River–human harmony model to evaluate the relationship between humans and water in river basin

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With the rapid population growth, ecological pressure caused by human activities on rivers is growing. Decision makers are often faced with the dilemma of how to maintain economic growth while also maintaining the resources of a river and its environment. In this study, a model has been proposed for the assessment of river–human relationship. The method establishes a complete index system to quantify the abstraction of river–human relationship and evaluation. The model provides a comprehensive assessment of river basin human–water relationship through 21 indicators and three dimensions, which include river health, human development and human–river coordination. The analytic hierarchy process is used to determine the index weights. This model is applied in Wei River Basin, northwestern China, where the present situation is evaluated along with finding the advantages and shortcomings. Thus the study provides a method for future development and water management.

Keywords: Human development, human–river coordination, river health, river–human harmony model.

RIVERS have been an integral part in the establishment and growth of human civilizations. During ancient times, human settlements were usually located near a river, with utilization of water for both agricultural purposes and raising livestock. Even in modern times, cities have been built alongside the rivers to use the water resources to support the development and progress of human civilization. Hence, human civilization is inseparably linked with rivers. However, the ecological balance of the river system is greatly affected due to anthropogenic activities like construction of dams, groundwater mining, pollution discharging and so on. Many rivers of the world are currently facing moderate to severe water crises due to population growth, industrialization, improved living standards and poor water management strategies[1]. More than 25% of the population of the world lives in arid or semi-arid areas where a shortage of water is a critical problem that requires resolution[2]. Although the development of various sectors like industries and agriculture is greatly dependent on the sustenance of water resources, the increasing water crisis due to inefficient utilization of available water resources is a serious threat to development[3]. Nowadays, water crisis occurs mainly because of water shortage, severe soil erosion, water pollution and water ecological degradation[4]. Improper or excessive utilization of water resources and the consequent water-related problems (e.g. stalinization, pollution, flooding, water scarcity, etc.) have hampered sustainable development of human societies. Thus, the human–water conflict has escalated on a global scale due to improper utilization of limited freshwater supplies. Hence, for a few decades the focus of discussion has been the imbalance of relationship between humans and river. The conflicts have been indicated as water vulnerability, water poverty, water deterioration, water scarcity and water security[5–8]. In recent times, more and more countries are facing water-related problems; these are not limited to countries lacking water, but also to water-rich countries[9].

Till date human–river relationship has experienced three stages of development and follows a predictable trajectory[6,10]. The first stage started in the primitive times, wherein human settlements were located near rivers and major waterways were used for both crop irrigation and fishing. However, the vulnerability to water disaster limited the development of human society. The second stage developed in traditional agrarian societies, when humans began building simple water conservation projects whose impact on the environment was minimal. This led to a brief period of harmony where the human–river relationship stabilized because of the comparatively low water demand. After the industrial revolution, human–river relationship entered the third stage. This was a period of rapid development in productivity and progress in human science and technology. Large-scale water conservancy facilities were constructed to facilitate better use of river resources. During this period, human activities resulted in several disasters, and the relationship between human and river has become increasingly hostile.

After numerous water disasters, many studies have been conducted to explore new evaluation models to assess the river–human relationship. Pimentel *et al.*[11] conducted a detailed data analysis of the status of the world's water and concluded that the development in

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every aspect of human life is closely linked with water. In another study, which was based on the connection between water and the ecological system, the concept of green water and blue water was introduced and vivid analysis was conducted to analyse the relationship between water, ecology and human society[12]. Vorosmarty *et al.*[13] argued that human activities are changing the global water cycle. They also pointed out that the impact of human activities like industrialization, urbanization and utilization of water resources had ten times direct effect on the water cycle on Earth than its impact on climate. Nilsson *et al.*[14] showed the influence on large river systems, due to human activities like dam construction. Recent studies involve the analysis of virtual water and the close relationship between economic and ecological human society[15]. The Global Water System concept provided by Hoff[16] considers the water cycle to be the global suite of water-related human, physical, biological and biogeochemical components and their interactions. These models are more concerned with human needs; they emphasize the long-term use of human resources and rivers, but ignore the requirements of the river itself.

Must a choice in human resource development be made to improve the human–river relationship? In Western culture, the concept of harmony was first proposed by the Greek philosopher and mathematician Pythagors. The Greek philosopher Plato (427–347 BC) adopted the theory to the political field, and famously wrote ‘justice is harmony’ in his book *The Republic*. In ancient China, according to Lao-tzu (571–471 BC) and Confucius (551–479 BC), harmony is an orderly, coordinated and natural development trajectory. Chuang-tzu (396–286 BC) first proposed the idea about the unity of nature and humans. In recent years, research is being done regarding human–water relationship. Zuo *et al.*[17] put forward human–water harmony evaluation model, for evaluating the relationship between humans and water. Ding *et al.*[10] combined the human–water harmony and developed the human–water harmony index evaluation system which has been utilized in several cities in China. Compared with the previous evaluation model, the harmonious development of thought is multidimensional and coordinated development. The model completes the balance of the time to reflect continuity and space. The harmonious model emphasizes inclusion and equality, while also considering a broader target. Based on earlier research, we propose the river–human harmony (RHH) theory. RHH refers to river and human systems being in a coordinated state and virtuous cycle, i.e. improving a river system under the premise of self-maintenance and development, and making river resources available for human survival, social, economic and sustainable development.

In this article, we discuss the architecture and functional modules of RHH model as well as the procedure for its design and application. This model is designed not only to systematize data and facilitate the evaluation of the river–human relationship, but also to analyse the weaknesses and advantages of river resources management and to guide decision makers to create targeted planning. To understand the complex river system and human system, a comprehensive analysis and evaluation can be performed using the RHH to facilitate the quantitative criteria. In the model, three dimensions – river health (RH), human development (HD) and human–river coordination (HRC) – and 21 indicators have been employed.

Methods

River system and human system are inseparable. The water cycle acts as a link between the two systems and forms a complex giant system. In our daily life, the river system provides various kinds of resources and energy for us to support the development of human society. At the same time the human population affects the river system through various activities, such as agricultural and industrial pollution discharge, water withdrawals for irrigation, domestic purposes and drainage, and dam construction. Thus, the river system is closely integrated with the human system and both interact as well as influence each other. The river system is composed of three subsystems – water resources, water environment and water disaster, whereas the human system comprises of society, economy and science (Figure 1).

RHH model

After analysing the constitution and function of the river system and human system respectively, we developed an evaluation index model to further evaluate river–human relationship. To make a comprehensive analysis of the river–human system, the concept of RHH should be transferred into quantitative description. On account of the constitutional and structural characteristics, with integration of the RHH concept, three principles are implemented in this study:

(1) River health: This is an evaluation dimension. The relationships between environmental variables that affect aquatic biota, such as habitat structure, flow regime, energy sources, water quality and biotic interactions, and biological condition comprise this dimension. Thus, a river system with undamaged ecological function has the ability of repairing, updating and possessing anti-interference. Additionally, for a river basin, water resources, the situation of water environment, and the frequency of occurrence of water disaster, are all important indexes to assess the health of a river basin.

(2) Human development: The key to growth of human civilization is the development in various sectors. Development implies the increase in socio-economic resources

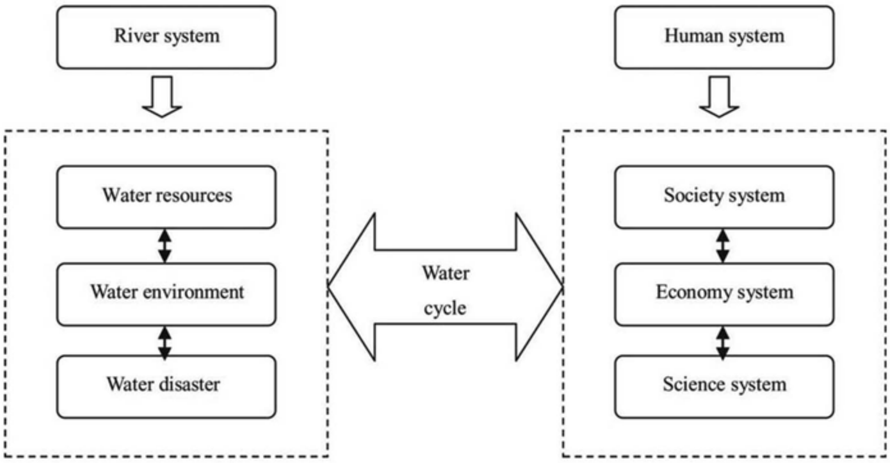

Figure 1. The framework of river–human system.

with sustainable utilization of Earth's life-supporting resources. Thus, development is a double-edged sword that requires a balanced approach and careful attention. Economic development without consideration for the environment can be extremely disastrous. However, restraining the social progress is also not desirable. Therefore, the establishment of a balance between river system and human system is important.

(3) Human–river coordination: The aforementioned two dimensions assess human system and river system and their coordination is primarily the interaction between both systems. Coordination refers to the state of mutual sustenance between human system and river system. Thus, for the river system to provide the necessary support and security for social and economic development of the human system, the latter should continuously provide protection to the health of the river basin and take up measures to improve river–human relationship. The lack of coordination may lead to severe conflicts between humans and river. This dimension reflects the sustainable development capacity in a particular region.

Selection of sub-indicators

The RHH model can be divided into three dimensions to evaluate river–human relationship, as described in the previous section, but the three dimensions are too abstract and provide only a preliminary analysis of the whole system. Since the dimensions are too abstract to be measured directly, they should be divided into basic indicators. Yang *et al.*[8] have summarized the indicator selection criteria, that is, the indicators should be theoretically well-founded, clear in content, relatively stable and independent, measurable and comparable, easy to quantify, regionally specific and acquirable. When selecting the indicators in this study, we primarily considered the diversity of data, availability and integrity. Accordingly, we can develop an accurate assessment of the study area. These indicators are basic cells of the complex system. Based on theory, we can establish the index system.

Step 1: According to the characteristics of the three dimensions, we selected 100 representative indicators and constructed the preliminary evaluation index system.

Step 2: Twenty-five water conservation experts were invited to offer advice on the index system established in step 1 and complete a questionnaire. If more than half of the experts considered the indicator to be reasonable, then it was retained.

Step 3: The second round questionnaire on the indicators filtered in step 2 was completed, step 2 repeated, and then the second round evaluation index system were constructed.

Step 4: The independence and sensitivity of the indicators selected in step 3 were analysed.

Step 5. If the decision makers were not satisfied with the indicators, then we return to step 3 until they considered it to be reasonable.

The data of RHH model mainly include three aspects – continuous improvement of the river system health, sustainable development of human system, and coordinated development of human and river systems. Appropriate data can be collected using two main approaches: first, we can access relevant data, such as research papers, books, government documents and some technical methods can also be effective, such as remote sensing. Second, surveys can be used; we can make some field surveys at the study area. Based on these, 21 indicators were selected for the RHH model (Table 1).

Normalization of the indicators

Some of the indicators are qualitative and are based on the subjective feeling of people. These indicators are quantified using the Delphi method[18]. The indicators in the basic indicator system can be classified into two

Table 1. Basic indicators of river–human harmony (RHH)

Dimension	Category	Basic indicator
River health (RH)	Water resources system	Water amount per unit area (m^3/km^2)
	Water environment system	Percentage of monitoring river sections with water quality better than Class III (including class III)*
		Percentage of forest cover
	Water disaster system	Frequency of flood disaster
		Rural erosion rate
Human development (HD)	Economy system	Per capita GDP (Yuan RMB)
		GDP growth rate (%)
		Urban–rural income gap (Yuan RMB)
	Society system	Population density ($people/km^2$)
		Urbanization rate (%)
		Population growth rate (%)
		Per capita output of grain (kg/people)
	Science system	Industrial production water consumption of 10,000 Yuan RMB (m^3/Yuan RMB)
		Norm of irrigation water capacity (m^3/km^2)
		Industrial wastewater recycling rate (%)
Human–river coordination (HRC)	Water–society	Degree of satisfaction water supply (%)
		Degree of satisfaction of the ability of water hazard emergency management (%)
	Water–economy	Degree of satisfaction water pollution treatment (%)
		Degree of satisfaction of soil and water loss treatment (%)
	Water–price	Degree of satisfaction of water price (%)
	Water–science	Water-saving conscience (%)

*Class III refers to class III in the national water quality standard of China. Water quality better than Class III (including class III) mainly requires: dissolved oxygen ≥ 5 mg/l, COD ≤ 20 mg/l, BOD_5 ≤ 4 mg/l and ammonia nitrogen ≤ 1.0 mg/l.

categories. One is positive, bigger the better, and the other is negative, i.e. smaller the better. Then, the dimensionless values of both positive and negative indicators are calculated as shown in eqs (1) and (2) below. Both equations result in the index value in the range 0–1.

$$\mathrm{SR}_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}, \tag{1}$$

$$\mathrm{SR}_i = 1 - \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}, \tag{2}$$

where SR_i is the index indicating the study region i, x_i the actual value of the basic indicator of the study region i, and $x_{\min}$ and $x_{\max}$ are the minimum and maximum values in the sample set respectively.

Calculation of the dimensions

As mentioned earlier, in the RHH system the three dimensions are RH, HD and HRC. Once the values of the 21 indicators have been determined, the values of the three dimensions are determined using eqs (3)–(5).

$$\mathrm{HR}_i = \sum_{i=1}^{n_1} w_{i\mathrm{H}} \mathrm{SR}_i, \tag{3}$$

$$\mathrm{DR}_i = \sum_{i=1}^{n_2} w_{i\mathrm{D}} \mathrm{SR}_i, \tag{4}$$

$$\mathrm{CR}_i = \sum_{i=1}^{n_3} w_{i\mathrm{C}} \mathrm{SR}_i, \tag{5}$$

where HR_i is the value of RH for the study region i, DR_i the value of HD for the study region i, CR_i the value of HRC for the study region i, $w_{ix(x=\mathrm{H,D,C})}$ is the weight expressing the importance of indicator i in three dimensions and n_i is the number of indicators of each dimension.

Considering that the impact of the three dimensions on the final result of RHH is interactional, we chose multiplicative function to calculate the final result. The composite value of the RHH system was then calculated using eq. (6) as follows

$$\mathrm{RHH}_i = \mathrm{HR}_i^{\beta_\mathrm{H}} \cdot \mathrm{DR}_i^{\beta_\mathrm{D}} \cdot \mathrm{CR}_i^{\beta_\mathrm{C}}, \tag{6}$$

where RHH_i is the RHH system value of study region i, $\beta_{x(x=\mathrm{H,D,C})}$ is the index weight expressing the importance among the three dimensions.

Determination of weights using analytic hierarchy process

The accuracy of the evaluation models depends extensively on the weighing functions. The three dimensions considered in this study were given equal importance. Thus, equal weights were applied for the three dimensions.

Table 2. Weights of the RHH system

System (R)	Dimension (D)	Basic indicator (B)	Indicator weight R–D	Indicator weight D–B
RHH	RH	Water amount per unit area (m^3/km^2)	0.3333	0.4073
		Percentage of monitoring river sections with water quality better than Class III (including class III)		0.2546
		Percentage of forest cover		0.1555
		Frequency of flood disaster (%)		0.1280
		Rural erosion rate (%)		0.0546
	HD	Per capita GDP (Yuan RMB)	0.3333	0.1000
		GDP growth rate (%)		0.1000
		Urban–rural income gap (Yuan RMB)		0.1000
		Population density ($people/km^2$)		0.1000
		Urbanization rate (%)		0.1000
		Population growth rate (%)		0.1000
		Per capita output of grain (kg/people)		0.1000
		Industrial production water consumption of 10,000 Yuan RMB (m^3)		0.1000
		Norm of irrigation water capacity (m^3/km^2)		0.1000
		Industrial wastewater recycling rate (%)		0.1000
	HRC	Degree of satisfaction water supply (%)	0.3333	0.3959
		Degree of satisfaction ability of the water hazard emergency management (%)		0.2014
		Degree of satisfaction of water pollution treatment (%)		0.0597
		Degree of satisfaction of soil and water loss treatment (%)		0.0810
		Degree of satisfaction of water price (%)		0.0810
		Water saving conscience (%)		0.0810

The weighting criteria adopted for the sub-indicators is based on the analytic hierarchy process (AHP), which is a multi-criteria evaluation technique frequently employed for defining the weights of indicators[19]. The AHP decomposes a complex problem into a multi-level hierarchy structure of objectives, alternatives, criteria and sub-criteria. The AHP provides a fundamental scale of associative magnitudes expressed in dominance units to represent judgments in the form of paired comparisons. A ratio scale of relative magnitude expressed in priority units is then comprehensive to obtain a ranking of the alternatives. In this article, AHP has been used for capturing the perceptions of stakeholders on the relative severity of different socio-economic impacts, which will help the authorities in prioritizing their water management[20]. Table 2 lists the weights obtained for the indicators with AHP. The consistency ratio of the indicator weights in the RH, HD and HRC dimensions is 5.1%, 6.0% and 6.4%, respectively.

The weights w_{ix} and β_x are all between 0 and 1 and add up to 1 according to eqs (7) and (8).

$$\sum_i w_{ix} = 1, \tag{7}$$

$$\sum_i \beta_x = 1. \tag{8}$$

Figure 2 shows the entire RHH system calculation process.

Case study: Wei river Basin

The study area is a branch of the Yellow River located in northwest China (34°27′–37°53′N, 103°88′–100°12′E). The region is characterized by a dry climate, minimal rainfall, high evaporation capacity, high soil stalinization, low vegetation cover and presence of areas with water shortage. The major river in the study area is the Wei River, with its main tributaries being the Jing and Beiluo rivers. The length of Wei River is 818 km. The length of the Jing and Beiluo rivers is 455 and 680 km, respectively. The total area of Wei River Basin is 134,800 sq. km. The mean annual precipitation is 500–800 mm, which is concentrated between July and August. The mean annual potential evaporation is 600–1600 mm. The average run-off of the Wei River, once it flows through the Liaoshu Mountains, is 100.40×10^8 m^3, of which 76.40×10^8 m^3 is used for irrigation purposes. Flood irrigation causes a portion of the irrigation water to return to the groundwater system. The agricultural history of the study area, which currently has highly developed irrigation facilities, dates back approximately to 2300 years.

More than 70% of the population and 90% of the cropland in the study area are concentrated on the sides of Wei River and its tributaries. Historically, the Wei River Basin was once the most developed area in China. To date, many prosperous cities have developed in this region resulting in high population density. On account of the historically excessive development in the Wei River Basin, the people are plagued by a series of water

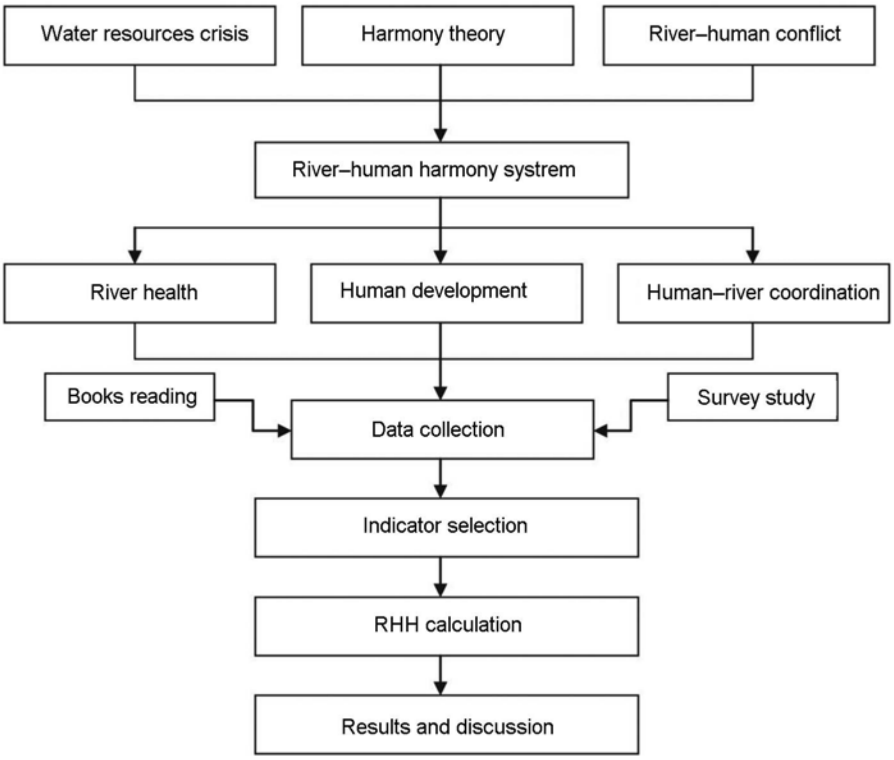

Figure 2. Flowchart of the river–human harmony model.

problems. Based on the hydrological data recorded since 1970, floods have occurred more than 120 times in the Wei River Basin, which has caused an economic loss of approximately 86.4 billion RMB Yuan. Furthermore, in the Basin, the exploitation of groundwater resources has a 300-year history. Groundwater exploitation was limited before the 1970s, but since the 1980s groundwater has been extensively exploited, which is illustrated by the rapid increase in the number of pumping wells along the Wei River in the 1990s and 2000s. The shortage of water resources has become a bottleneck for socio-economic development in the Wei River Basin. Increasing industrialization and urbanization has resulted in deterioration of water quality and, therefore, the phenomenon of water pollution is serious in the Basin. The Ecological Water Transfer Project (EWTP) of the Wei River Basin was implemented after obtaining authorization from the State Council in 2002, with the objective of allowing more water to be used in the lower reaches. Implementation of EWTP has changed the trends of land degradation and ecological deterioration in the Basin[21].

As a case study, the developed RHH model was utilized to evaluate the condition of river resources in Wei River Basin. To facilitate the model calculations, the study area was divided into five sub-areas: Jing River Basin (JRB), Beiluo River Basin (BRB), the upper Wei River Basin (UWRB), the middle Wei River Basin (MWRB) and the lower Wei River Basin (LWRB) (Figure 3).

Two approaches employed to collect data for the study period (January–December 2012) for each indicator were analysis of government documents[22] and household surveys. Reviewing the data collected from government organizations and household surveys provided the base information to quantify the values for the RHH model. Table 3 lists collected data and the value of RHH model can be subsequently calculated.

Results

The application of the RHH model provides a new approach to accessing the human–river relationship in Wei River Basin. To evaluate the water resources situation, the study area was divided into five sub-areas. Table 4 lists the calculated indicators for each sub-area along with the RHH model values.

River health

As shown in Table 4, the order of the five sub-areas from good health to poor health is as follows: the tributary area, JRB (0.7313) and BRB (0.6856) are in good health, followed by UWRB (0.3623), MWRB (0.2971) and LWRB (0.1312) with the poorest health. In combination with Table 3, the indicators of water resources and water environment belong to positive index. The regional water resource quantity per unit area for JRB, BRB, UWRB,

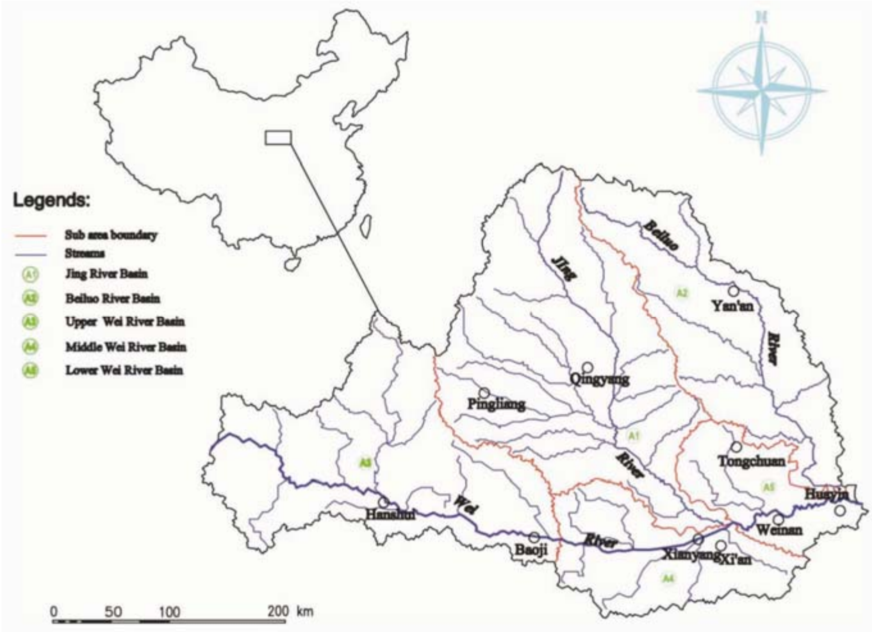

Figure 3. Map of the Wei River Basin, China.

Table 3. RHH value of the five sub-areas of study in 2012

Dimension	Basic indicator	JRB	BRB	UWRB	MWRB	LWRB
RH	Water amount per unit area (m^3/km^2)	37,280	44,260	32,480	31,560	29,370
	Percentage of monitoring river sections with water quality better than Class III (including class III)	33.50	31.15	21.57	17.42	15.57
	Percentage of forest cover	32.14	45.24	27.35	22.17	25.78
	Frequency of flood disaster (%)	15.12	14.33	20.15	20.67	23.87
	Rural erosion rate (%)	2.45	3.77	4.12	4.58	5.21
HD	Per capita GDP (Yuan RMB)	27,845	25,689	26,487	41,567	38,457
	GDP growth rate (%)	11.25	10.58	12.75	15.89	14.17
	Urban–rural income gap (Yuan RMB)	11,204	9,875	14,821	10,130	13,574
	Population density (people/km^2)	624	537	712	805	848
	Urbanization rate (%)	56.4	58.2	62.7	68.5	70.4
	Population growth rate (%)	3.78	4.21	2.33	2.58	3.14
	Per capita output of grain (kg/people)	858	675	512	298	358
	Industrial production water consumption of 10,000 Yuan RMB (m^3)	331	363	235	221	275
	Norm of irrigation water capacity (m^3/km^2)	1902	1887	573	422	424
	Industrial wastewater recycling rate (%)	71.2	66.8	88.5	89.5	82.4
HRC	Degree of satisfaction of water supply (%)	92.2	93.1	80.5	75.3	70.4
	Degree of satisfaction of ability of water hazard emergency management (%)	91.7	94.5	83.1	77.2	74.1
	Degree of satisfaction of water pollution treatment (%)	86.3	88.2	79.3	70.6	67.3
	Degree of satisfaction of soil and water loss treatment (%)	85.4	87.3	83.5	76.1	72.4
	Degree of satisfaction of water price (%)	98.5	96.4	97.5	99.2	99.7
	Water saving conscience (%)	74.2	66.8	91.5	92.4	93.5

MWRB and LWRB is 37,280, 44,260, 32,480, 31,560 and 29,370 m^3/km^2 respectively. Although the whole river basin is considered as water-shortage area, the population density of BRB and JRB is low. Thus, water demand for residents, livestock, agricultural and industrial needs is low compared to UWRB, MWRB and LWRB. Therefore, the local water resources completely meet the needs of the society in comparison to LWRB, which has the least water resource quantity in five areas while the population density is highest causing extensive pressure on the limited water resources.

In terms of water environment, the highest percentage of forest cover in the five sub-areas of the study area was in BRB (45.24), followed by JRB (32.14), with the other three sub-areas of main stream of Wei River Basin being lower than 25. The water quality indicator is the percentage of monitoring river sections with water quality, which is better than Class III (including Class III). As shown in Table 3, the best is JRB (33.50%), whereas the worst is LWRB (15.57%). In general, the tributary areas, JRB and BRB, have plentiful water resources quantity, high forest cover and good water quality; all these factors certainly affect the final values. As mentioned earlier, the high salinity of Wei River Basin has a major influence on water quality. But the water quality is relatively good at JRB and BRB as the natural inflow is larger and, therefore, offers an efficient use of the river. The water quality is low in the main stream of the Wei River Basin. In the upper reaches, flooding results in a large amount of water, and thus the water quality condition is relatively better, but in the middle and lower reaches of Wei River, the amount of water is often low and the river water quality and ecological environment are seriously affected.

Regarding the water disasters in Table 3, the two indicators used are the frequency of flood disaster and soil erosion rate. The frequency of flood disaster is highest for LWRB (23.87%) and lowest for BRB (14.33%). Table 3 shows the flood control standard of the three main streams of the Wei River Basin to be at 10-year intervals, whereas the standard for the two tributaries is every 30 years[23]. The major cause for this heavy construction along the main streams of Wei River, which results in low flood control standard. The soil erosion rate does not indicate much regional difference in the five sub-areas. However, compared with the other regions of the world, the Wei River Basin belongs to an area of serious soil loss. Because the Basin is located in the loess plateau of China, the soil erosion intensity is high and therefore, the Basin is one of the major soil erosion areas of the Yellow River.

Human development

As can been seen from Table 4, MWRB HD has the highest value (0.7954) followed by UWRB (0.5799), LWRB (0.5608), JRB (0.3361) and BRB (0.3141). The ten indicators of human development reflect economic, scientific and technological development. The comprehensive development of society is reflected by the social development in a district.

The first three development indicators are economic indicators, the next three are population indicators, and the last four are science and social indicators. The economic indicators can be observed from the perspective of GDP for the five sub-areas. Both the per capita GDP and GDP growth rate in MWRB and LWRB were significantly higher than that of two tributaries and UWRB. In terms of per capita GDP from Table 3, the highest value is for MWRB (41,567 Yuan RMB) which is significantly higher than BRB (25,689 Yuan RMB). In terms of GDP growth, values are significantly higher in MWRB and LWRB than those of UWRB and the two tributaries. With respect of population and urbanization rate, the same holds true for the entire population; this is more focused in the middle and lower reaches of the Wei River Basin. From Figure 3, it can be seen that almost all the large cities of the Basin are concentrated in the area, with high population density and a high degree of urbanization being the most obvious characteristics of the two sub-areas. The other three sub-areas have relatively low population concentration, low degree of urbanization and a relatively underdeveloped economy. The study shows that there is an imbalance in the economic development of the whole basin. A combination of science and social indicators benefitted from the less populated areas where agriculture is the pillar of local industries. For JRB and BRB, the per capita grain output is far higher than that of the other three sub-areas. Although the water resources of JRB and BRB are better than those of the other three sub-areas, utilization efficiency of water resources is low. Thus, industrial water consumption is much higher compared with the three sub-areas of the main stream of Wei River Basin. Additionally, the industrial waste water recycling utilization rate is far lower for JRB and BRB.

In general, the large difference in HD is primarily a result of imbalance in economic development and population, which is caused by the difference in the development of science and technology. Decision makers must consider steps to mitigate this problem of regional imbalance in future development.

Table 4. Basic indicators for the five sub-areas in 2012

Dimension subarea	JRB	BRB	UWRB	MWRB	LWRB
RH	0.7313	0.6856	0.3623	0.2971	0.1312
HD	0.3361	0.3141	0.5799	0.7954	0.5608
HRC	0.7529	0.7380	0.4616	0.2920	0.1620
RHH	0.6068	0.5792	0.4679	0.4615	0.2847

Human–river coordination

HRC was primarily considered via a questionnaire survey and by telephone interview, quantifying the subjective feeling of people by employing statistical methods. Figure 4 shows that for each sub-area, the coordination dimension for the two tributaries, JRB (0.7529) and BRB (0.7380) has the highest value followed by UWRB (0.4616) and MWRB (0.2920), and the lowest value is for LWRB (0.1620).

From the six indicators for the coordination dimension, the two indicators for water resources security are the satisfaction degree of water supply and the ability to manage water hazard emergency. These two indicators illustrate that the residents in tributary area have greater satisfaction in both areas compared to the three sub-areas of the primary stream of Wei River Basin. As implied from the RH and HD dimensions, there are more disasters in the middle and lower reaches of the watershed, high population pressure, water loss and soil erosion. Hence there is lesser satisfaction with regard to water supply and water disaster response. Additionally, in the middle and lower reaches of the river basin, the Government invests more manpower and money into river disaster management every year compared to the two tributaries[23].

The next two indicators of the water environment include the opinion of the residents on wastewater treatment and soil erosion phenomenon. Although in the main stream of Wei River Basin, especially at the middle and lower parts, the Government spends considerable money every year on sewage treatment and on the prevention and control of soil and water loss[22], the satisfaction level of the residents of the three main river valleys is far less than that those residing near the two tributaries. This may be because, in the short term, the effect is not obvious. This finding was noted from the telephone survey of the inhabitants at the middle and lower reaches of several big cities in the Basin.

The last two indicators are the degree of satisfaction of water price and water-saving consciousness. The statistical analysis reveals that the values for MWRB and LWRB are fairly good with most of the respondents being satisfied with the current price of water. Additionally, these sub-areas have better water-saving consciousness as a result of the propaganda by the local government departments[22]. However, residents near the two tributaries are not overly concerned about water saving because of lack of association with the local government.

However, in the three sub-areas of the main stream of Wei River Basin, despite the Government putting in more effort and money in response to water disasters and water pollution compared to the two tributaries, the actual implementation effect is not obvious[22,23]. The residents of UWRB, MWRB and LWRB in the surrounding regions are not satisfied with the water environment, which seriously affects the scores of the coordination dimension.

RHH results

Table 4 shows the RHH values of five sub-areas: JRB (0.6068) and BRB (0.5792), followed by UWRB (0.4679) and MWRB (0.4615), with LWRB having the lowest value (0.2847). The RHH system is determined by three dimensions, 21 indicators, including the aspects of human and river systems, demonstrating that the five sub-areas have their own characteristics. For a clearer analysis, radar charts were made depicting the RHH dimensions (Figure 5). JRB and BRB in terms of RH and HRC have higher values, whereas HD is less than that of the three sub-areas of the main stream of Wei River Basin. However, after comprehensive calculation, the overall value is still higher for JRB and BRB, whereas MWRB shows high value for RH and HD, but not for HRC. UWRB is more balanced, but in comparison, LWRB shows the lowest value for all the three dimensions (RH, HRC and HD). A regional comparison using the RHH model reveals the strengths and weaknesses of each sub-area of Wei River Basin. Thus, the model can provide guidance for future developments and enable a comprehensive evaluation for planning and construction.

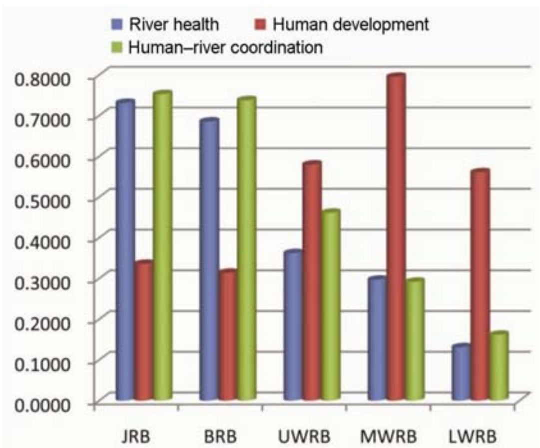

Figure 4. Comparison between RHH dimensions values for the five sub-areas of study.

Discussion

This study is an attempt at assessing the river–human relationship using the RHH model, which comprises of three dimensions and 21 indicators. The detailed evaluation of a regional river–human relationship status has been made for the Wei River Basin.

River health is considered to assess the general situation of the river system. As the calculations clearly demonstrate, the areas rich in natural water with no pollution are the key to have high scores for a river basin. Rivers with abundant water supply tend to have high RH values, as well as a high final RHH value. In contrast, river basins with meagre water resources, such as LWRB, have low RH and RHH values.

HD also plays an important role in the model. This dimension is a comprehensive evaluation on the society, economy and science systems. These factors determine the efficiency of the local government, which employs mechanisms in the Basin to improve the existing river health. Development dimensions are also integrated with

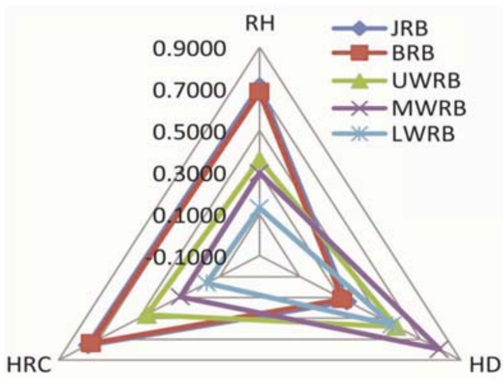

Figure 5. Radar diagram of RHH dimensions for the study areas.

the condition assessment of the residents of the area. The areas that have a high level of development have high RHH value.

HRC plays a vital part in RHH system. Whether the society, economy, environment, and science systems interact with the water resources in a healthy way is as important as their respective developments. Here, we mainly utilized the satisfaction of people. We can obtain detailed information from the people residing in the areas to evaluate the regional river–human harmonious degree and not just use the Government reports alone. In fact, through our study, we were able to evaluate that even though the development indicators were good in the some of the sub-areas, the satisfaction of residents was not high. Thus, the river–human one is a complex system in which two main parts are humans and water. The accurate physical data from the government can provide only the external attributes, while the inner relations, such as affordability, convenience, comfort and aesthetics can be obtained by subjective surveys.

Conclusion

In this study, an evaluation model for the river–human relationship has been presented. The index provides a rational process to combine water system knowledge to give a single and comparable value. These simple indicators provide quantitative assessment for the abstract human–river relationship. The model is composed of three dimensions, each representing the different aspects of the human–water system. RHH will enable us to identify the flaws in the water development plan of the Basin, so as to devise strategies and policies to build more harmonious human–river interactions.

Although the Wei River Basin falls under the water-shortage area, each sub-area has its own advantages and problems. Among the five study areas, JRB has the highest value, while LWRB has the lowest. The other three sub-areas have similar values, but of the weakness three dimensions is completely different in human–river relationship. Because the Wei River is a cross-border river, the RHH system also provides a new method for evaluating river resources management and river–human relationship of a trans-boundary river between provinces or countries. This approach can be used for other rivers around the world, provided the index of indicators is suitable for the local situation.

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