredders	M33
Richness	Proportion of individuals of dominant taxa	M10		Proportions of individuals of (shredders + scrapers)	M34
	Proportion of individuals of the first three dominant taxa	M11	Habitat quality	Proportions of individuals of clingers (	M35
	Proportion of individuals of Trichoptera	M12		Number of clingers taxa	M36
	Proportion of individuals of Ephemeroptera	M13	Diversity	Shannon–Wiener diversity index	M37
	Proportion of individuals of Tubificidae	M14		Evenness index	M38
	Proportion of individuals of Chironomidae	M15		Margalef's index	M39
	Proportion of individuals of Diptera	M16		Simpson's diversity index	M40
	Proportion of individuals of Mollusca	M17			
	Proportion of individuals of (Crustacea + Mollusca)	M18			
	Proportion of individuals of (Amphipoda + Mollusca)	M19			
	Proportion of individuals of Hydropsychidae in Trichoptera	M20			
	Proportion of individuals of Chironomidae in Diptera	M21			
	Proportion of individuals of Baetidae	M22			
	Proportion of individuals of (Other Diptera + non-Insecta)	M23			
	Proportion of individuals of Oligochaeta	M24			

and very poor" were classified by ratio score method based on the final B-IBI scores: The 95% percentiles of B-IBI scores were identified as the threshold of "excellent," and 75th, 50th, 25th were identified "good," "normal," "poor," and "very poor," respectively.

B-IBI discrimination

The sensitivity of the B-IBI to anthropogenic disturbance according to its distinctions between reference sites and impaired sites was tested using box-and-whisker plots.

Significant differences of B-IBI between reference sites and impaired sites indicate it is suitable to assess Qin River health. Pearson's correlation using SPSS 22.0 between B-IBI values and environmental variables was used to estimate the suitability of the B-IBI in the Qin River. If the index significantly discriminated between reference sites and impaired sites and significantly correlated with environmental variables, it can reflect biological, chemical, and land use characteristics.

Results

Spatial distribution of benthic macroinvertebrates

Species composition

A total of 38 species belonging to 6 classes, 10 orders, and 19 families were identified at 49 sites (Fig. 3). Seventeen species belonging to Insecta were identified, mainly including *Ephemera orientalis*, *Baetis vaillanti*, and *Cinygma sp.* belonging to Ephemeroptera, *Chironomus riparius Meigen*, *Polypedilum nubeculosum* belonging to Diptera, and *Hydropsyche sp.* Belonging to Trichoptera. Two species belonging to Malacostraca were identified, mainly including *Caridina denticulate sinensis.* Thirteen species belonging to Gastopoda were identified, mainly including *Bellamya aeruginosa*, *Radix lagotis*, *Bellamya purificata*, and *Bithynia sp.* Only one species, *Corbicula fluminea*, belonging to Lamellibranchia was identified.

Four species belonging to Oligochaeta were identified, mainly including *Limnodrilus claparedianus*, *Branchiura sowerbyi*, *Limnodrilus hoffmeisteri*, and *Tubifex sinicus.* Only one species, *Barbronia weberi*, belonging to Hirudinea was identified.

Spatial distribution of tolerant groups and intolerant groups

Ephemera orientalis, one intolerant species to pollution, was found at some sites (sites 4–6, 8–12, 15, 17, 20, 23, 26, 28) in the main stream of the Qin River. Its abundances were more than 50% at six sites 9, 12, 20, 23, 26, and 28. As an important tolerant species, *Chironomus riparius Meigen* had more than 50% abundance at seven sites (sites 8, 10, 13, 18, 33–35) (Fig. 3). Abundances of the species belonging to Tubificida were more than 50% at four sites (11, 21, 24, 36) and ranged from 25 to 50% at nine sites (sites 3, 5, 6, 7, 17, 18, 35, 38, 47) (Fig. 3). These sites were mainly distributed upper-middle reach of the Qin River and middle reach of the Dan River. In this study, twenty-three sites with the abundance of tolerant species more than 50% were found, and eight sites were found with 25 to 50% abundance of tolerant species.

Biodiversity of macroinvertebrates

The mean value of Shannon–Wiener index in Qin River (1.34) was higher than that in Dan River (1.05). In this study, seven sites (sites 3, 5, 6, 17, 22, 47, 48) with Shannon–Wiener index greater than 2 were found (Fig. 4), accounting for

Fig. 3 Abundances of macroinvertebrates species in Qin and Dan rivers in the Jincheng region, China
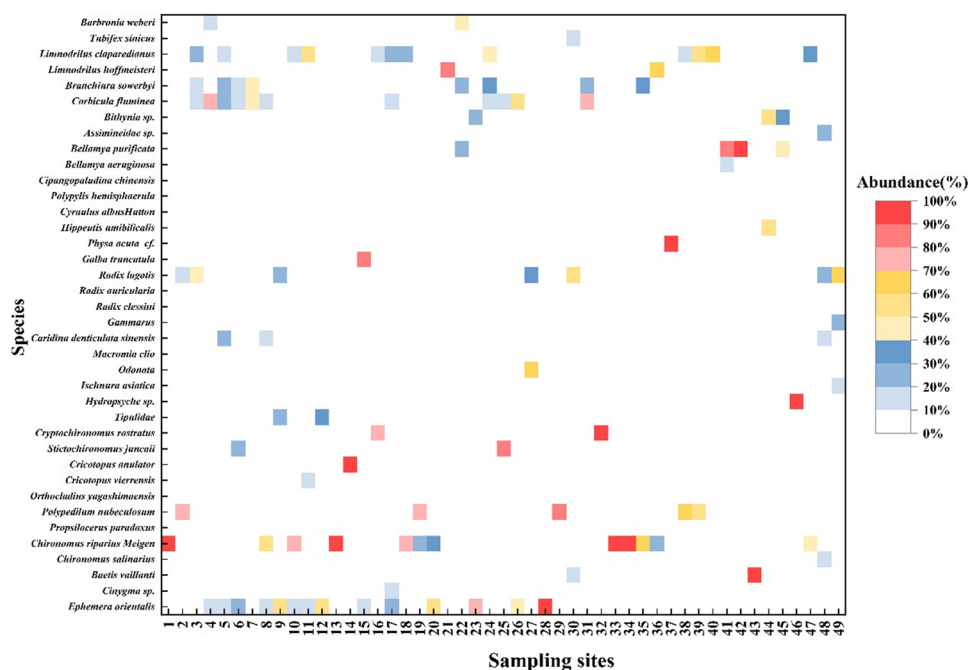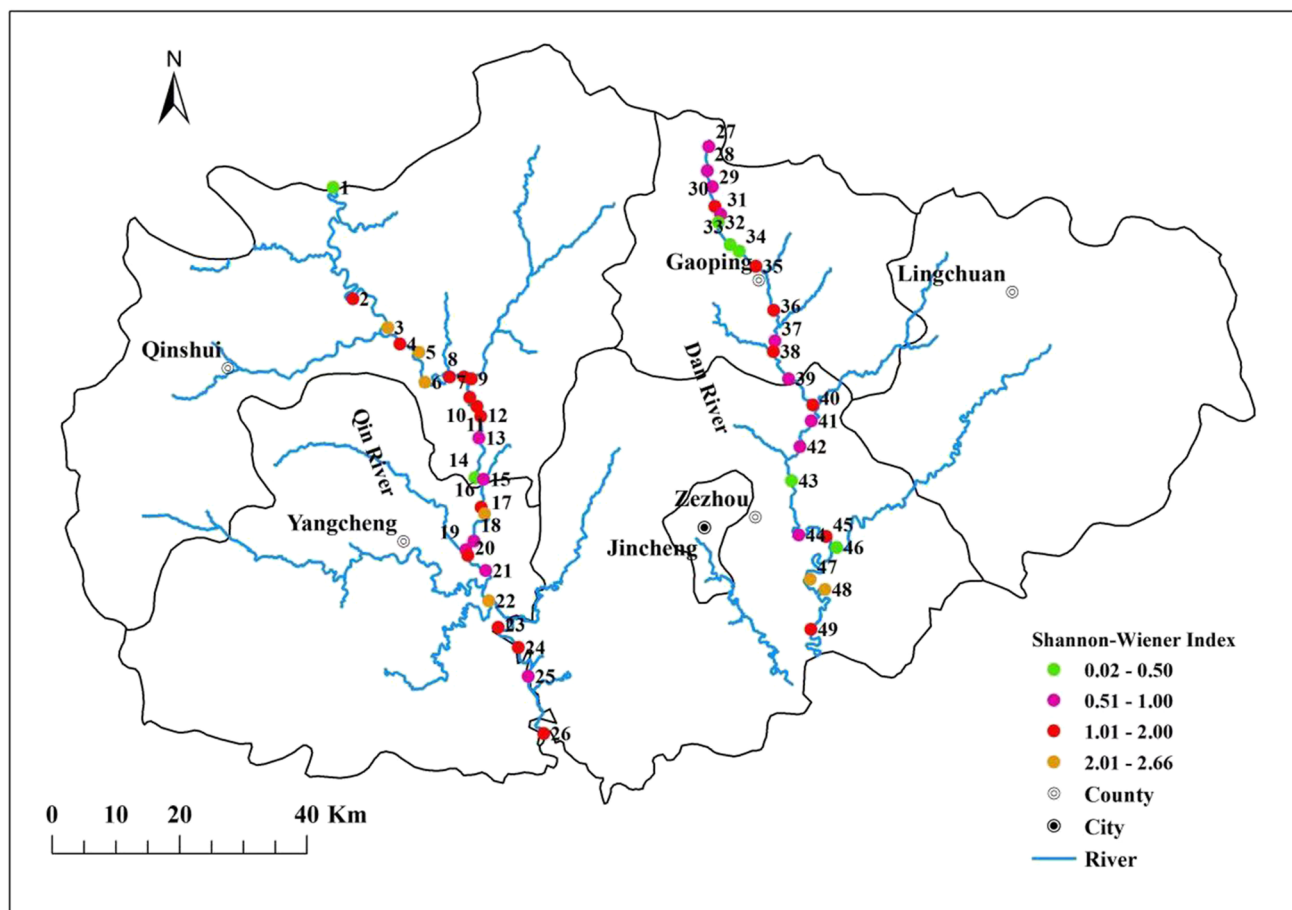
Fig. 4 Shannon–Wiener index of all sampling sites in Qin and Dan rivers in the Jincheng region, China

12.3% of all sites. There were 21 sites (sites 2–21 and sites 45–49) with Shannon–Wiener index greater than 1 and lower than 2 (Fig. 4), accounting for 42.9% of all sites. These sites mainly distributed in the upper-middle reach of Qin River and lower reach of Dan River in the Jincheng region. The values of Shannon–Wiener index at the impaired sites were less 1, whereas the values at the reference sites were more than 1, indicating that the metrics can reflect the environmental variables.

Functional feeding groups

The collector-filterers and collector-gatherers were the main component of community in Qin River, followed by scrapers, predators, and shredders. The species belonging to the collector-filterers and collector-gatherers were found at more than 60% of the sites. All species at sites 1, 19, and 32 belonged to collector-gatherers. There were fourteen sites (2, 8, 10, 13, 14, 16, 18, 25, 29, 33, 34, 35, 38, 39) with the abundance of collector-gatherers more than 50%. All species at sites 24 and 31 belonged to collector-filterers.

There were ten sites (3, 4, 5, 7, 11, 21, 26, 36, 39, 40) with the abundance of collector-filterers more than 50% (Fig. 5). The dominant collector-filterers species were *Corbicula fluminea*, *Branchiura sowerbyi*, *Limnodrilus hoffmeisteri*, and *Limnodrilus claparedianus*. The dominant collector-gatherers species were *Chironomus riparius Meigen*.

Assessment of ecosystem health on the basis of B-IBI

Selection of reference sites

TN, NH_4^+–N, Cl^-, and LDI were selected to construct ILWQ using PCA and Pearson correlation methods using SPSS 22.0. The scores of ILWQ at each site are summarized in Table 2. Five sites (sites 2, 3, 4, 26, and 46) were chosen as the reference sites due to their low ILWH values (≤ 2), and five sites (sites 37, 38, 39, 40, and 41) were chosen as the impaired sites due to their high ILWH values (≥ 4). The NH_4^+–N, TN, and Cl^- in the final selected reference sites ranged from 0.04 to 0.41 mg/L, 1.13 to 2.82 mg/L, and 18.59 to 28.39 mg/L, respectively.
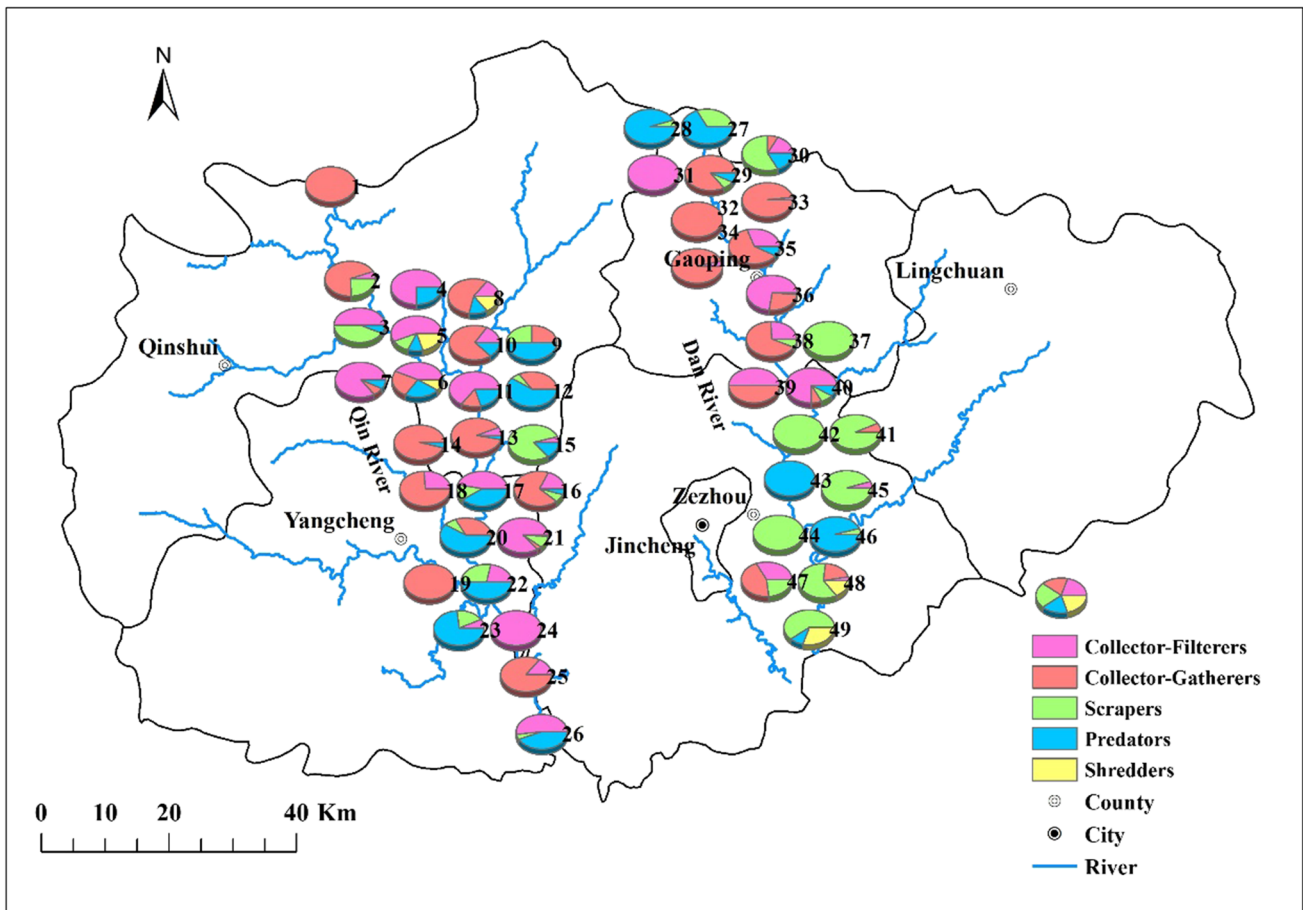
Fig. 5 Functional feeding groups of all sampling sites in Qin and Dan rivers in the Jincheng region, China

Core metrics selection

Three metrics (Number of Trichoptera taxa, proportion of individuals of Trichoptera, and proportion of individuals of Hydropsychidae in Trichoptera) were eliminated because their values were 0 at 95% sites. Twenty-eight metrics were excluded because no significant discrimination between the reference sites and impaired sites was found (Fig. 6). The remaining eight metrics (M6, M8, M9, M15, M26, M28, M30, and M32) were screened to avoid redundant information using Pearson correlation. The results showed that number of Chironomidae taxa (M6) was significantly correlated with proportion of individuals of Chironomidae (M15) ($p < 0.05$, $r = 0.66$), number of Amphipoda and Mollusca taxa (M9) was significantly correlated with number of Crustacea and Mollusca taxa (M8) ($p < 0.05$, $r = 0.99$), proportion of tolerant taxa (M28) was significantly correlated with number of tolerant taxa (M26) ($p < 0.05$, $r = 0.71$), and proportion of individuals of predators (M32) was significantly correlated with proportions of individuals of collector-gatherers (M30) ($p < 0.05$, $r = -0.41$). M6, M9, M28, and M32 were excluded because the other metrics may explain more information. The

final B-IBI was constructed based on four remaining metrics: number of (Crustacea + Mollusca) taxa, proportion of individuals of Chironomidae, number of tolerant taxa, and proportion of individuals of collector-gatherers.

Assessment of Qin River health

Each selected core metric was normalized by the ratio score method (Shi et al. 2017), with each ranging from 0 to 1. The normalization formula is shown in Table 3. The 95% percentiles of M8 were identified as the upper expectation limits because their values decrease with increasing human disturbance, while the 5% percentiles of M15, M26, and M30 were identified as the upper expectation limits because their values increase with increasing human disturbance. The score of B-IBI at each site was calculated based on the sum of the scores of five core metrics. The final B-IBI scores varied from 0.75 to 3.75, with five sites in "excellent," ten sites in "good," ten sites in "fair" status, twelve sites in "poor" status, twelve sites in "very poor" (Fig. 7). The sites with "excellent and good" and "poor and very poor" accounted for 30.6% and 49.0%, respectively, indicating that ecological conditions of the Qin River in Jincheng region need to be rehabilitated.

Table 2 The measured concentrations of chemical variables, the scores of land use index, ILWQ, B-IBI, and health status

Sites	Land use index	TN (mg/L)	NH_4^+–N (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)	ILWQ	Disturbance	B-IBI	Health status
1	0.24	3.00	0.27	29.59	124.35	1.42	2.30	M	0.75	Very poor
2	0.41	2.08	0.45	21.89	126.32	1.00	1.88	R	2.34	Poor
3	0.45	2.29	0.26	17.29	123.37	1.18	1.49	R	2.75	Normal
4	0.40	2.82	0.41	22.54	97.64	1.51	2.00	R	3.00	Good
5	0.36	3.12	0.34	45.59	139.56	1.68	2.69	M	3.25	Good
6	0.44	4.17	0.20	23.69	121.96	2.30	2.39	M	2.32	Poor
7	0.44	2.73	0.46	31.99	117.45	1.73	2.40	M	2.43	Poor
8	0.52	2.76	0.27	34.49	120.97	1.28	2.52	M	1.86	Poor
9	0.98	5.00	0.13	18.54	49.70	2.16	2.26	M	2.75	Normal
10	0.65	12.97	0.55	27.64	66.04	1.55	3.15	M	0.80	Very poor
11	0.61	16.99	0.26	12.60	51.68	1.10	2.58	M	1.94	Poor
12	0.38	4.01	0.16	38.89	46.04	2.11	2.83	M	2.65	Normal
13	0.22	15.29	0.45	20.59	47.80	1.39	2.82	M	0.44	Very poor
14	0.84	21.73	2.82	24.49	46.18	1.23	3.32	M	0.83	Very poor
15	1.02	4.68	0.44	55.32	554.79	2.30	3.34	M	2.50	Normal
16	0.82	3.91	0.33	31.76	104.59	2.13	2.75	M	1.33	Poor
17	0.83	3.95	0.45	29.04	108.37	2.10	2.67	M	3.25	Good
18	0.64	8.47	2.02	56.58	33.66	3.40	3.47	M	1.03	Very poor
19	0.48	4.94	0.76	26.34	253.23	3.04	2.70	M	0.75	Very poor
20	0.49	5.09	0.62	59.58	154.28	1.77	3.30	M	2.33	Poor
21	0.39	4.03	0.17	33.79	190.55	2.49	2.71	M	2.69	Normal
22	0.28	5.18	0.92	33.32	162.52	2.67	2.95	M	2.75	Normal
23	0.13	4.95	0.61	36.89	199.70	3.16	2.97	M	3.50	Excellent
24	0.16	5.10	0.38	36.36	196.46	1.46	3.00	M	2.75	Normal
25	0.15	5.19	0.28	28.29	158.58	2.90	2.73	M	1.54	Poor
26	0.13	1.70	0.23	28.39	137.17	1.04	1.91	R	3.50	Excellent
27	0.57	4.02	0.31	34.64	102.66	1.75	2.80	M	3.00	Good
28	0.65	6.96	0.95	20.69	120.13	1.70	2.69	M	3.00	Good
29	0.60	4.32	0.17	27.46	127.50	1.54	2.63	M	1.29	Very poor
30	0.52	2.09	0.30	157.95	252.85	1.13	3.10	M	2.92	Normal
31	0.41	3.05	0.66	80.97	301.96	0.81	2.97	M	2.75	Normal
32	0.74	3.68	0.75	68.65	212.05	1.00	3.11	M	1.00	Very poor
33	0.72	3.71	1.09	80.41	182.10	0.44	3.20	M	0.28	Very poor
34	0.71	2.15	1.52	44.75	137.80	0.56	2.60	M	0.58	Very poor
35	1.06	1.99	0.53	72.54	191.68	0.42	2.88	M	1.02	Very poor
36	0.80	0.91	0.58	62.01	332.62	0.44	2.12	M	1.98	Poor
37	0.59	12.16	0.56	146.15	192.73	2.58	4.02	I	3.25	Good
38	0.98	7.54	0.41	129.39	237.31	2.53	4.01	I	1.14	Very poor
39	0.59	8.29	0.37	130.56	393.52	3.19	3.99	I	1.75	Poor
40	0.65	8.43	0.46	126.46	367.46	3.20	3.98	I	2.33	Poor
41	0.54	11.41	0.45	140.99	259.14	5.21	4.01	I	3.12	Good
42	0.45	1.44	0.38	86.14	286.18	0.25	2.60	M	3.25	Good
43	0.47	7.68	0.55	39.99	1437.89	2.07	3.27	M	3.00	Good
44	0.55	1.96	0.48	180.68	378.15	0.76	3.13	M	3.50	Excellent
45	0.35	2.80	0.40	209.34	378.15	0.79	3.31	M	3.50	Excellent
46	0.40	1.13	0.04	18.59	93.01	0.43	1.48	R	3.75	Excellent
47	0.35	1.09	0.75	171.68	444.23	0.29	2.46	M	2.38	Poor
48	0.13	1.59	0.16	130.79	509.72	0.64	2.71	M	3.09	Good
49	0.13	2.72	0.09	57.45	204.92	1.51	2.62	M	2.75	Normal

Disturbance is the classification of the environmental quality: *R*, reference sites; *M*, moderately deteriorated sites; *I*, impaired sites
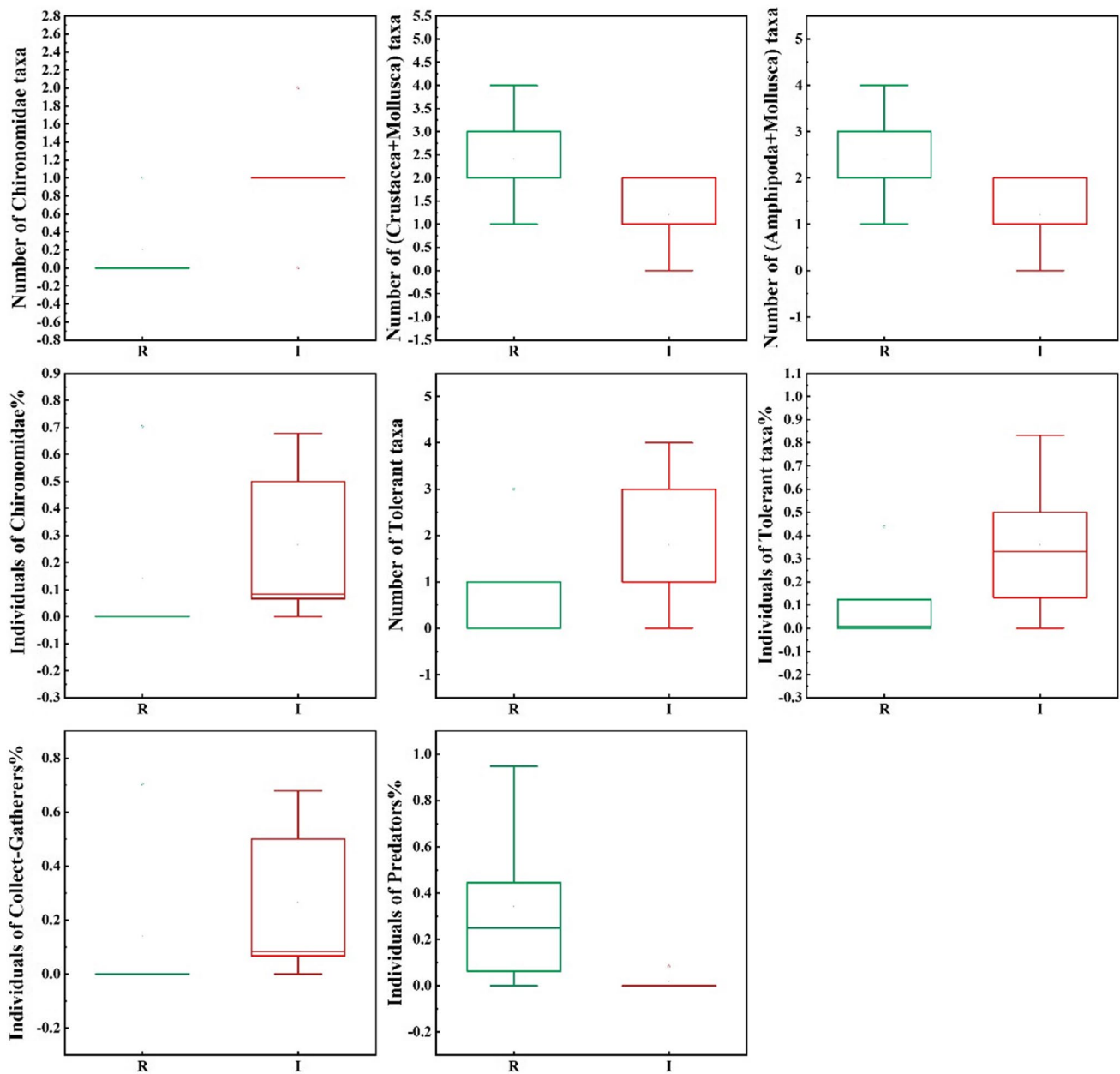
Fig. 6 Box-whisker plots of eight biological metrics between reference (R) and impaired (I) sites

Discussion

Analysis of macroinvertebrate community characteristics

In this study, the species mainly belonged to phylum Arthropoda and Mollusca, which is consistent with previous studies in China (Shi et al. 2017; Su et al. 2019; You et al. 2021; Zhang et al. 2019). Most species belonging to Ephemeroptera, such as Baetidae, Heptageniidae, Ephemeridae species are mainly fed on algae, protozoa, and decaying plants and are important components of

Table 3 Formula for normalizing the core metrics

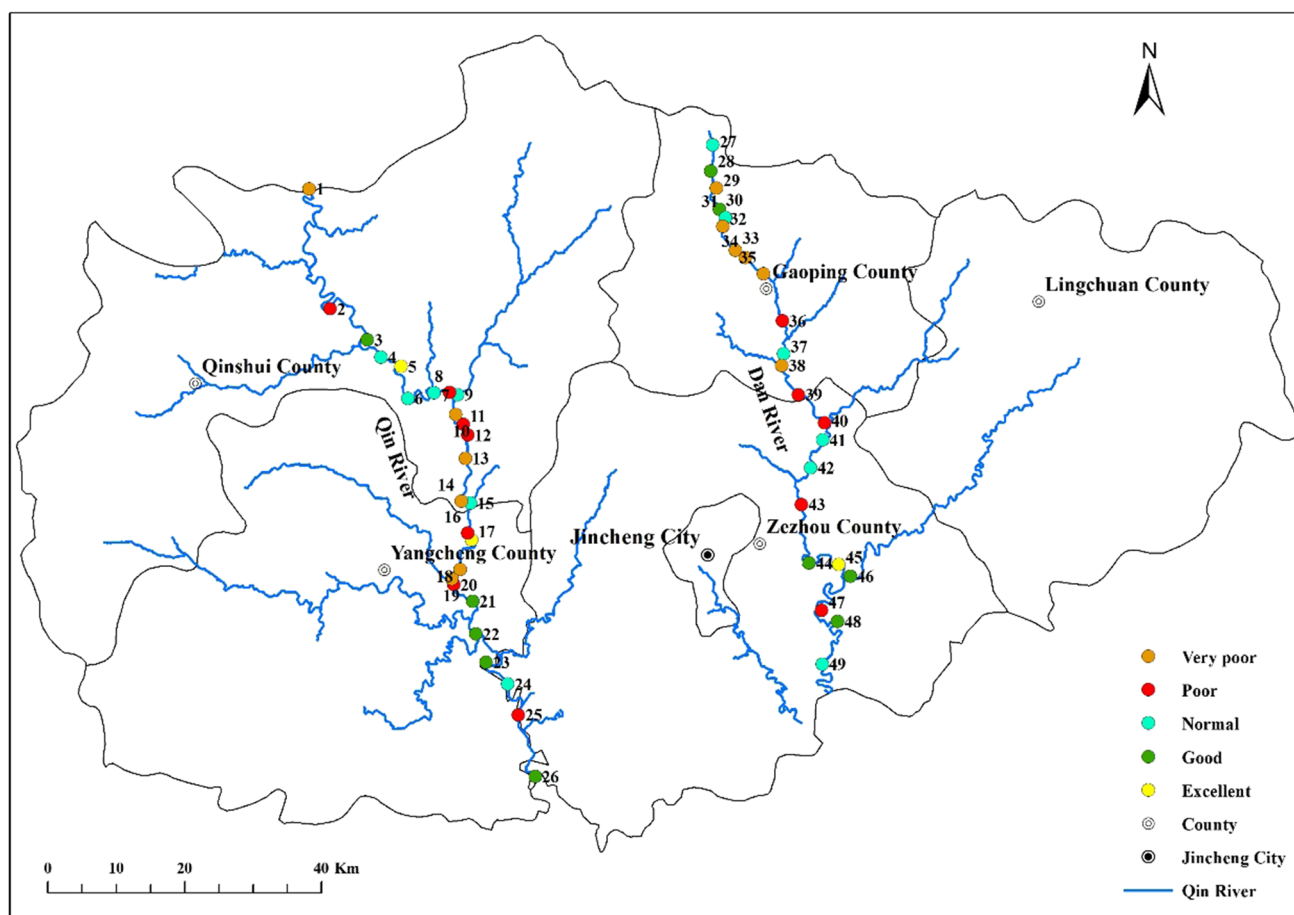| Abbreviations	Metrics	Equations
M8	Number of (Crustacea + Mollusca) taxa	M8/4
M15	Individuals of Chironomidae%	$(1 - M15)/1$
M26	Number of tolerant taxa	$(4 - M26)/4$
M30	Individuals of collector-gatherers%	$(1 - M30)/1$

Fig. 7 Evaluation of ecosystem health of all sampling sites based on B-IBI

macroinvertebrates in undisturbed rivers. They are classified into intermediate group according to tolerance values (Bressler et al. 2006). They usually firstly disappear when water pollution occurs (Moran et al. 2017). In this study, one Baetidae species was found at only two sites (30, 43). *Ephemera orientalis* belonging to Ephemeridae family was found at fourteen sites (sites 4–6, 8–12, 15, 17, 20, 23, 26, 28). Among the fourteen sites, only one site (28) was distributed in Dan River. One species belonging to Heptageniidae was found at only one site (17). The results suggested that serious pollution occurred in Qin and Dan River in the Jincheng region, and water quality of Qin River was better than that in Dan River. The dominant species including *Branchiura sowerbyi*, *Limnodrilus claparedianus*, and *Chironomus riparius Meigen* have high tolerance values more than 8.0, and their abundances were more than 50% at sixteen sites (1, 2, 8, 10, 13, 18, 19, 20, 22, 25, 31, 33, 34, 35, 39, 40), which suggested that ecological conditions at these sites need to be improved. The health statuses of these sites were "poor" and "very poor," indicating that the results of health assessment were supported by the community characteristics of macroinvertebrates.

Selection of the reference sites

The core metrics were selected according to their discrimination between the reference sites and impaired sites. Thus, the selection of reference sites and impaired sites was decisive for the construction of the B-IBI. Many studies selected the reference sites, considering land use patterns, water quality, and physical habitat conditions. The reference sites for the Hai River assessment (Shi et al. 2017) were selected using physicochemical parameters and the land use type. Arman et al. (2019) determined the reference sites based on the habitat index (HBI) values. You et al. (2021) applied the LDI by multiplying land use percentage by a weighting factor to select the reference sites. Fierro et al. (2018) applied an integrated disturbance index (IDI), combining catchment and local disturbance index to select the reference sites in the Mediterranean Ecoregion of Chile. Wu et al. (2014) applied an index integrating water and habitat quality to select the reference sites in Wei River. In this study, A multi-index integrating the land use index and physicochemical variables was constructed to select reference sites. The reference sites were characterized by the high percentage

of forest and grass (15.8–79.9%) and low percentage rural land (0–6.3%) at 300-m buffer. The final thresholds of variables used to select the reference sites in other research were as follows: NH_4^+–N < 0.258 mg/L, conductivity < 276 μS/cm, DO > 9.5 mg/L in the Hai River basin (Shi et al. 2017). NH_4^+–N < 0.22 mg/L and conductivity < 100 μS/cm in the Li River basin (Chen et al. 2014), and NH_4^+–N < 1 mg/L, DO > 6 mg/L and conductivity < 500 μS/cm in the Taihu basin (Huang et al. 2015). Some differences of the thresholds of variables were found in different studies. The threshold of NH_4^+–N was higher than previous studies, which suggested serious pollution in the Qin River basin in the Jincheng region.

Core metrics selection and B-IBI construction

The B-IBI was constructed based on four core metrics from three categories: richness, tolerance, and functional feeding groups. Among these core metrics, number of (Crustacea + Mollusca) taxa is the number of Crustacea and Mollusca that are sensitive to the change of water quality, and has been widely included into assessment approaches (Liu et al. 2019). In this study, (Crustacea + Mollusca) taxa accounted for more than 50% of the total taxa at 15 sites (2, 17, 23, 25, 26, 27, 31, 37, 41, 42, 44, 45, 46, 47, and 48). Among these sites, three (sites 2, 26, and 46) were in the group of reference sites, and ten sites had less than 3.0 of ILWQ, which indicated that the species belonging to Crustacea and Mollusca were mainly distributed in the less-disturbed and intermediate-disturbed habitat (Yin et al. 2021). Proportion of individuals of collector-gatherers is the proportional abundance of an important functional group that is mainly fed by deposited organic particles. It is preferred to the habitats with low velocity. Metrics for functional feeding groups were also frequently used in macroinvertebrate-based bioassessment (Fierro et al. 2018; Shi et al. 2017; Yang et al. 2017). In this study, collector-gatherers were the most abundant, which is consistent with the finding in Bloukrans River in the Eastern Cape Province of South Africa (Mangadze et al. 2019). The sites with high abundance of collector-gatherers were characterized by high NH_4^+-N and TN concentrations, indicating that high abundance of the collector-gatherers can indicate the nitrogen pollution. Number of tolerant taxa is the number of the taxa that are tolerant to pollution and are also a synthetic index reflecting the river-pollution-tolerant characteristics (Li et al. 2016). To date, the metric has been widely used to assess river health (Arman et al. 2019; Shi et al. 2017). In this study, twenty-one sites were characterized by high proportions of tolerant taxa, accounting for more than 50% of total taxa, which indicated that the ecological conditions in Qin and Dan River need to be improved. Among these 21 sites, five sites (1, 18, 33, 34, and 35) were characterized by all species belonging to the tolerant taxa. Proportion of individuals of Chironomidae is the proportional abundance of Chironomidae species that are tolerant to pollution and are mainly distributed in the silt and sand habitat. This metric has been used in some studies (Liu et al. 2019; Yin et al. 2015). In this study, the abundance of Chironomidae was more than 50% at 13 sites (2, 8, 10, 13, 14, 16, 18, 25, 29, 33, 34, 35, and 38).

High values of the three metrics including individuals of Chironomidae%, number of tolerant taxa, and individuals of collector-gatherers% and low values of number of (Crustacea + Mollusca) taxa were shown in the same sites. Among these sites, most showed "poor" and "very poor" health status. These results suggested that higher values of above three metrics effectively indicate worse ecological conditions, whereas higher values of number of (Crustacea + Mollusca) taxa effectively indicate better ecological conditions.

Health assessment in Qin River basin

As shown in Fig. 7, the "excellent" sites (23, 26, 44, 45, 46) were located in the middle-lower reaches of Qin and Dan Rivers in the Jincheng region. High B-IBI scores of the five sites were mainly due to very low proportions of individuals of Chironomidae, proportion of individuals of collector-gatherers, and the number of tolerant taxa. The values of the first two metrics were 0 at the five sites, and the number of tolerant taxa was less than 2. The "very poor" sites (1, 10, 13, 14, 18, 19, 29, 32, 33, 34, 35, 36, 38) and "Poor sites" (2, 6, 7, 8, 11, 16, 20, 25, 36, 39, 40) were mainly located in the upper-middle reaches of Dan River and the middle reaches in Qin River in the Jincheng region. Among these sites, site 2 was the reference site with ILWQ value less than 2 but was identified as "poor" status due to high abundance of individuals of Chironomidae (0.70), and high proportion of individuals of collector-gatherers (0.70). Above results corresponded well with the community characteristics. All "poor" or "very poor" sites were characterized by high abundance of tolerant species including *Limnodrilus hoffmeisteri*, *Limnodrilus claparedianus*, and *Chironomus riparius Meigen*. It was reported that many industrial and mining plants including nitrogenous fertilizer, mining, chemical material manufacture are around the middle reach (sites 8 to 20) of Qin River and the upper reaches (sites 31 to 35) of Dan River, which resulted in high concentration of NH_4^+–N and COD and bad ecological conditions (Li 2019). Much domestic sewage is discharged into the reach (sites 36 to 40), which resulted in bad water quality and ecological conditions (Li 2019).

B-IBI discrimination

The criteria for assessment of river health were very distinct in different study areas with different environmental conditions. It is easy to find the non- or least-disturbed sites in the mountainous streams, which make the criteria for selection of the reference sites much stricter. However, the undisturbed sites in urban streams are almost non-existent, which necessitate a higher threshold of the criteria for assessment. The threshold of "good" is 3.66 in Liao River basin (Zhang et al. 2007), 3.04 in Taihu (Gao et al. 2012), whereas only 0.66 in Xitiao River (Li et al. 2007). The threshold of "good" in Xitiao is lower than that in other rivers because the "good" sites of Xitiao River were not disturbed by human activities, while non-disturbed sites cannot be found in Liao River and Taihu. The water quality in Qin and Dan rivers in the Jincheng region was in classes III–V according to the environmental quality standard for surface water of China, which makes the threshold of criteria for assessment much higher. The threshold of "good" criteria for assessment is 3.0 and is equivalent with that in Taihu.

The correlations between environmental parameters, including physicochemical variables and the land use index, and the core metrics, B-IBI, were analyzed (Table 4). NH_4^+–N and TN concentrations were negatively correlated with number of (Crustacea + Mollusca) taxa and B-IBI, and positively correlated with proportion of individuals of collector-gatherers. Su et al. (2019) also found the increased nitrogen concentrations favored tolerant species in Wei River. Cl^- concentrations and LDI values were positively correlated with number of Crustacea and Mollusca. The results indicated nitrogen and ammonium were the main driving factors of the community characteristics of macroinvertebrates in Qin River in the Jincheng region. Similar results were found in the finding of HunTai River (Zhang et al. 2007). Significantly negative correlations between B-IBI and the core metrics, NH_4^+–N, TN, and

LDI suggested that B-IBI may reflect biological, chemical, and land use characteristics in the Qin River basin in the Jincheng region.

Sixty percent of the reference sites (4, 26, 46) had "good" ecological status, 60% of the impaired sites (38–40) had "poor and very poor" ecological status, which suggested the water quality is corresponding to the ecological condition in Qin River. The B-IBI scores distinguished between least-disturbed sites and intermediate-disturbed sites or most-disturbed sites. The 50th percentile of the reference group was out of the box of the group of impaired sites (Fig. 8), indicating the suitability of the B-IBI.
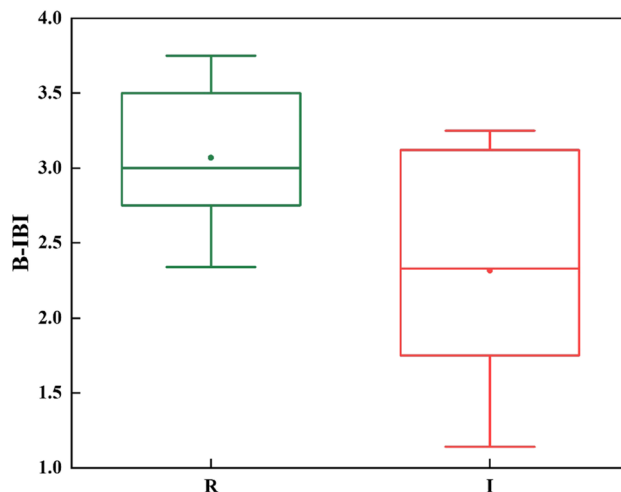

Fig. 8 Box-whisker plots of B-IBI between reference (R) and impaired (I) sites

Table 4 Correlations of B-IBI and biological metrics and environmental variables

	M8	M15	M26	M30	NH_4^+-N	TN	Cl^-	LDI	IBI
M8	1	−0.435[**]	0.114	−0.452[**]	−0.320[*]	−0.421[**]	0.373[**]	−0.299[*]	0.658[**]
M15	−0.435[**]	1	−0.003	0.987[**]	0.418[**]	0.227	−0.156	0.221	−0.922[**]
M26	0.114	−0.003	1	−0.017	0.002	0.063	0.043	0.277	−0.383[**]
M30	−0.452[**]	0.987[**]	−0.017	1	0.398[**]	0.220	−0.174	0.239	−0.924[**]
NH_4^+–N	−0.320[*]	0.418[**]	0.002	0.398[**]	1	0.446[**]	−0.031	0.293[*]	−0.434[**]
TN	−0.421[**]	0.227	0.063	0.220	0.446[**]	1	−0.102	0.196	−0.299[*]
Cl^-	0.373[**]	−0.156	0.043	−0.174	−0.031	−0.102	1	0.042	0.175
LDI	−0.299[*]	0.221	0.277	0.239	0.293[*]	0.196	0.042	1	−0.302[*]
IBI	0.658[**]	−0.922[**]	−0.383[**]	−0.924[**]	−0.434[**]	−0.299[*]	0.175	−0.302[*]	1

[*]Correlation is significant at the 0.05 level (2 tailed)

[**]Correlation is significant at the 0.01 level (2 tailed)

Conclusions

To be fully aware of the ecosystem health status of Qin River in the Jincheng region, Shanxi Province, China, benthic macroinvertebrates were investigated and community characteristics were analyzed in the autumn of 2020; a Benthic index of Biotic Integrity (B-IBI) was established. The index can provide quick evaluation of ecological conditions. Four metrics incorporated into the index effectively discriminated the reference from impaired sites and correlated with the environmental variables, indicating that the final index is capable of determining the ecological integrity in our study area. The health assessment of Qin and Dan rivers indicated that the two rivers have experienced strong anthropogenic pressure and substantial changes in community characteristics of benthic macroinvertebrates. This study found that total nitrogen and ammonium input is associated with the dominance of collector-gatherers and has strong negative impacts on Qin and Dan river health, suggesting that minimizing nitrogen input should be paid more attention in river management. This study also found collector-gatherers were largely abundant across the riparian areas with high percentages of rural land and agricultural land, indicating the importance of riparian vegetation in preventing and minimizing nutrition inputs and providing habitats to various species. Conservation measures including minimizing wastewater discharge from nitrogenous fertilizer, mining, chemical material manufacture, and increasing forest and grass land in the riparian areas should be implemented to prevent and remediate the continuing degradation of the rivers.

Author contribution Yanli Li conceived the study and drafted this manuscript. Xue Li analyzed the hydrochemical compositions and investigated the plankton communities in Qin River in Jincheng region. Data collection and analysis were performed by Qingwei Liu, Zongxue Xu, and Mingshi Wang. All authors read and approved the final manuscript.

Data availability Data can be requested from the corresponding author.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication All authors are approved for this publication.

Competing interests The authors declare no competing interests.

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