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Emergy-based Health Assessment of Baiyangdian Watershed Ecosystem in Temporal and Spatial Scales

Rong Zeng, Yanwei Zhao*, Zhifeng Yang

State Key Laboratory of Water Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing, China, 100875

Abstract

The shrinking Baiyangdian Lake and drying up rivers are widely observed in recent years. Due to the significant advantages in integrated analyses of natural and economic systems, emergy analysis is introduced in this paper to assess the health status of Baiyangdian Watershed. First, we establish a emergy based conceptual framework for the assessment, delineate an emergy flow diagram of Baiyangdian Watershed Ecosystem, and propose an emergy-based comprehensive assessment index system, which includes 11 indices categorized into 4 groups, i.e., ecosystem efficiency, ecosystem organization structure, ecosystem service function and ecosystem load. In the principle of ecosystem health assessment, six indicators from efficiency, organization structure, service function and load are integrated to construct an emergy-based ecosystem health index (EHI). In temporal scale, the health status of Baiyangdian Lake is evaluated from 1975 to 2009 which divided into five time periods. In spatial scale, Baiyangdian Watershed are divided into six sub-watershed based on DEM, the change of EHI in the six sub-watershed are compared. The results show that, in temporal scale, ecosystem service function has decreased sharply, while ecosystem load has been improved, self sufficiency of ecosystem, emergy yield and competitiveness have been damaged severely. The condition of ecosystem health of Baiyangdian Lake has deteriorated continuously especially after 1985. The results in spatial scale show that Fu River sub-watershed and Tang River sub-watershed have poorer health status, Juma River sub-watershed and Zhulong-Xiaoyi River sub-watershed has better health status. Shortage of instream flow, deterioration and sedimentation are the most dominated factors resulted in poor health status in Baiyangdian Watershed Ecosystem.

Keywords: Ecosystem, health assessment, emergy analysis, Baiyangdian Watershed

1. Introduction

Ecosystem health is a major organizing paradigm for protecting and sustaining the quality of the environment. There are many definitions of ecological health and a review of the concepts in relation to rivers can be found in Norris and Thoms [1]. River health is usually used to give measure of the overall conditions of river ecosystem and define in terms of ecological integrity. The working definition of river health used by the Australian National River Health Program (NRHP) is: The ability of the aquatic ecosystem is to support and maintain key ecological processes

* * Corresponding author. Tel.: +86-010-588-01719; fax: +86-010-588-01719.
E-mail address: awei-a@163.com.

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and a community of organisms with a species composition, diversity, and functional organization as comparable as possible to that of undisturbed habitats within the region [2].

Aquatic ecosystem health assessing methods can be broadly divided into two types: biological monitoring method and comprehensive indicators method. The health status of aquatic ecosystem effect the aquatic organisms' type, abundance, density, community structure and function. By monitoring a number of indicators such as biomass, productivity, structural indicators to describe the health condition of aquatic ecosystem have been wildly applied. Fish has a long growth cycle and easily can be indentified, different species composition can reflect water status change. Index of Biotic Integrity (IBI) developed by Kleynhans[3] is widely used to evaluate the status, trends and changing reasons of river in the United and Europe. The macroinvertebrates are representative as indicator species, River Invertebrate Prediction and Classification System (RIVPACS) is developed by British scholar in 1970s, through continuous improvement these 30 years, it is applied in evaluating ecological quality of rivers, providing important basis for river protection and management. In 1994, supported by NHRP, Cooperative Research Center for Freshwater Ecology developed Australian River Assessment System (AUSRIVAS) based on RIVPACS. AUSRIVAS has been used to assess health status of more than 14500 rivers in Australia[1] (Norris et al, 1999). Canada[4], Indonesia [5-6] also have been applied.

Biological monitoring has many shortcomings; a single indicator can only reflect one facet of the river health status, which hardly can express the comprehensive characteristic of the ecosystem health. Thus, comprehensive indicators including physical, chemical, biological and even socio-economic indicators become an important toll in ecosystem health assessment. Index of stream condition (ISC)[7] including 19 indicators about river hydrology, the physical structural characteristics, riparian conditions, water quality and aquatic organisms five elements, carried out scoring method to make comparative assessment of rivers. RBPs（Rapid Bioassessment Protocols）developed from 1980s to recently, covering invertebrates, algae, fish and habitat evaluation techniques which become a mature system. Xu[8] developed an ecosystem health index methodology including indicators about biomass, exergy and structural exergy to assess an Italian lake.

Emergy analysis is a technique that determines the value of nature and human economy based on the principles of thermodynamics, system theory and system ecology. Its fundamental assumption is that the value of resource is proportional to the energy required to produce the resource. It was first developed by Odum[9]. No matter what kind of resources or services origin from solar energy, solar energy is the standard measure for each kind of resource and service. In the emergy concept, the quality of energy is expressed with transformity that is defined as the quotient of products emergy divided by its energy. The emergy concept has provided many new perspectives regarding conflicts between development and conservation [10]. Emergy analysis overcomes the limitations of different resources that have different unit. It can evaluate long-term sustainability and comparisons of emergy-based indices, also it can be used to compare efficiency and environmental input between various production systems. Farming system, industrial system and agricultural system were widely evaluated due to the connecting functions between efficiency and inputs. Rydberg & Haden[11] used it in agricultural ecosystem; Yang[12] considered the impacts of wastes and improve existing emergy analysis methods for industrial ecosystem in order to making process system engineering decisions; Bastianoni[13] assessed the artificial water cycle from waste water collection to discharge in to the environment; Brown & Buranakarn [14] used emergy in the life cycles of major building materials, in order to evaluating emergy inputs to waste disposal and recycle systems. The evaluating region is related to cities, including Baotou[15], Rome [16], Taipei [17]. Emergy analysis is widely used not only in single production system, it has advantage in integrated analyzing environmental sustainability and economic polices of macro-ecosystems, and total global biosphere[18]. Brown and McClanahan[19] investigated both the total Thailand economy and two proposed dams on the Mekong River, made a conclusion that cost of sediment and inundating terrestrial systems was highlighted that almost offset the benefits dam brought. Kang and Park[20] further explored a proposed dam in Korea, implying that proposed dam contributed much more for the Korean economy than the current system without the dam. Chen B and Chen GQ[21] assessed the level of resource depletion, environmental impact and local sustainability of the Yellow River basin based on emergy accounting, a set of indices manifested that mechanism of the Yellow River basin is profoundly changed by the purchased social input.

Energy systems theory provides a theoretical basis for defining, measuring, and interpreting the concepts of ecological integrity and ecosystem health[22].

2. Study Area

Baiyangdian basin, with an area of 3.12×104km2, locates in the middle of Hebei Province (113º40’–116º20’E and 38º10’–40º00’). It crosses Baoding, Langfang, Cangzhou, Beijing, Zhangjiakou, Shijiazhuang and Hengshui, 70.8% of the drainage area locates in Baoding. Basin terrain tilt from northwest to southeast, mountains in northwest which elevation is between 100-2500m, plains in the middle which elevation is between 10-100m, low-lying areas and Baiyangdian Lake in the east which elevation is between 7-10m. The area of water bodies accounts for 50% of the total area of Baiyandian Lake drainage area, which are usually distributed below the elevation of 7.5m. Reed and moss land account for 36%, cropland, shallow lake and coastal area occupy 14%. It is in the semiarid monsoon climate zone and the average annual precipitation is 570.2mm, which usually accurse during July-August. There are nine rivers belongs to Daqing River system flows into Baiyandian Lake (Fig. 1). These rivers have become seasonal in the recent years. The average annual evaporation in the region is 1369mm, which is far higher than the average annual precipitation[23]. Soil erosion usually occurs in flood period of mountains, Tang River is more serious.

Baiyangdian Lake is the largest natural fresh water body in North China Plain. Due to the dam catchment area controls 60% of the mountain area, a large number of floods have been blocked. Coupled with the impact of continuous dry years, Baiyangdian Lake always dry up after 1980s. When water level falls below 6.5m, it will dry up and the whole wetland will disappear when it falls below 5.5m. In some dry years, the lake retains only a very small amount of water and typically becomes a marsh. In 2000-2004, average water level is 6.99m in wet season which dropped 3.31m compared to 1950s. Recently, the water quality in the drainage degraded mainly caused by agricultural runoff and waste water discharge from Baoding City. Meanwhile, the reduction of lake surface area and depth worsen the entropic situation. Its unique environment and human landscape has been gradually disappeared.

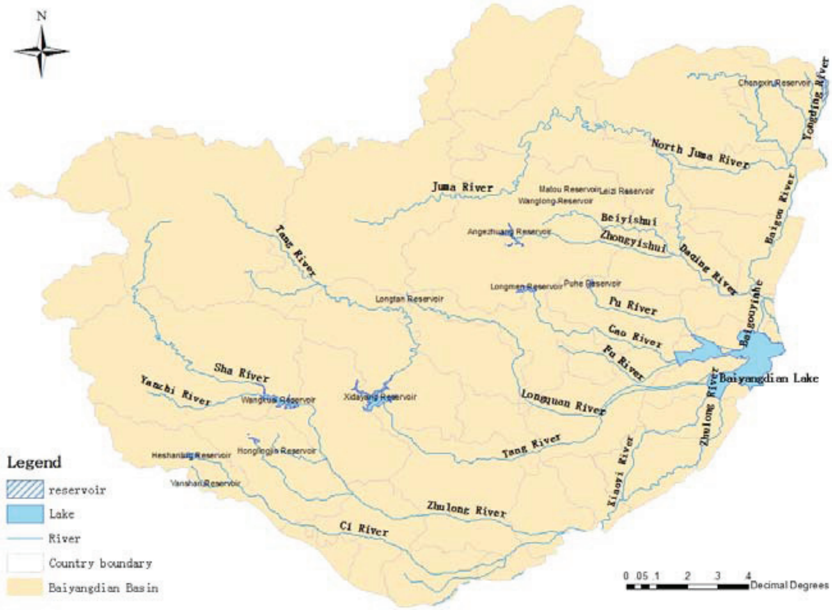

Fig. 1 Baiyangdian watershed

3. Method

3.1. Conceptual framework of the Baiyangdian Lake metabolic ecosystem

Vannote et al [24] put forward River Continuum Concept (RCC), this concept treats the watershed as a continuous system, river changes upstream can transfer to downstream even affect the entire basin. A lake can be conceptualized as a special kind of organism which embodies certain metabolic processes locating downstream. Besides renewable resources input such as sunlight, wind, earth cycle, rain et al, an important factor impact the ecosystem health is river flow upstream. Materials and energy flows into Baiyangdian Lake with river. To simulate a natural process, a conceptual model of Baiyangdian Lake metabolic system can be established as shown in Fig. 2. It represents the transfer relation between rivers and lake in dendrite structural basin.

From this meaning, the river ecosystem is an open system which carries out energy and material flows among river flows to lake ecosystem. River flow brings water, sediment and wastes into lake ecosystem. Water consumption in upstream, water transfer by each dams and rainfalls are factors which have effect on water input. Urban system, agricultural system and industrial system have effect on wastes input. Meaning while, sediment input attribute to soil erosion upstream and dam interception.

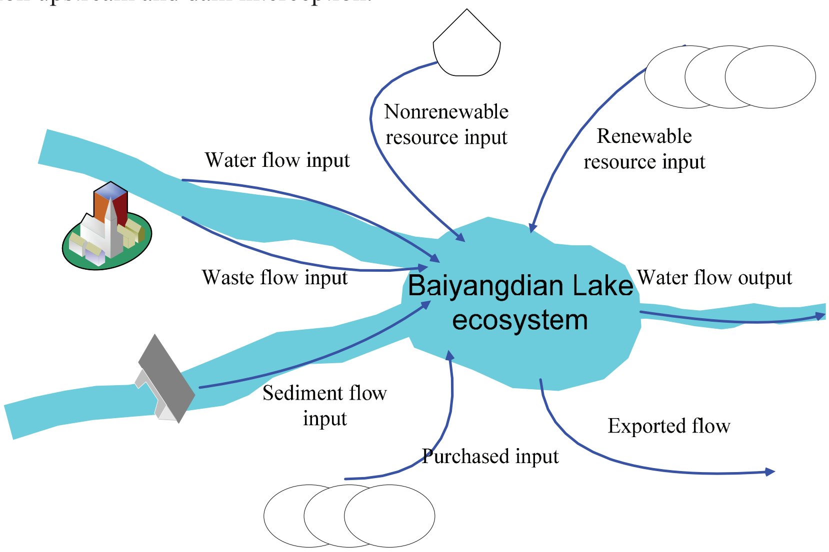

Fig. 2 Energy flow of Baiyangdian Lake ecosystem

3.2. Emergy synthesis

The general methods for employing emergy synthesis were given fully by Odum[25]. Emergy of a type is defined as the sum of all flows of energy that are directly and indirectly required to create it, emergy values of all input items should first be determined (emergy input analysis) and then allocated to internal pathways and exported items (emergy output analysis). The first step is to draw an emergy systems diagram which depicts the environmental basis for the ecosystem and its connection to the larger socioeconomic system. The energy system language which developed by Odum[25] was used to provide a holistic picture of the lake ecosystem and specify the main forcing functions, internal components, process interactions and exported products. Develop an emergy system diagram proceeds as follows:

Define the spatial boundary as the Baiyangdian Lake, define the temporal boundary as 1975-2009.

Develop a list of import and export items, arranging each forcing factors and components in order of their solar transformity, calculate preliminary values of solar emergy of the items meaning while filter out unessential parameters which emergy value below 5% of the total emergy flow.

Draw a final ecosystem diagram, including those major components which represented greater than 5% of emergy flow, indicating the input and output emergy flow of the Baiyangdian Lake ecosystem. Fig. 3.

To sustain the functions of the lake metabolic ecosystem, the basic emergy flows represented by the indices must be ensured. There are four types of emergy according to the lake ecosystem, renewable resources emergy (R), nonrenewable resources emergy (N), the resources emergy imported from the external system (IMP), and the resources emergy exported to the external system (EXP). Renewable resources emergy (R) mainly includes emergy from sunlight, rain, wind, earth cycles and river flows from upstream. Nonrenewable resources emergy (N) equals the sum of the emergy of dispersed rural sources such as soil erosion. Besides input from the natural system, there are services, goods, money and equipments et al import from external system (IMP). To sustain organization and function, flows of emergy are exported from ecosystem like produced goods and services (EXP). The emergies of lake metabolic flows are calculated as flows:

$$U=R+N+IMP \quad (1)$$

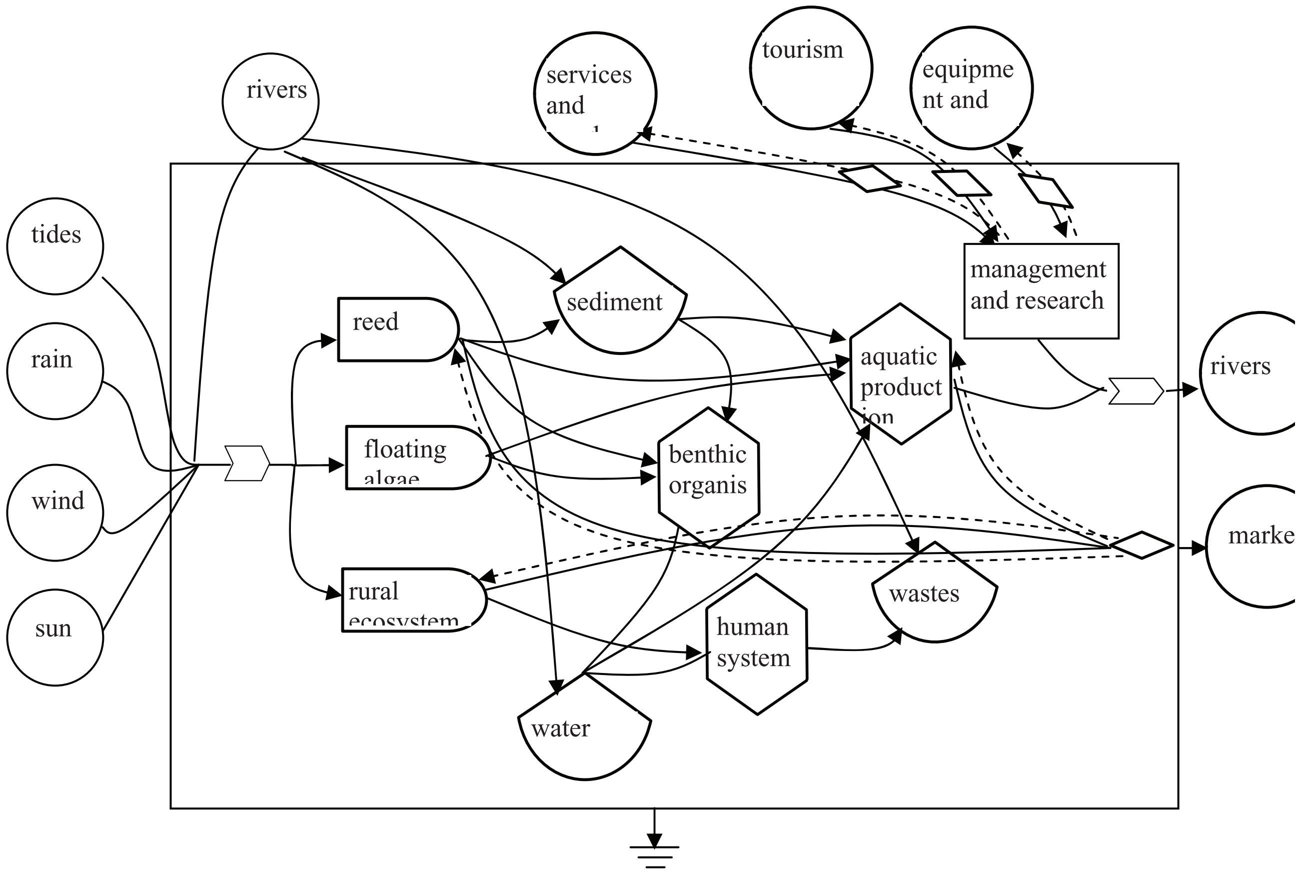

Fig. 3 Emergy flow diagram of Baiyangdian Lake ecosystem

3.3. Design ecosystem health index system

In order to quantitatively assess the health status of each subsystem, an ecosystem health indicator system needs to be established. Health Index (EHI) is first developed by Costanza including vigor, organization and resilience. Many scholars improved the health assessment index base on that. Sufficiency, several factors generally can indicate the health condition like vigor, efficiency, organizational structure, resilience, function maintenance, environmental safety and influence on a neighboring system. Based on five factors of systematic understanding of healthy ecosystem and its features, efficiency, organizational structure, function maintenance and environmental safety, they are chosen as the standards for assessing drainage ecosystem health. Indices belong to them and their formulas are shown as Table 1. Efficiency refers to the ecosystem input-output cycle of the material energy capacity, can be expressed by emergy yield ratio and input-output ratio ; the organizational structure means the ecosystem's stability and rationality, using non-renewable energy resources ratio and renewable resources ratio; function to maintain the system mainly refers to its ability to provide service functions which can be expressed by self-sufficiency rate and emergy density; environmental safety refers to the system in the current under stress pattern and structure to maintain the ability to load and use the environment loading ratio and the sustainability index.

Table 1. Emergy-based comprehensive assessment index system

item	*Emergy index*	*expression*
Ecosystem efficiency	Emergy yield ratio	EXP/(U-R-N)
	Environment yield ratio	(OMY+SY)/U
	input-output ratio	EXP/U
Ecosystem structure	renewable energy ratio	R/U
	emergy investment ratio	IMP/(R+N)
	emergy exchange ratio	IMP/EXP
Ecosystem function	self-sufficiency rate	(R+N)/U
	emergy density	U/area
	Ecosystem service ratio	SY/EXP
Ecosystem load	ELR	(U-R)/R
	Waste ratio	W/U

4. Result and discussion

4.1. Emergy-based accounting for Baiyangdian Lake ecosystem from 1975 to 2009

Collecting from the investigations and statistical yearbooks of Baoding City complied by the local government, the material, energy, money flow data of Baiyangdian Lake ecosystem from 1975 to 2009 are classified and sorted to five intervals to evaluate the changes in the health status of Baiyangdian Lake ecosystem. Through the calculations of each emergy transformity, the results are summarized in Table 2. In this table, we have separated waste emergy into two inputs, one is flows in with river flows, and the other is from rural life of Baiyangdian Lake. In accordance with the emergy flow diagram (Fig. 3), I performed the corresponding calculations for each indicator in the diagram and summarized the results in Table 3.

Table 2. Emergy evaluation of Baiyangdian Lake ecosystem from 1975 to 2009

components	*Emergy* ***(sej)***				
	1975	1985	1995	2005	2009
Renewable resources					
Sunlight	1.96×10^{19}	1.96×10^{19}	1.96×10^{19}	1.96×10^{19}	1.96×10^{19}
Rain chemical	2.82×10^{19}	1.49×10^{19}	2.37×10^{19}	2.89×10^{19}	2.16×10^{19}
Wind	3.33×10^{18}	3.33×10^{18}	3.33×10^{18}	3.33×10^{18}	3.33×10^{18}
River	8.41×10^{19}	5.42×10^{19}	4.13×10^{19}	3.23×10^{19}	3.17×10^{19}
Nonrenewable resources					
Sediment	6.87×10^{20}	5.44×10^{20}	4.58×10^{20}	3.59×10^{20}	3.21×10^{20}
Water body	1.60×10^{20}	6.97×10^{19}	8.54×10^{19}	6.29×10^{19}	7.19×10^{19}

Imports					
Electricity	1.78×10^{20}	6.55×10^{20}	1.26×10^{21}	1.99×10^{21}	2.12×10^{21}
Fertilizer	8.18×10^{18}	1.30×10^{19}	2.51×10^{19}	4.13×10^{19}	7.67×10^{19}
Pesticide	1.73×10^{17}	3.54×10^{17}	4.06×10^{17}	6.14×10^{17}	1.44×10^{18}
Capital investment	9.33×10^{19}	1.49×10^{20}	1.92×10^{20}	3.91×10^{20}	5.54×10^{20}
Research investment	6.18×10^{19}	1.03×10^{20}	2.73×10^{20}	3.26×10^{20}	4.40×10^{20}
Wastes					
Wastes in lake	1.41×10^{19}	1.66×10^{19}	2.12×10^{19}	2.85×10^{19}	3.31×10^{19}
Wastes from river	6.85×10^{18}	9.38×10^{18}	2.39×10^{19}	4.97×10^{19}	7.18×10^{19}
Exports					
Organic production					
Reed	4.37×10^{17}	5.76×10^{17}	3.23×10^{17}	4.42×10^{17}	4.25×10^{17}
Floating alga	3.52×10^{17}	5.54×10^{17}	2.84×10^{17}	5.01×10^{17}	4.00×10^{17}
Aquatic products(fish)	1.51×10^{20}	1.41×10^{20}	2.99×10^{20}	5.43×10^{20}	4.93×10^{20}
Benthic organism	3.86×10^{17}	1.36×10^{17}	3.23×10^{17}	6.02×10^{17}	4.74×10^{17}
Ecosystem service					
Purification	5.04×10^{20}	2.42×10^{20}	3.88×10^{20}	3.39×10^{20}	2.91×10^{20}
Hydrological regulation function	1.81×10^{18}	8.70×10^{17}	1.39×10^{18}	1.22×10^{18}	1.04×10^{18}
Economic service					
Tourist service	2.55×10^{18}	1.89×10^{19}	4.71×10^{19}	1.32×10^{20}	1.74×10^{20}

Table 3. Summary emergy table of Baiyangdian Lake ecosystem from 1975 to 2009

Emergy components	*Symbol(sej)*	*1975*	*1985*	*1995*	*2005*	***2009***
Renewable resources	$R\times10^{20}$	1.35	0.92	0.88	0.70	0.65
Non-renewable resources	$N\times10^{20}$	8.46	6.13	5.43	4.22	3.93
Imports	$IMP\times10^{20}$	3.62	9.46	18	28.2	33

Wastes	W×10^{20}	0.21	0.26	0.45	0.78	1.05
Organic production	OMY×10^{20}	1.52	1.42	3.00	5.44	4.95
Ecosystem service	SY×10^{20}	5.06	2.43	3.89	3.40	2.92
Economic service	I×10^{20}	0.03	0.19	0.47	1.32	1.74
Exports	EXP×10^{20}	6.60	4.04	7.36	10.2	9.60
Total emergy used	U×10^{20}	13.4	16.5	24.3	33.3	37.7
Renewable emergy per captia	R/P×10^{15}	0.51	0.26	0.23	0.17	0.16
Emergy used per captia	U/P×10^{16}	5.04	4.83	6.32	8.37	9.04

According to the emergy flows change of Baiyangdian ecosystem, summary the emergy used and exports variation as follows:

There is little change of emergy used from renewable resources like sunshine, rainfall and river, emergy used from them decrease slightly mostly due to dry climate and reduced rainfall, emergy input from river gradually reduce after 1985, in 2009, river input decreased nearly as the 1/3 of 1975. Non-renewable resource input decreased after 1975, mainly because four large reservoirs upstream constructed in 1950s, under the influence of construction and impoundment, collapse and soil erosion resulted increasing sediment input of Baiyangdian Lake, but the change of sediment input became little after 1985 when erosion and deposition has been basically stable. As the continuous economic development, socio-economic system input emergy increased in the past 34 years, socio-economic system input in 2009 are 10 times higher than 1975, and emergy using structure has tremendous changes, from basing on non-renewable resources to socio-economic input.

Emergy used per capita is characterized by the use of people's living standard and welfare indicators. Renewable resource per capita in 2009 declined half more than in 1975. According to emergy used per capita level classified by Mao [26], Baiyangdian Lake ecosystem belongs to the third category, indicating that Baiyangdian Lake ecosystem has inadequate natural resources and little economic development potential, some improvement of emergy used structure should be done to reduce water resources utilization.

The organic production of Baiyangdian Lake ecosystem has a large climb in past 34 especially after 1995, ecosystem service function was the major output in 1975-1985, but less river input and rainfall made Baiyangdian Lake shrinking, purification and hydrological regulation function severely impaired. With increasing economic investment, economic output of Baiyangdian lake ecosystem also increased year by year especially in past 20 years. Overall, total emergy output has an increase except in 1985, economic output increased remarkably and ecological service functions continuously decrease, output in organic production and service function has absolute advantage in emergy output far more than economic output.

4.2. Ecosystem health assessment of Baiyangdian Lake based on emergy synthesis

According to the summary table of Baiyangdian Lake ecosystem, calculated the emergy index as formula, get the comprehensive evaluation index system from ecosystem efficiency, ecosystem structure, ecosystem function and ecosystem load four aspects.

Table 4. health assessment index system of Baiyangdian Lake

item	*Emergy index*	*1975*	*1985*	*1995*	*2005*	***2009***

Ecosystem efficiency	Emergy yield ratio	1.82	0.42	0.40	0.36	0.29
	Environment yield ratio	0.49	0.23	0.28	0.27	0.21
	Input-output ratio	0.49	0.24	0.30	0.31	0.25
Ecosystem structure	Renewable energy ratio	0.101	0.056	0.036	0.021	0.017
	Emergy investment ratio	0.37	1.34	2.85	5.73	7.21
	Emergy exchange ratio	0.55	2.34	2.45	2.76	3.44
Ecosystem function	Self-sufficiency rate	0.73	0.43	0.26	0.15	0.12
	emergy density	3.66×10^{12}	4.5×10^{12}	6.64×10^{12}	9.09×10^{12}	10.3×10^{12}
	Ecosystem service ratio	0.77	0.60	0.53	0.33	0.30
Environment load	ELR	8.93	16.93	26.61	46.57	57
	Waste ratio	0.0156	0.0158	0.0185	0.0234	0.0278

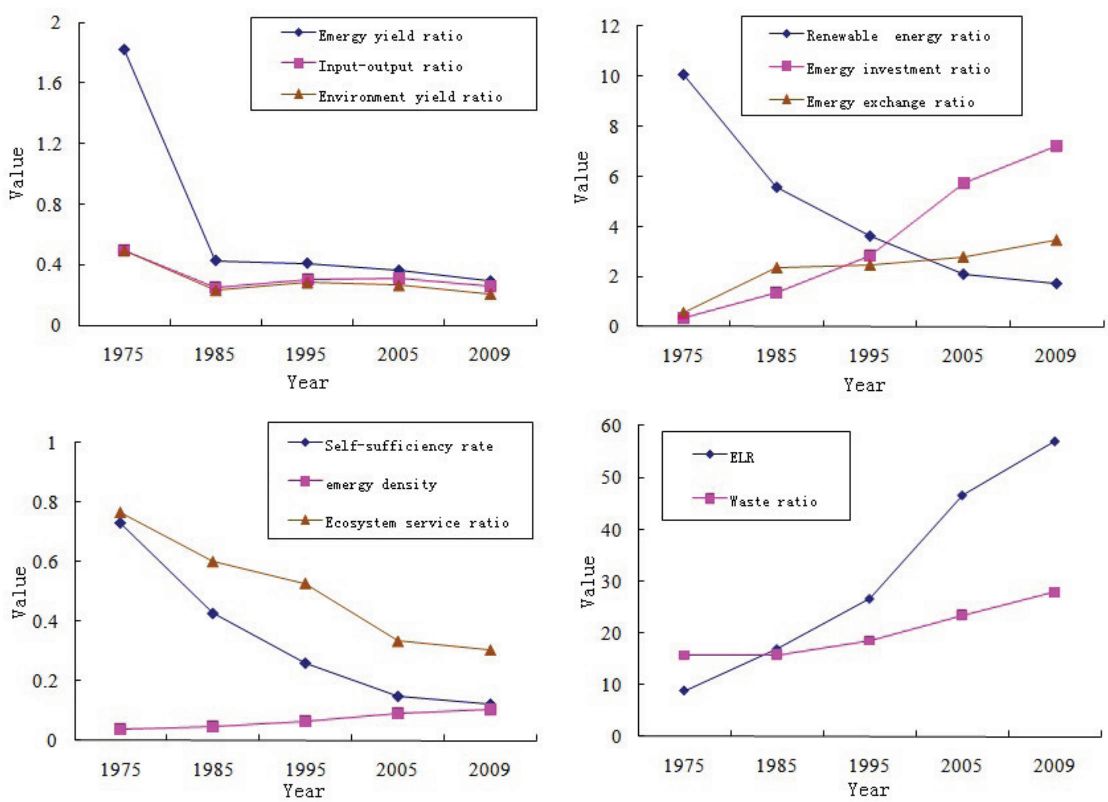

Fig. 4 Baiyangdian Lake ecosystem change based on health index system

4.2.1. Ecosystem efficiency

In the past 34 years, the emergy yield ratio has a continuous decrease especially in 1985 it appears sensible. The reasons may attribute to two aspects. One is the little stream discharge result in emergy output decreased nearly three times. Another is emergy input from socio-economic system increased threefold. Generally speaking, developed region has the emergy yield ratio more than 6, the ecosystem nearly no ecologic and economical efficiency when it falls below 1. Now, Baiyangdian Lake ecosystem is ringing the alarm.

Environment yield ratio characterized of ecosystem efficiency in environment, it declines from 1975 to 1985, upgrade slowly after 1985. The turning point in 1985 indicate that ecosystem service function and organic production impaired due to less river input, under the artificial breeding measures reed and aquatic production increase steady. In all, environment yield ratio has a marked decrease trend compare to 1975.

Input-output ratio has the same trends as environment yield ratio, because environment output is the major output of Baiyangdian Lake ecosystem, the change of environment yield ratio definitely determine the change of input-output ratio.

4.2.2. Ecosystem structure

In thirty four years time scale, the renewable resource input held comparatively firm, but the purchased emergy input continuously enlarge to meet the requirements of economic development which induce total emergy input enlarged. The renewable energy ratio decrease in contrast, the natural resource provided by ecosystem became small.

Emergy investment ratio increased stable as the enlarged input form sco-ecosystem. Compare to other region like Mississippi River and Amazon, the emergy investment ratio of Baiyangdian Lake has a faster growth, has a growing dependence on the socio-economic input emergy.

Emergy exchange ratio rise in 1985, totally because it was low socio-input and high output in 1975, as the increase of service and goods input and decrease of ecosystem service function and aquatic production, this ratio rise rapidly from 1985 to 1995. After 1995, the ecosystem provide more products and tourist services, the emergy exchange ratio return down.

4.2.3. Ecosystem function

Ecosystem is not a closed and isolated system, the development depends on the self-reliance and the linkages with the outside system, and self-sufficiency is a prerequisite and foundation for the ecosystem development. In 1975, Baiyangdian lake ecosystem has the self-sufficient of 73.2%, the resources used mostly from ecosystem inside. The self-sufficient ratio decrease 1.5% one year after 1975, ecosystem dependence on natural environment lower and dependence on socio-economic system higher.

Development of ecosystem has grades and classes, the emergy density larger, indicating that the higher level of ecosystem development. The emergy density has a steady increase in the thirty four years, the average growth rate is 5%, and this indicates that the ecosystem is in intensive developing, if it maintains the intensity may result in greater pressure on the environment.

4.2.4. Ecosystem load

The environmental loading ratio is 8.29 in 1975, indicating the ecosystem itself is more fragile than other region, it has been up to 57 in 2009 which is much higher than the average data of China. It means that high pressure on ecosystem is likely to exceed the critical value, may trigger ecological crisis, and cause irreversible ecosystem degradation or loss of function.

Waste ratio characterizes environmental pollution stress economic activity leading to. The waste ratio has been up to from 0.0257 from 0.0156, nearly tripled, and the growth rate is significantly accelerated, is 6 times more than Northwest region in China, the results show that environmental problems of Baiyangdian Lake have been very serious, especially in the current of purification function degradation, increase of waste ratio will no doubt give Baiyangdian Lake ecosystem a huge strike.

4.3. Ecosystem health assessment of Baiyangdian Watershed

Baiyangdian Lake ecosystem health has a close relationship with upstream rivers. The upper reaches by the dam interception, pollution, erosion factors may impair the health status, the normal energy flow be broke up, the unhealthy state of upstream rivers will be passed to the Baiyangdian Lake, therefore, it is necessary to evaluate the damage level of upstream rivers, which can provide evidence for watershed management and controlling measures. They are Zhulong-Xiaoyi River sub-watershed, Pu-Cao River sub-watershed, Tang River sub-watershed, Baigou Channel sub-watershed, Juma River sub-watershed and Fu River sub-watershed.

Collect river flow, waste pollution and sediment data of six rivers, calculate the EHI of each sub-watershed as follow

Table 5. Comparison of EHI in six sub-watersheds

	Zhulong-Xiaoyi River	*Tang River*	*Fu River.*	*Pu-Cao River*	*Juma River*	*Baigou Channel*
EHI	0.0883	0.0565	0.0095	0.0829	0.224	0.0735

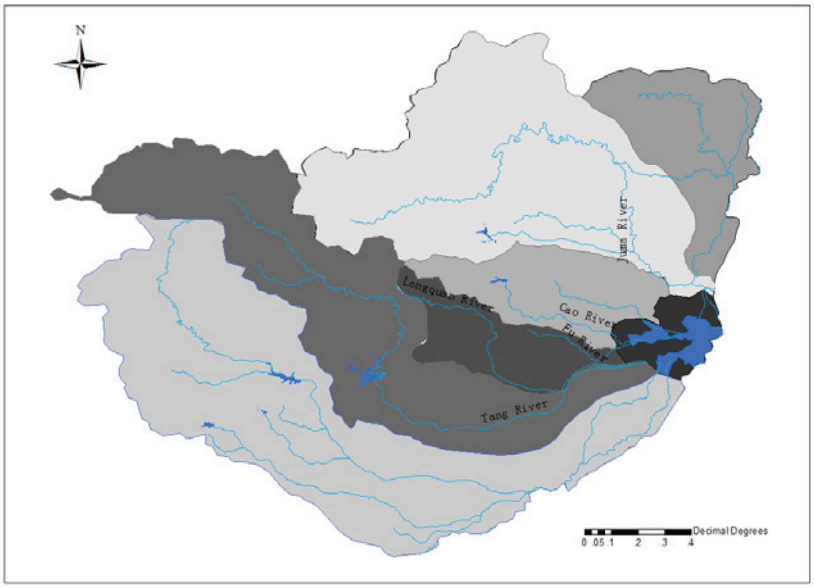

Fig. 5 health status comparison in six sub-watersheds

The results in spatial scale show that Fu River sub-watershed and Tang River sub-watershed have poorer health status, Juma River sub-watershed and Zhulong-Xiaoyi River watershed have best health status, Cao-Pu River and Baigou channel sub-watershed are in the middle.

Juma River has steady flow and better water quality, river sediments is small, the average annual flow into Baiyangdian Lake amount of 250 million m3, strenghthen the protection of riparian vegetation and make scientific management has a significant meaning to Baiyangdian Lake ecosystem health.

Zhulong-Xiaoyi River flow through mountainous and has less population and wastes pressure, river flow is more plentiful than other rivers. But the sediment deposition has to be concerned strengthen.

Compare the waste input of six sub-watershed, we find that Fu River flows nearly 40% of the total waste, so Fu River is the key monitoring area. Most of the wastes in Fu River are from Baoding industrial and domestic pollution. The current annual waste emission are 0.63 million m3, the water quality are basically V, aquatic life has been devastating damaged, the biological structure has been severely damaged, a large number of stain resistance algae reproduction. Living and industrial sewage of Baoding City flow into the lake year after year has a tremendous impact on Baiyangdian water quality and safety.

Cao-Pu River also has a large proportion of waste input, accounting for nearly 25%, mainly from industry pollution of Mancheng country, more than 200 paper making enterprises repeatedly raised the dead fish contamination of Baiyangdian Lake, although the wastes were controlled not flow into lake in dry season, but once flood season coming, the contaminated water flow into lake concentrated, pose great risk on Baiyangdian Lake water quality.

Baigou channel is drying up these years, dried up river bed has serious infiltration problems, there is a sediment deposition region which nearly 1.4km^2 in estuary ,which hindered water flows into lake in some extent.

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