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# Research on Theory and Method of River Health Assessment

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**Abstract:** On the basis of comprehensive analysis on connotation, assessment methods and index system of river health, combined with the national river health assessment pilot project, river health assessment system is improved by increasing indicators and correcting their weights. The weights of ecological health and functional health of each zone in the national ecological function zoning are revised. According to each river's characteristics and ecological function type in water ecological zone, the weights of four indicators (hydrology, physical form, water quality and aquatic life) of ecological health are determined by the procedure of expert proposal - initial determination - feedback - inspection - revision. Taking the mainstream of the Yellow River from Huayuankou Station to Gaocun Station as an example, its health condition is assessed by determining weights of ecological health (including the weights of its four indicators in criteria layer) and functional health according to the ecological-functional partition and water ecological zoning it belongs to. The result is at the lower limit of good level.

**Keywords:** Assessment, index system, river health, water ecology, weight.

## 1. INTRODUCTION

The river is the source of life and the cradle of human civilization. River health is the material basis and assurance of human survival and economic development. However, with the rapid development of the social economy, demand for water increases continuously. River has become the focus of development as a major source of fresh water. Construction of sluices, dams, water diversion project benefits human greatly. While under the dual factors of large-scale development and climate change, some rivers and lakes appears problems such as water deterioration, change of morphology, structure and hydrological condition, habitat degradation as well as disappearance of important or sensitive aquatic life in varying degrees. Human development needs a healthy river system. Human need to maintain the sustainable use of river resource, and river management needs a new development model. Therefore research on river health has an important practical implication.

## 2. CONNOTATION OF RIVER HEALTH

River health assessment is an evaluation tool for river management. It assesses the river health condition timely and objectively and offers scientific basis for monitoring and coordinating sustainable utilization of water function and sustainable development of economy. In 1970s, the concept of river health began to be used in river management in the United States. In 1990s, Australia, South Africa launched a National River Health Plan. In the late 1990s, British established a river protection assessment system. In the early 2000s, basin authorities such as the Yangtze River, Yellow River, Pearl River Water Resources Commission has taken actions in the river health assessment index system and river health theory and management. On the national level, the Ministry of Water Resources launched a national river health assessment pilot project in 2010, but the assessment report has not been officially announced currently. From the research results at home and abroad, the connotation of river health should include two aspects. One is the health of the river itself, which mainly refers to the river's water quantity, water quality, physical form and aquatic life. It is not only the basis of river life, but also the premise for river to realize every function. The other is the social service functions of river, namely the degree of its support and contribution to human society and economy. It is a comprehensive reflection of the river's contribution to human society and economy, and the significance of human maintaining river health in mind. It is an important symbol of the river vitality, and ultimately affects the basin's sustainable development of society and economy. In summary, healthy river means the river has good natural ecology, resistance and resilience to long-term effects of natural disturbances, as well as sustainable social service function.

## 3. METHOD OF RIVER HEALTH ASSESSMENT

Scholars at home and abroad divided methods of river health assessment into indicator species method and comprehensive index method based on the content of the evaluation. Indicator species method takes fish, diatoms and macroinvertebrates as objects to assess the health of river ecosystem. This method is relatively simple, but there is obvious a

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defect, that is, different study objects and monitoring parameters will lead to different assessment results. Comprehensive index method a ecosystem heath assessment method which integrates indicators such as physics, chemistry, biology, and social economy to reflect different scales of information. It can reflect the health condition, the social function level and the change trend of ecosystem health of river. IBI, RCE and ISC are representative.

The methods will be divided into the forecasting model method and multi-index assessment method according to the principle of evaluation. Forecasting model method compares the theoretic (*i.e.*, without human disturbance) species composition with the actual species composition to assess the river health condition. This method evaluates river health condition by comparing a single species, and assumes that any change of the river will be reflected in the changes of this species. If damages of river health are not reflected in the changes of selected species, it can't reflect the real situation. RIVPACS and AUSRIVAS are representative. Multi-index assessment method scores biological, chemical and morphological characteristics of the river respectively based on the evaluation standard, and takes the total score as a basis for the river health assessment. Multi-index assessment method uses far more factors than the forecasting model method. But it is difficult to establish the evaluation standard, so it lacks precision and overshadows information of a single parameter to some extent. RHS, RHP, ISC are representative.

Foreign scholars divided river health assessment methods into a top-down evaluation method and the bottom-up evaluation method by analyzing the assessment framework. Top-down evaluation method tests the system's basic reaction under external pressure. Its disadvantage is that it is difficult to ensure that reactions of all system components under external pressure are taken into account in assessment system. Bottom-up evaluation method is based on the simple causal relationship between external pressure and its influence on the system revealed by the accumulated data to assess the health condition of the system, and it emphasizes the structural properties of natural system. This method requires a lot of temporal and spatial information of river, and it's also necessary to consider the reaction of system to a single external pressure or more.

## 4. ASSESSMENT INDEX SYSTEM

River health condition is influenced by both nature and human activities. Reducing disturbances from human activities and nature and improving the ability of river to resist unhealthy factors can improve the health level of river. River health assessment index system is to be able to describe and reflect accurately the health level of river in a certain period and identify the pressure influencing river health and the relationship between stresses and changes of river health to serve to maintain river health, and provide basis for government to make decisions regularly. Therefore, assessment index system must be able to reflect the river health condition truly, objectively, completely and accurately, so that the assessment result is able to provide analysis on current condition and changing trend of river health and reasons of river health recession. The following factors should be considered when choose the river health assessment indicators: (1) the changing reasons of indicator can be basically identified; (2) the indicator can be long-term monitored and assessed; (3) the indicator can reflect the dual natural-artificial characteristics; (4) the assessment results can provide a basis for horizontal comparison so that results of similar rivers in different regions can be compared.

Assessment index system in "Indicators, Standards and Methods of River Health Assessment (for experimental work)" issued by the Ministry of Water Resources uses 3 layers, *i.e.*, target layer, criteria layer and indicator layer, to assess river health based on the principle of analytic hierarchy process (AHP). Target layer reflects the holistic river health condition and includes the ecological health and functional health. It is a comprehensive evaluation of the river health, calculated gradually from criteria layer and indicator layer. Criteria layer assesses the health of the river from five aspects including hydrology, physical form, water quality, aquatic life and social service function. Ecological health consists of four indicators in criteria layer, namely hydrology, physical form, water quality and aquatic life. Functional health is constituted by social service function. Indicator layer uses quantitative or semi-quantitative indicators selected from every criteria layer to reflect the river health condition directly. It includes obligatory indicators and optional indicators according to the actual situation of the river selected. It is impossible for the assessment system in our country to achieve the degree of foreign focusing on ecological conservation. It is unscientific and irrational to maintain the original state of the river realistically. So we need to unify the protection and development of rivers, and determine the weights of natural function and social function. It will build a better river health assessment system by making the connotation of river health clear according to the actual condition. Assessment index system recommended in the document is shown in Fig. (**1**). Weights of ecological health and functional health proposed in it are 0.7 and 0.3, and weights of hydrology, physical form, water quality and aquatic life in criteria layer are 0.2, 0.2, 0.2 and 0.4. Indicator layer is constituted by 12 obligatory indicators and optional indicators of the basin which are scored according to pre-set scoring standard. But because China has a vast territory and a plenty of river types, different rivers are different in natural conditions such as geographical location and climatic regime, even conditions such as climate, topography, biological systems and dominant ecological functions of different reaches of the same river are different greatly because of different natural zones. At the same time, socio-economic development and water resources utilization degree of different regions in our country are also quite different, so the characterizations of river health are different and using uniform weights can't distinguish functional focuses of different partitions. Key to establish the national river health assessment standard is to build a river health assessment system which reflects both common ecological characteristics of national rivers and peculiar characteristics of different basins and reaches. Dividing partitions reasonably, highlighting the weights of indicators and reflecting features of the region are factors which must be considered.

The obligatory indicators in the assessment index system recommended by the Ministry of Water Resources can't re-

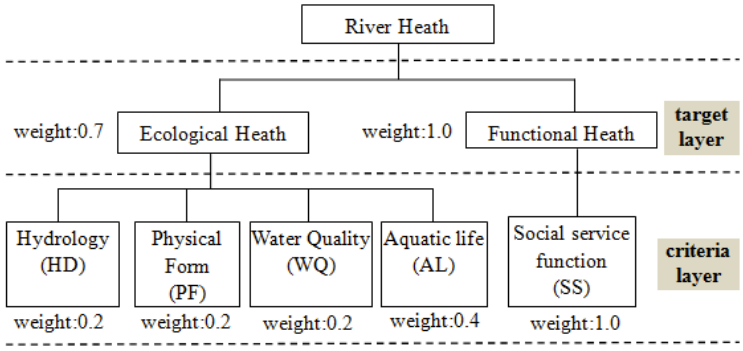


**Fig. (1).** The river health assessment index system (recommended).

**Table 1. Recommended weights of ecological health and functional health in target layer of each ecological function zone Grade 2.**

| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $E_6$ | $E_7$ | $E_8$ | $E_9$ |
|---|---|---|---|---|---|---|---|---|---|
| ecological health | 0.95 | 0.90 | 0.90 | 1.00 | 0.90 | 0.75 | 0.80 | 0.70 | 0.65 |
| functional health | 0.05 | 0.10 | 0.10 | 0.00 | 0.10 | 0.25 | 0.20 | 0.30 | 0.35 |

flect groundwater condition. Natural contact and mutual exchange of surface water and groundwater are of great significance to maintain eco-system of rivers and basins. Premise of maintaining the contact and exchange is to avoid over-exploitation of groundwater or to maintain a reasonable groundwater level, so it is recommended to take the groundwater exploitation coefficient as an obligatory indicator of hydrology.

According to "The National Ecological Function Zoning", ecological function zone Grade 1 has 3 types, *i.e.*, ecological regulation zone, products providing zone and residential guarantee zone, which include 31 partitions. Ecological function zone Grade 2 has 9 types, *i.e.*, water conservation ($E_1$), water and soil conservation ($E_2$), wind-break and sand-fixation ($E_3$), biodiversity conservation ($E_4$), flood regulation ($E_5$), agricultural products providing ($E_6$), forest products providing ($E_7$), metropolitan group ($E_8$) and important urban agglomeration ($E_9$), which include 67 partitions.

Based on the water resources partition and ecological function zoning in our country, there are four water ecological zones in the first grade, namely eastern zone, central zone, northwest zone and southwest zone. Water ecological zone Grade 1 is divided into 34 partitions according to ecological functions such as climate, rainfall, population density, metropolitan distribution, water conservation, biodiversity, soil and water conservation, wind-break and sand-fixation, agricultural products base and considering national ecological function zoning and water resources partition. There are 13 in eastern zone, 10 in central zone, 6 in northwest zone, 5 in southwest zone.

Due to natural attribute and leading service function of different water ecological zone are different, there are different focuses for river health assessment in different water ecological zone. Weights of ecological health and functional health are determined according to the ecological function zone the river studied belongs to. Weights of hydrology, physical form, water quality and aquatic life in criteria layer and evaluation indicators are determined according to the main ecological function of water ecological zone and water resources partition the river studied belongs. There are obligatory indicators to facilitate national comparison among assessment results. While there are optional indicators reflecting characteristics of basins to reveal differences of rivers. Recommended weights of ecological health and functional health in target layer for each ecological function zone are determined in Table **1** considering major function of the zone.

Ecological health in target layer includes hydrology, physical form, water quality, aquatic life in criteria layer. Their recommended weights are determined by the procedure of expert proposal - initial determination - feedback - inspection - revision combined with the key factors and characteristics of water ecological zones, water resources partitions and ecological function zones (Table **2**).

## 5. CASE STUDY

The article studies river health assessment index system taking the Yellow River from Huayuankou Station to Gaocun Station as a study region. The reach length is 189km, and the main tributary is Tianranwenyanqu. Within the lower reach from Huayuankou Station which is important to flood control in the Yellow River, the mainstream wanders frequently with many shoals in the broad river and dikes are built. The reach from Huayuankou Station to Dongbatou Station is wide and shallow and the river channel of the reach from Dongbatou Station to Gaocun Station is above the beachface on both sides. According to the water resources partition in Yellow River Basin, this reach is divided into the lower mainstream interval from Huayuankou Station of water resources partition Grade 2, which belongs to the lower mainstream from Huayuankou Station of water resources partition Grade 1. This reach includes mainly Kaifeng, Puyang, Xinxiang and Zhengzhou of Henan Province. Water function zones it belongs to are drinking and industrial water consumption zones of Kaifeng and Puyang

**Table 2. Recommended weights of indicators in criteria layer of ecological health.**

| Number | Water Ecological Zone | Main Eco-Functions | HD | PF | WQ | AL |
|---|---|---|---|---|---|---|
| 1 | Sanjiang Plain | biodiversity conservation, agricultural products providing | 0.2 | 0.15 | 0.15 | 0.5 |
| 2 | Xiaoxing anling and Changbai Mountains | water conservation, forest products providing | 0.35 | 0.1 | 0.35 | 0.2 |
| 3 | Songnen Plain | water conservation, agricultural products providing | 0.35 | 0.15 | 0.35 | 0.15 |
| 4 | Liaohe Plain | wind-break and sand-fixation, agricultural products providing | 0.35 | 0.35 | 0.1 | 0.2 |
| 5 | Hills around Bohai | water and soil conservation, agricultural products providing | 0.35 | 0.2 | 0.1 | 0.35 |
| 6 | Huanghe-Haihe Plain | agricultural products providing | 0.25 | 0.25 | 0.25 | 0.25 |
| 7 | Huaihe Plain | agricultural products providing | 0.25 | 0.25 | 0.25 | 0.25 |
| 8 | Dabie-Tongbai Mountains | water conservation, agricultural products providing | 0.35 | 0.15 | 0.35 | 0.15 |
| 9 | Middle and lower plain of the Yangtze River | water and soil conservation, biodiversity conservation, agricultural products providing | 0.3 | 0.2 | 0.2 | 0.3 |
| 10 | Yangtze River Delta | biodiversity conservation, agricultural products providing | 0.3 | 0.2 | 0.15 | 0.35 |
| 11 | Zhejiang-Fujian-Taowan Hills | water and soil conservation, biodiversity conservation, forest products providing | 0.3 | 0.25 | 0.15 | 0.3 |
| 12 | Nanling-Jiangnan Hills | water conservation, water and soil conservation, agricultural products providing | 0.35 | 0.15 | 0.3 | 0.2 |
| 13 | South China Coast | biodiversity conservation, agricultural products providing | 0.3 | 0.15 | 0.2 | 0.35 |
| 14 | Daxing anling Mountains | water conservation, forest products providing | 0.35 | 0.1 | 0.35 | 0.2 |
| 15 | Taihang-Yanshan-Funiu Mountains | water conservation, water and soil conservation | 0.35 | 0.15 | 0.25 | 0.25 |
| 16 | Fen-Wei Basin | water and soil conservation, agricultural products providing | 0.3 | 0.25 | 0.2 | 0.25 |
| 17 | Loess Plateau | water and soil conservation, wind-break and sand-fixation | 0.3 | 0.3 | 0.1 | 0.3 |
| 18 | Ningmeng Irrigation Area | wind-break and sand-fixation, agricultural products providing | 0.25 | 0.25 | 0.25 | 0.25 |
| 19 | Qinba Mountains | water conservation, biodiversity conservation, agricultural products providing | 0.35 | 0.15 | 0.35 | 0.15 |
| 20 | Sichuan Basin | water conservation, agricultural products providing, forest products providing | 0.35 | 0.15 | 0.3 | 0.2 |
| 21 | Yunnan-Guizhou Plateau | water conservation, water and soil conservation, biodiversity conservation | 0.25 | 0.1 | 0.3 | 0.35 |
| 22 | Guizhou-Guangxi Mountains | water conservation, water and soil conservation, biodiversity conservation | 0.25 | 0.1 | 0.25 | 0.4 |
| 23 | Southern Yunnan Valley | agricultural products providing, biodiversity conservation | 0.2 | 0.15 | 0.15 | 0.5 |
| 24 | Inner Mongolia Plateau | water and soil conservation, agricultural products providing | 0.35 | 0.2 | 0.1 | 0.35 |
| 25 | Qilian Mountains and Hexi Corridor | water conservation, wind-break and sand-fixation, agricultural products providing | 0.35 | 0.2 | 0.25 | 0.2 |
| 26 | Altai Mountains | biodiversity conservation, agricultural products providing | 0.2 | 0.15 | 0.15 | 0.5 |
| 27 | Tianshan Mountains | agricultural products providing, water conservation, wind-break and sand-fixation | 0.35 | 0.2 | 0.25 | 0.2 |
| 28 | Northern slope of Kunlun Mountains | biodiversity conservation, agricultural products providing, wind-break and sand-fixation | 0.25 | 0.1 | 0.15 | 0.5 |
| 29 | Northwest China Desert | wind-break and sand-fixation | 0.3 | 0.2 | 0.2 | 0.3 |

**Table 2. Contd…..**

| Number | Water Ecological Zone | Main Eco-Functions | HD | PF | WQ | AL |
|---|---|---|---|---|---|---|
| 30 | Qaidam Basin and Qinghai Lake | wind-break and sand-fixation, biodiversity conservation, water conservation | 0.2 | 0.1 | 0.35 | 0.35 |
| 31 | Sanjiang Yuan | water conservation | 0.3 | 0.4 | 0.1 | 0.2 |
| 32 | Qiangtang Plateau | biodiversity conservation | 0.2 | 0.1 | 0.2 | 0.5 |
| 33 | South Tibet Vally | biodiversity conservation, water conservation, agricultural products providing | 0.2 | 0.1 | 0.3 | 0.4 |
| 34 | Hengduan Mountains | biodiversity conservation, water conservation, agricultural products providing | 0.2 | 0.1 | 0.3 | 0.4 |

**Table 3. The river health assessment index system.**

| | Target Layer | Criteria Layer | Indicator Layer | Note |
|---|---|---|---|---|
| River health assessment index system | Ecological health (0.65) | Hydrology (HD) (0.25) | Flow process variability degree(0.30) | Reflecting the differences between actual monthly runoff process and natural monthly runoff process |
| | | | Ecological flow satisfaction degree(0.45) | Flow process for maintaining ecosystem structure and function in different degree |
| | | | Groundwater exploitation coefficient(0.25) | The ratio of actual exploitation to allowable exploitation of groundwater in certain region |
| | | Physical Form (PF) (0.25) | Riparian condition(0.20) | Reflecting the slope stability, riparian vegetation coverage and artificial disturbance |
| | | | River connectivity condition(0.15) | Reflecting whether construction of sluices and dams obstructs runoff and fish |
| | | | Retention rate of natural wetlands(0.15) | Reflecting superiority of river eco-environment |
| | | | Flow capacity of main channel(0.25) | Reflecting cross section morphology, size and sidewall roughness of main channel |
| | | | Elevation difference between beach and channel(0.25) | The difference of average elevations between beach and channel |
| | | Water quality (WQ) (0.25) | Dissolved oxygen (DO) | The concentration of dissolved oxygen in water |
| | | | Oxygen-consumption organics | Reflecting oxygen consumption of river by four indicators, namely $COD_{Mn}$, $COD_{Cr}$, $BOD_5$, $NH_4^+$-N |
| | | Aquatic life (AL) (0.25) | Benthic index of biotic integrity(B-IBI) | Parameters include species number, species richness, species diversity indicator, resistance to fouling and resilience |
| | | | Fish loss exponent (FLE) | The ratio of fish species number surveyed to that of 1981 in river studied |
| | Functional health (0.35) | Social service function (SS) (1.00) | development and utilization rate of water resources(0.15) | The ratio of utilization to total volume of water resources in river |
| | | | standard-reaching rate of water function zones(0.15) | Scoring it based on ratio of standard-reaching number to total number of water function zones |
| | | | flood control indicator(0.30) | Reflecting integrity of engineering measures and non-engineering measures in flood control |
| | | | public satisfaction(0.20) | Public satisfaction to river landscape, aesthetic value and so on |
| | | | safe condition of drinking water source(0.20) | Evaluating it from water quantity, water quality, pollution sources in water source conservation zones and so on |

**Table 4. River health assessment levels.**

| Level | Score | Note |
|---|---|---|
| Excellent | 80~100 | Close to reference condition or expected target |
| Good | 60~80 | A little different from reference condition or expected target |
| Fair | 40~60 | Different from reference condition or expected target |
| Bad | 20~40 | Very different from reference condition or expected target |
| Worst | 0~20 | Obviously different from reference condition or expected target |

**Table 5. Score of ecological flow satisfaction degree of the main hydrologic section in reach studied.**

| Section | Minimum Daily Flow ($m^3/s$) | | Average Daily Flow of Many Years ($m^3/s$) | | Percentage (%) | | Score of Each Indicator | | Final Score |
|---|---|---|---|---|---|---|---|---|---|
| | Apr.~Sept. | Oct.~Mar. | Apr.~Sept. | Oct.~Mar. | Apr.~Sept. | Oct.~Mar. | $EF_1$ | $EF_2$ | |
| Gaocun | 406 | 466 | 1610.67 | 1736.07 | 25.21 | 26.84 | 35 | 94 | 35 |

mainly. Water ecological zone it belongs to is the Huanghe-Haihe Plain.

According to the characteristics of the reach, assessment system consists of 17 indicators. 4 indicators, namely the retention rate of natural wetlands, the flow capacity of main channel, elevation difference between beach and channel and the safe condition of drinking water source are added as the basin's optional indicators in addition to 13 obligatory indicators and weights of indicators in target layer and criteria layer are built combined with ecological function zoning and water ecological zoning (Table **3**).

## 5.1. River Health Index

Obligatory indicators are scored using calculation method and scoring standard in the document and optional indexes are calculated according to its characteristics and actual situation. River health assessment scores indicators in each layer and uses weighted sum to calculate health index comprehensively. According to public understanding to the river health and acceptance, the assessment results are divided into 5 levels (Table **4**): excellent, good, fair, bad and worst, instead of the original 5 levels: ideal, healthy, sub-healthy, unhealthy and sick.

### *5.1.1. Indicator Assessment of Hydrology*

#### *5.1.1.1. Flow Process Variability Degree*

According to the formula of flow process variability degree in the document (calculating with this formula hereinafter unless noted otherwise), flow process variability degree (FD) at Gaocun Station is 2.43, and variability degree is relatively large because water consumptions in August, September and October are large and the total water consumption accounts for more than 70% of natural runoff.

According to scoring standard for indicator of flow process variability degree, its score at Gaocun Station is 18.03 with linear interpolation method. From the result, its score is low and it is in worst level.

#### *5.1.1.2. Ecological Flow Satisfaction Degree*

Ecological flow satisfaction degree, *i.e.*, the minimum percentages of measured average daily flows from April to September and from October to March for average daily flow of many years, at Gaocun Station in 2010 is calculated with the recommended formula. The minimum percentages (EF1 and EF2) in two periods are scored with linear interpolation method according to scoring standard and the minimum score is taken as the score of the indicator (Table **5**), from which we know the reach studied is in bad level.

#### *5.1.1.3. Groundwater Exploitation Coefficient*

Groundwater exploitation coefficient is the ratio of actual exploitation to allowable exploitation of groundwater in certain region. In development and utilization of groundwater, groundwater level will continues to decline, forming a regional groundwater funnel, leading the contact and conversion between surface water and groundwater interrupt and river runoff attenuation if actual exploitation exceeds the allowable exploitation of groundwater. Average annual groundwater exploitation coefficient is the ratio of average annual actual exploitation to average annual allowable exploitation, whose units are both ten thousand m3, in development and utilization of groundwater. Table **7** is scoring standard of groundwater exploitation coefficient.

According to data of water resources partition in "Water resources Bulletin in the Yellow River Basin (2012)", groundwater exploitation coefficient in region studied is 95%. Its score is 75.0 and it's in good level.

Score of hydrology is calculated according to the scores of above three indicators. Weights of flow process variability degree, ecological flow satisfaction degree indicator and groundwater exploitation coefficient are 0.30, 0.45, 0.25 respectively. And score of hydrology in criteria layer is 39.91.

**Table 6. Scoring standard of groundwater exploitation coefficient.**

| Groundwater Exploitation Coefficient | <80 | ≤90 | ≤100 | ≤130 | >130 |
|---|---|---|---|---|---|
| score | 100 | 80 | 70 | 40 | 20 |

**Table 7. Score of water quality in criteria layer.**

| Section | | Score of Each Indicator | | Score of WQ |
|---|---|---|---|---|
| | | DO | Oxygen-Consumption Organics | |
| 2010 | Huayuankou | 85 | 83.9 | 83.9 |
| | Gaocun | 87.7 | 84.2 | 84.2 |
| | Comprehensive evaluation | 86.4 | 84.1 | 84.1 |

**Table 8. Assessment results of the FLE indicator.**

| Reach | FLE | Score of FLE | Level |
|---|---|---|---|
| Huayuankou to Liuyuankou | 0.42 | 23.60 | Bad |
| Liuyuankou to Gaocun | 0.29 | 13.20 | Worst |

### *5.1.2. Indicator Assessment of Physical Form*

#### *5.1.2.1. Riparian Condition*

Riparian condition is evaluated from the slope stability, riparian vegetation coverage and artificial disturbance. Riparian condition of reach from Huayuankou Station to Gaocun Station is scored with linear interpolation method according to scene investigation and scoring standard. Riparian vegetation coverage is scored directly according to investigation results of terrestrial vegetation (trees, shrubs and herbages) coverage in riparian. Artificial disturbance reflects the influence of 10 kinds of human activities in riparian and land area nearby, including riverbank hardening lining, sand excavation, buildings, roads, waste landfill sites, riverside park, pipelines, mining, agriculture farming and livestock breeding. Score reduces correspondingly if there is a kind of human activity. After calculation, scores of slope stability, riparian vegetation coverage and human disturbance are 35, 42.1, 90 respectively. Comprehensive score of riparian condition is 52.3.

#### *5.1.2.2. River Connectivity Condition*

River connectivity condition reflects whether construction of sluices and dams obstructs runoff and fish. There is no sluices and dams within reach from Huayuankou Station to Gaocun Station. So there is no obstruction and score is 100.

#### *5.1.2.3. Retention Rate of Natural Wetlands*

The mainstream of the lower Yellow River wanders frequently. Floodplain develops well, and there are a large number of wetlands on both sides, *i.e.* Henan Yellow River Natural Wetland, Zhengzhou Yellow River Natural Wetland, Kaifeng Liuyuankou Natural Wetland and Xinxiang Yellow River Natural Wetland according to the survey. According to natural wetland remote sensing interpretation data of the middle and lower reaches of the Yellow River in the 1980s and recent years, the natural wetland retention rate of this reach is 57.6%. So the score of natural wetland retention rate is 37.1.

#### *5.1.2.4. Flow Capacity of Main Channel*

The flood and sediment discharge capacity of main channel is related mainly to channel width, depth, cross section area, slope and so on. Bankfull discharge is the flow capacity of main channel when beachface is awash. It reflects cross section morphology, size and sidewall roughness comprehensively. The indicator assessment is reflected by calculating the ratio of the mean value to standard value of bankfull discharge of downstream main section in flood season and the score is 80. Gaocun Section can meet the standard bankfull discharge and channel morphology is in good level.

#### *5.1.2.5. Elevation Difference Between Beach and Channel*

The relationship between beach and channel of downstream riverbed in the 1950s, prior to the construction of the Sanmenxia Reservoir, is reasonable, based on historical data. Therefore, score of measured elevation difference between beach and channel in Gaocun reach is 70 according to scoring standard.

The score of physical form is calculated according to scores of above five indicators. Weights of riparian condition, river connectivity condition, retention rate of natural wetlands, flow capacity of main channel and elevation difference between beach and channel are 0.20, 0.15, 0.15, 0.25, 0.25 respectively, and score of physical form in reach from Huayuankou Station to Gaocun Station is 68.53.

**Table 9. River health assessment result of the reach studied.**

| Target Layer | Criteria Layer | Indicator Layer | Score | | | |
|---|---|---|---|---|---|---|
| | | | Target Layer | Criteria Layer | Indicator Layer | |
| Ecological health (0.65) | Hydrology (HD) (0.25) | Flow process variability degree(0.30) | 18.03 | 39.91 | 52.84 | 60.24 |
| | | Ecological flow satisfaction degree(0.45) | 35.00 | | | |
| | | Groundwater exploitation coefficient(0.25) | 75.00 | | | |
| | Physical form (PF) (0.25) | Riparian condition(0.20) | 52.30 | 68.53 | | |
| | | River connectivity condition(0.15) | 100.00 | | | |
| | | Retention rate of natural wetlands(0.15) | 37.10 | | | |
| | | Flow capacity of main channel(0.25) | 80.00 | | | |
| | | Elevation difference between beach and channel(0.25) | 70.00 | | | |
| | Water quality (WQ) (0.25) | Dissolved oxygen (DO) | 86.40 | 84.10 | | |
| | | Oxygen-consumption organics | 84.10 | | | |
| | Aquatic life (AL) (0.25) | Benthic index of biotic integrity(B-IBI) | 45.00 | 18.40 | | |
| | | Fish loss exponent (FLE) | 18.40 | | | |
| Functional health (0.35) | Social service function (SS) (1.00) | development and utilization rate of water resources(0.15) | 100.00 | 74.00 | 74.00 | |
| | | standard-reaching rate of water function zones(0.15) | 0.00 | | | |
| | | flood control indicator(0.30) | 100.00 | | | |
| | | public satisfaction(0.20) | 75.00 | | | |
| | | safe condition of drinking water source(0.20) | 70.00 | | | |

### *5.1.3. Indicator Assessment of Water Quality*

#### *5.1.3.1. Dissolved Oxygen (DO)*

DO is important to aquatic plants and animals, and too much or too little DO will harm aquatic life both. The average scores of DO in flood season and non-flood season are calculated respectively, and the minimum value between them is the final score of DO.

#### *5.1.3.2. Oxygen-Consumption Organics*

Oxygen-consumption organics include permanganate index (CODMn), chemical oxygen demand (CODCr), five-day biochemical oxygen demand (BOD5), ammonia-nitrogen (NH4+-N) and so on. The average scores of these indicators in flood season and non-flood season are calculated respectively, and the minimum value between them is the final score of oxygen-consumption organics.

Score of water quality is the minimum score between DO and oxygen-consumption organics (Table **7**).

### *5.1.4. Indicator Assessment of Aquatic Life*

#### *5.1.4.1. Benthic Index of Biotic Integrity (B-IBI)*

B-IBI is evaluated according to recommended assessment standard. 95% quantile of reference point is 27. The maximum value should be 70.33 in the formula. The optimum expected value is 5% quantile of reference point, namely 11.9. The evaluation result indicates that B-IBI of reach from Huayuankou Station to Gaocun Station is 1.21 and its score is 45. This reach is in fair level.

#### *5.1.4.2. Fish Loss Exponent (FLE)*

Theo the formula of the fish loss exponent (FLE). Compared with historical data, fish species i fish species number in the downstream surveyed in 1981 is taken as criterion according t n the reach from Huayuankou Station to Liuyuankou Station reduce to 27 from 65, so FLE of this reach is 0.42 and the score is 23.6; fish species in the reach from Liuyuankou Station to Gaocun Station reduce to 19, so FLE of this reach is 0.29 and the score is 13.2 (Table **8**).

Score of B-IBI in reach from Huayuankou Station to Gaocun Station is 45, and score of FLE is 18.4, so the score of aquatic life in criteria layer is 18.4. B-IBI is in fair level, FLE is in worst level, and aquatic life of the entire reach studied is in bad level.

### *5.1.4. Indicator Assessment of Social Service Function*

Scores of indicators such as standard-reaching rate of water function zones, development and utilization rate of water

resources, flood control indicator, safe condition of drinking water source and public satisfaction are 100.00, 0.00, 100.00, 75.00, 70.00 respectively according to their own scoring formulas. Weights of all indicators are 0.15, 0.15, 0.30, 0.20, 0.20 respectively with AHP. Score of social service function in indicator layer of reach from Huayuankou Station to Gaocun Station is 74.0. From scoring results, scores of all other indicators are more than 70, except score of water resources development and utilization rate is very low. Social service function in the reach studied is in good level comprehensively.

### 5.2. River Health Assessment Result of the Reach Studied

The reach studied is in important urban agglomeration (E9) of ecological function zone Grade 2 according to "The National Ecological Function Zoning". Weights of ecological health and functional health are 0.65, 0.35 respectively based on the above outcomes. Water ecological zone it belongs to is the Huanghe-Haihe Plain. Weights of hydrology, physical form, water quality and aquatic life in criteria layer are all 0.25. River health assessment result is in Table **10**. From the result, ecological health of this reach is in fair level, functional health is in good level. Score of health condition is 60.24 at the lower limit of good level, which is a little different from the reference condition.

## CONCLUSION

On the basis of the national river health assessment pilot project, river health assessment system is improved further based on the dual natural-artificial characteristics by increasing groundwater evaluation indicator and correcting weights of river's ecological health and functional heath in different ecological function zones. It not only considers common ecological characteristics of national rivers to guarantee assessment results can be compared horizontally, but also reflects river's peculiar characteristics of different water ecological zones to coordinate the ecological function of water ecological zone and health assessment of river's ecological function from ecological health in the target layer. The Yellow River from Huayuankou Station to Gaocun Station is taken as a object and its score is 60.24, which is at the lower limit of good level. This result has a slight improvement compared with assessment result (sub-healthy level) in the national river health assessment pilot project and can reflect the actual health condition of the river well. This river health assessment system has a good prospect of application.

## CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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