J. Mater. Environ. Sci. 6 (9) (2015) 2631-2646
ISSN: 2028-2508
CODEN: JMESCN

Assessment of Water Bodies using Eco-exergy based Ecological health index Methodology

Saurabh Mishra[1*], M.P. Sharma[2] and Amit Kumar[3]

[*1, 2, 3] *Biomass and Ecosystem Lab, Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Uttarakhand, 247667, India*

Received 12 Nov 2014, Revised 10 May 2015, Accepted 10 May 2015
**Corresponding author: saurabhmishra20057@gmail.com, Mbl. No +91-7417575326*

Abstract

Human-affected freshwater ecosystems are becoming stressed and dysfunctional at regional and global level. Ecosystem health integrates the factors like ecological, economic, social and human health. The services provided by these ecosystems are extremely important to human welfare and therefore, it is essential to assess the ecological health of water bodies. The paper reviews the indices and indicators used by researchers for assessing the ecological health. Out of the large number of indices, few indices developed like IMEERA, HEHI, etc. are reported to provide precise results, but are time consuming and needs lengthy proceed. In the present paper, the ecological health index methodology (EHIM) along with/without tropical state index (TSI), being less time consuming and provide precise results, has been applied as a tool to assess the ecological health of Baiyangdian Lake (China) and found to have results similar to that obtained by Xu et al. [25] using eco-exergy based index (EBI) with TSI. The results indicated that the ecological health of Baiyangdian Lake is of middle health category i.e. (EHIM, 40-60), indicating bad quality of water with no life supporting ability. EHIM, therefore, as an important tool based on eco-exergy to assess the ecological health of water body in any geographical region and can recommended for ecological health assessment of water ecosystems.

Key words: Ecological Health, Water Body, Indicators, Indices, EHIM.

Nomenclature

BOD: Biological Oxygen Demand.
DO: Dissolve Oxygen.
TDS: Total dissolved solid
COD: Chemical Oxygen Demand.
Chl-a: Chlorophyll-a.
TN: Total Nitrogen.
TP: Total Phosphate.
SD: Secchi Depth.
TSI: Tropic State Index.
WQI: Water Quality Index.
BHI: Bay health index.
HEHI: Holistic Ecosystem Health Index.
IMEERA: Indice Multimetricodel Estado Ecologicopara Rios Altoandinos.
EHIM: Ecosystem Health Index Methodology.
EBI: Eco-exergy Based Index.
P-IBI: Planktonic Index of Biotic Integrity.
SDM: Structural Dynamic Model.
IBMA: Antillean Macro Invertebrate Biotic Index;
ISI: Invertebrate Species Index.
BMAI: Benthic Macro Invertebrate Assemblages Indices.
BMI: Biotic Macro-invertebrates Index.
LICOI: Limnological Conditions Index.
EQI: Ecological quality index.
SSMI: New Multi-metric Salt Marsh Sediment Microbial Index.
PMMI: Predictive Multi-metric index.
EFAI: Estuarine Fish Assessment Index.
EPI: Eco Path Model.
HEHI: Holistic Ecosystem Health Index.
EBLE: Environmental Quality, Biology and Ecology, Landscape Pattern and Ecosystem Management Index.
FMM: Fuzzy Mathematical Models.
GSM: Gray System model.
IHRs: Integrated Health Responses.

ISSN: 2028-2508
CODEN: JMESCN

1. Introduction

Water is essential for the existence of life on earth. With increase in population, the quantity and quality of water is increasingly being used in domestic, agricultural, industrial, recreational, and other commercial activities. Of the total water availability, globally about 97.5% of total available water is saline while the balance 2.5% is freshwater, most of which is available as deep and frozen in Antarctica as well as in Greenland, while only 0.26% is available in rivers, lakes, soils, shallow aquifers, etc. for use by human [1-2]. The water bodies are complete ecosystem in themselves and perform important functions of satisfying a number of human demands by acting as a source for resources and sink for the waste. These water bodies are self-sustaining and self-regulating in the sense that up to certain pollutant addition, these have good regenerative capacity and can undergo self-purification and other ecological processes to maintain their health. In recent times, due to rapid industrialization and urbanization, the pressure on the water bodies has reached to a level, where their revival becomes difficult due to the significant reduction in their carrying capacity. The assessment of ecological health and carrying capacity of such water bodies is, therefore, becoming important, not only for developing countries but also for developed ones. Therefore, there is an urgent need to develop systematic diagnostic tools to assess the health of water bodies, so that the corrective measures can be taken in time to restore the health and carrying capacity of given aquatic ecosystem [3].

The present paper covers the concept of ecosystem health and reviews the methodologies adopted by researchers and finally selecting appropriate assessment system applicable to a given water body. Beside this, the literature reviewed for the analysis of work done in field of ecological health assessment of water bodies in India. Furthermore, the selected assessment methodology is applied to assess the ecological health of Baiyangdian Lake (China), based on the parameters data obtained from literature comparison of result shows that the selected assessment methodology can be recommended as a tool to assess ecological health of water bodies in India and abroad.

2. Concept of Ecological Health of Water Body

As per literature, ecological health is a scientific tool to classify ecosystems with respect to human cause. The term “ecological health” was coined early in 19^{th} century due to its benefits in terms of services, functions, its components, and indicators [4]. The ecological health can also be defined on basis of water uses, water quality, biota, watershed, anthropogenic disturbances etc., and therefore, different types of indices are used to quantitatively assess the ecological health of water bodies [5-6]. An ecological health of ecosystem is considered as `stable and sustainable', meaning, thereby, that all food chains in the system are balanced with no shortage/accumulation of production/wastes.

3. Indices used to assess the Ecological Health

In complex ecosystem, the ecological indicators play an important role to understand the functioning of the system. Large numbers of indicators are developed to assess various aspects of the ecosystem but it is difficult to select suitable indicators to simplify the complexity [7]. The indicators like physiochemical (DO, BOD, SD etc.) and biological parameters (planktons, benthos, fishes etc.) etc. can be used to assess the health of water bodies. These indicators are helpful in understanding the changes in water quality and trends in aquatic life. Based on the literature, the different types of indices used for ecological health assessment of rivers, lakes, and wetland are reviewed and presented in Table 1.

Table 1: Indices for Ecological Health Assessment for Water Bodies

Sl. No.	Name of Indices	Indicators	Range of indices	Limitations	Index formula/methodology	Scope	Ref. No.
1.	The Planktonic Index of Biotic Integrity (P-IBI) methodology.	• Phytoplankton biomass, • Zooplankton biomass,	TP, Clh-a metrices range 1-5: • Eutrophic (1-3) • Mesotrophic (1-5) • oligotrophic lakes (>5)	Availability of historical datasets and sampling frequency should be important considerations.	• $P-IBI=\frac{1}{B}\sum_{k=1}^{B}\frac{1}{S}\sum_{j=1}^{S}\frac{1}{M}(EA_{jk}+$ CBjk+RJjk+LMjk+RAjk+ZBjk Where, EA_{jk} is the 1st month biomass of edible algae taxa metric score; CB_{jk} is the1st month% indicator phytoplankton of total phytoplankton biomass metric score; RJ_{jk} is the 1st month zooplankton ratio metric score; LM_{jk} is the 2nd month indicator zooplankton density metric score; RA_{jk} is the 3rd month zooplankton ratio metric score; ZB_{jk} is the 3rd month crustacean zooplankton biomass metric score; M is the number of metrics; S is the number of sites (within a basin); and B is the number of basins.	• To assess offshore water quality of lakes • Used to monitor changes in lakes due to anthropogenic stressors.	[8]
2.	Eco-exergy Based indices (EBI)	• Phytoplankton biomass, • Zooplankton biomass, • Submerged plants.	NA	NA	• $Ex=\sum_{i=1}^{n}\beta_i C_i$ • $Ex_{st}=\sum_{i=1}^{n} C_i/C_t$ Where, Ex is the Eco-exergy; Ex_{st} is the Structural eco-exergy; β_i is the weighting factor of the ith component; C_i is the biomass of the ith component or the concentration of the ith component; n is thetotal number of components selected.; and C_t is the total biomass, which is the sum of all the C_i	Can be applied to any water bodies to assess its health.	[9]
3.	The Structural Dynamic	• Phytoplankton biomass,		• The number of selected parameters	Application of eco- exergy and structural eco-exergy is used for model calibration.	• The model may be	[10]

	Model (SDM)	• Zooplankton biomass, • Submerged plants.	NA	for optimizing eco-exergy is normally restricted due to technical limitations • Allometric principles for phytoplankton and restricted to the sizes of the two species		suitable for assessing the ecological health of different water bodies. • Can be applied in eco toxicology assessment.	
4.	Ecosystem Health Index Methodology (EHIM).	• Biomass concentration and dry weight of phyto& zooplankton. • The number of cells of phytoplankton, etc.	Range 0-100: • Worst (0–20). • Bad (20–40). • Middle (40–60). • Good (60–80). • Best (80–100).	NA	• $EHI = \sum_{i=1}^{n} w_i \times SUBEHI_i$ Where, EHI is the synthetic ecosystem health index; $SUBEHI_i$ is the i^{th} sub-ecosystem health index for the i^{th} indicator; n is the number of indicators considered in assessment; and w_i is the weighting factor for the i^{th} indicator.	Can be used to assess ecosystem health quantitatively and compare the states for single and different lakes, and also can be applied on other water bodies.	[11]
5.	Ecological quality index (EQI).	• Water temperature • Transparency • Turbidity • TSS, pH, DO, TN, TP, BOD • Riparian vegetation.	Range0-50: • Poor health (1). • Excellent health (50).	NA	• $EQI = [\text{status no. for EQI of CTSI} + \text{status no. for EQI of WQI} + 1SDI/3$ Where, CTSI is the Carlson tropic state index; WQI is the water quality index; and SDI is the Simpson diversity index.	Can be applied to any water bodies to assess its health	[12]
6.	Bay Health Index (BHI).	• Chl-a • DO • SD	The score ranges for each BHI component 0-100%.		• $BHI = \text{avg. of}(WQI + BI)$ Where, WQI is the water quality; and BI is the biotic indices.	Can be applied to other	[13]

		• Phytoplankton • Benthic invertebrates • Submerged aquatic vegetation	• Impaired (0%). • Unimpaired (100%).	NA	• Both WQI and BI are expressed as the average of the % attainment of their component metrics and biotic indices, are averaged to obtain the BHI.	watersheds also to assess health.	
7.	Limnological conditions index (LICOI).	• Temperature, DO, pH, conductivity, hardness, Cl, NH_3, NO_3, NO_2 and BOD. • Phytoplankton • Periphyton • Macro invertebrates, macrophytes	Range 0-100%. • Slightly contaminated (> 35%). • Moderately polluted (17.5-35%). • Heavily contaminated (4-17.5%). • Severely contaminated(< 4%).	NA	• $\text{LICOI} = [(100 - (\%\text{BIP } 0.3)) + 100{-}\%\text{BID } 0.3{+}100{-}\%\text{BII } 0.1{+}100{-}\%\text{BIM } 0.3$ Where, % BIP is the biotic index of phytoplankton; % BID is the biotic index of periphytic diatoms; % BII is the biotic index of aquatic macro-invertebrates; and % BIM is the biotic index of aquatic macrophytes.	Can be used to assess the ecological health of wetlands and can be extended to other aquatic environments.	[14]
8.	Environmental quality, biology and ecology, landscape pattern and ecosystem management index (EBLE).	• Environmental quality • Sediment quality • Habitat quality • Chl- a • Phyto& Zooplankton • Fish • Benthos • Landscape pattern • Ecosystem management	Range 0-1: • Bad (0–0.2). • Poor (0.2–0.4). • Moderate (0.4–0.6). • Good (0.6–0.8). • Excellent (0.8–1.0).	NA	• $\text{IEBLE} = (\text{IEQ} \times W_{EQ}) + (\text{IBE} \times W_{BE}) + (\text{ILP} \times W_{LP}) + (\text{IEM} \times W_{EM})$ Where, IEBLE is the comprehensive ecological integrity index in the estuary region; IEQ is the ecological integrity indexes environmental quality; IBE is the ecological integrity indexes biology ecology; ILP is the ecological integrity indexes, landscape pattern; IEM is the ecological integrity indexes of, ecosystem management; and W_{EQ}, W_{BE}, W_{LP} and W_{EM} are their weights, respectively.	It is comprehensive ecological integrity index and considers the multi-scale eco-environmental characteristics, and is very useful and can be applied to other estuary wetland heath assessment.	[15]
9.	Benthic macro	• Benthic macro	**M-AMBI** Range 0-1:	Azti Marine Biotic	• BMAI is comparative analysis of	Can be	[16-17]

	invertebrate assemblages indices (BMAI)	invertebrates	• High quality (>0.77). • Good (0.53-0.77). • Moderate (0.38-0.53). • Poor (0.20-0.38). • Bad (<0.20). **Bentix** range 0-6: • Normal/Pristine (4.5 ≤ BENTIX < 6.0). • Slightly polluted, transitional (3.5 ≤ BENTIX < 4.5). • Moderately polluted (2.5 ≤ BENTIX < 3.5). • Heavily polluted (2.0 ≤ BENTIX < 2.5). • Azoic (0).	index (AMBI), multivariate-AMBI (M-AMBI), and Bentix index are indices based on ecological groups, which are ranked according to their sensitivity to an increasing stress gradient. Groups considered varies with the index: 5 for AMBI and M-AMBI; 2 for Bentix.	AMBI, M-AMBI BENTIX indices, and BAT index • $AMBI = [(0 \times \%GI) + (1.5 \times \%GII + 3 \times \%GIII + 4.5 \times \%GIV + 6 \times \%GV/100$ • $BENTIX = (6 \times \%GS + 2 \times \%GT)/_{100}$ Where, GI is the species very sensitive to organic enrichment; GII is the species in different to enrichment; GIII is the species tolerant of excessive organic enrichment; GIV is the 2nd order opportunistic species; GV is the 1st order opportunistic species; %GS is the relative abundance of sensitive species is the %GI + %GII; %GT is the relative abundance of tolerant species is the %GIII + %GIV + %GV; and BAT index is a multimetric methodology that combines Margalef, Shannon Weiner and AMBI indices.	applied to any water bodies to assess its health	
10.	Biotic macro-invertebrates index (BMI)	• Benthic macro-invertebrates	Based on 10-point taxa scores in which • Highly pollution-tolerant taxa (1). • Highly pollution-sensitive taxa (10).	Ganga River System biotic score (GRSbios) is most reliable, followed by the Nepalese Biotic Score (NEPbios)-Extended, Hindu-Kush Himalayan Biotic Score (HKHbios), and Bagmati River System	• BI is combination of NEPbios, BRSbios, GRSbios, HKHbios, and NEPbios • The Receiver Operating Characteristic (ROC) methodology is used to calculate the accuracy of a biotic index. • A non-parametric Spearman's rank correlation coefficient method is used.	Can be used for water bodies in different geographic regions.	[18]

				biotic score (BRSbios).			
11.	The Antillean Macro invertebrate Biotic Index (IBMA)	• Macro invertebrate	Range 0.05- 0.98: • High–good (0.98-0.73) • Good–moderate (0.73-0.60) • Moderate–poor (0.60-0.48) • Poor–bad (0.48-0.35)	• Metrics for: Taxonomic diversity, Species abundance and some substratum types. • Each metric was weighted by its discrimination efficiency.	• $IBMA = \sum \frac{DE_M \times EQR_M}{SDE_M}$ Where, IBMA is the Antillean Macro invertebrate Biotic Index; DE_M is the discrimination efficiency of the biological metric 'M'; and EQR_M is the Ecological Quality Ratios value of the biological metric 'M'.	This might prove relevant to other Caribbean islands water bodies in biogeography area.	[19]
12.	The invertebrate species index (ISI)	• Benthic macro invertebrates	Range 1-10: On species scoring: • Restricted to undisturbed sites (10) • Taxon tolerant to excessive pollution and degradation (1).	• Small creeks and tributary streams catchment area of <50 km^2 and an altitude of <675 m. • Larger streams and rivers, of catchment area >50 km^2 and at an altitude of <100 m.	• $ISI = \frac{\sum_{i=1}^{n} S_{10i} \times W_i \times A_i}{\sum_{i=1}^{n} W_i \times A_i}$ Where, S_{10} is the Weighted average of all species scores; W is the indicator weight; and A is the abundance score of each species (i) as weights.	For streams in southeast Queensland, Australia.	[20]
13.	New Multi-metric Salt Marsh Sediment Microbial Index (SSMI)	• Physical–chemical and • Microbial parameters	Range 0-1: • Very low (<0.44). • Very high (>1.76). • Medium (0.89–1.32).	A Principal Component Analysis (PCA) was performed to select the appropriate measured parameters to integrate the index.	• $SSMI = \sum_{i=1}^{n} W_i S_i$ • $S = \frac{a}{1(1+(X/X_0)^b)}$ Where, W is the Principal component analysis weighing factor of the PCA selected variable; S is the respective score; x is variable verified value; a is the maximum score of the variable (in this case 1); x_0 is the average value of the variable; and b is the value of the slope of the equation.	• This index is valid for describing the salt marsh degree of maturity, halophytic species colonizing the sediment in marine ecosystem.	[21]

J. Mater. Environ. Sci. 6 (9) (2015) 2631-2646 Mishra et al.
ISSN: 2028-2508
CODEN: JMESCN

						• Can be used for marine ecosystem health assessment.	
14.	Índice Multimétrico del EstadoEcológicopara Ríos Altoandinos (IMEERA) index.	• Physiochemical parameters. • Hydro morphological • Aquatic macro invertebrate assemblages.	Range 0–100: • Poor quality (0). • Good quality (100).	The threshold between: • Good and moderate was established using the 25th percentile. • Very good and good was set using the 75th percentile of reference sites	• Index value = $\left(\frac{\text{score } 1+\text{score } 2\& \, score \ n}{\text{N}}\right)$ • Where, Score 1, 2. . . n is the value obtained for each metric in the score from 0 to 100; N is the number of calculated metrics;	Two versions of IMEERA: • For lower altitude bioregion streams (IMEERA-B index). • Higher elevation bioregion streams (IMEERA-P river type).	[22]
15.	Predictive multi-metric index (PMMI).	• Fish functional traits	NA	NA	Matrices of richness, abundance and biomass are calculated along with Indice Poisson Rivière (IPR) etc.	Can be applied on any water bodies to assess health.	[23]
16.	The Estuarine Fish Assessment Index (EFAI)	Fish-based • Species richness • Migrants species • Estuarine species • Piscivorous species • Diadromous species	Range 5-18: • Oligohaline (salinity <5). • mesohaline (5<salinity>18). • polyhaline (salinity>18).	NA	• EFAI include metrics revealing fish community structure and function as well as using key-species to evaluate specific impacts of anthropogenic activities. • The EFAI is expressed as the sum of all metrics scores.	Can be used for water bodies in hyaline zones or marine ecosystem.	[24]

		• Introduced species, • Disturbance sensitive species					
17.	Eco path model (EPM)	• Key food web (Fish, shrimp, crabs, and shellfish).	Range 0-1: • Data not rooted in local (0). • Data fully rooted in local data (1).	• In this model, value of EE (Eco trophic efficiency) should be between 0-1. • The respiration of each functional group is positive.	• $B_i \left({}^{P}/_{B}\right)_i EE_i = Y_i + \sum B_j \left({}^{Q}/_{B}\right)_j DC_{ij} + EX_i$ Where, B_i is the biomass of function group i; $(P/B)_i$ is the production /biomass rate; EE_i is Eco trophic efficiency; Y_i is the yield of group i; B_j is biomass of the predator group j; $(Q/B)_j$ is the relative food consumption ratio of j; and DC_{ij} is the fraction of prey i in the diet of predator j	• The maturity of the target and existing ecosystems is evaluated. • Can be applied to any water bodies to assess its health.	[25]
18.	Fuzzy mathematical models (FMM).	• Hydrological characteristics • Water environment quality • Structure and function of aquatic ecosystems • Structure of waterfront areas • Scenic effects • Stress factors	• Primary productivity of plankton plants, 2.5–7.5 g/ (m^2/d) as the critical state. • Width of the buffer zone of vegetation for healthy (10 m) and for unhealthy (5m).	• It is required to choose indicators and standard values according to the various objectives varying from site to site. • Avg. Depth of lake (1–2 m) • Minimum velocity 0.02 m/s	• $A = W \times R$ • $R = \begin{pmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \\ R_{41} & R_{42} & R_{43} \\ R_{51} & R_{52} & R_{53} \\ R_{61} & R_{62} & R_{63} \end{pmatrix}$ • $R_{ij} = (W_{i1} \quad W_{i2} \cdots W_{ik}) \begin{pmatrix} r_{1j} \\ r_{2j} \\ \vdots \\ r_{kj} \end{pmatrix}$ Where, A is a matrix which can reflect urban rivers and lakes health status; W is weight matrix of assessment elements; R_{ij} is the degree of membership of the element i to health standard j; and r_{ij} is the relative degree membership of the indicator k to standard j;	Can be applied to any water bodies to assess its health	[26]
19.	Gray system	• Hydrology			It include assessment of indicators by	To assess the	[27]

	model (GSM)	• Water environment • Physical habitat, • Biotic structure	NA	NA	evaluating their: • Reference sequence • Comparison sequence • Gray incidence coefficient • Degree of gray incidence	river ecosystem function	
20.	Holistic ecosystem health index (HEHI) methodology	• Ecological- Water quality, Watershed health, Land use and farming productivity, and Biodiversity • Social-Faming Income, Affluence • Interactive- Catchment protection, Environmental awareness	The scale 0-100 • Healthy (100). • Unhealthy (0).	NA	Mean and standard deviations of the health scores of the indicators for each dimension per decade are computed in for the overall HEHI index.	Can be applied to any water bodies to assess its health.	[28]
21.	Integrated Health Responses (IHRs) modeling	• Water chemistry analysis, • Habitat health, • Eco toxicity tests, • Molecular/biochemical, physiological biomarkers,	The IHRs model values • Highest correlations response to individual-population level ($r = 0.91$, $p < 0.01$) • Strongly relate to the parameters for other levels ($r > 0.80$, $p < 0.05$), r:correlation coefficient. p: parameter.	NA	All data were standardized to allow direct visual comparison of all responses at each sampling site and compared with the reference site.	Can be used for ecological health assessment and to identify biomarkers or bio indicator physiochemical and biological parameters for monitoring urban streams.	[29-30]

The Table 1 shows that the ecological health assessment based on biotic indicators like planktons, benthos, and physiochemical parameters is the need in today's world due to the rapid degradation of water bodies. Based on literature, the common parameters required for the evaluation of different indices and their advantage/disadvantage are given in Table 2.

Table 2: Parameters for Evaluation Indices and their Advantage/Disadvantage

Sl. No.	Indices	Parameters required for evaluation	Advantage (+)/Disadvantage (-)
1.	EBI, P-IBI, SDM, EHIM.	Planktons (phyto & zoo)	• Based on thermodynamic indicator (+). • EHIM can define holistic ecological health status of water body (+). • P-IBI, and SDM based evaluation is time consuming (-). • EBI may not be used to define holistic ecological health status of water body (-).
2.	IBMA, ISI, BMI, BMAI.	Benthic invertebrates	• It is based on only one type of indicator (+). • Physiochemical and other social aspects are not considered (-). • Restricted to geographical region (-).
3.	IMEERA, BHI, LICOI.	Planktons, benthos, and physiochemical parameters	• Both physiochemical and biotic indicators are considered (+). • Evaluation is very time consuming and requires good mathematical approach (-).
4.	EQI.	Physiochemical parameters and riparian vegetation [31-33]	• Evaluation less time consuming (+). • Do not consider the aquatic biota (-)
5.	SSMI.	Physiochemical Parameters and benthic invertebrates	• Principle component analysis requires good skill in statistics (-). • Restricted to marine ecosystem (-).
6.	PMMI, EFAI, EPI.	Fish traits	• It is based only on one type of indicator (+). • It is restricted to only fish assemblage data and other aspects have not been considered of ecosystem (-).
7.	HEHI, EBLE, FMM, GSM.	Physiochemical, biological, hydrological, and social parameters	• Result obtained is very precise (+). • Evaluation is very time consuming and requires good mathematical approach (-).
8.	IHRs.	Biochemical markers	• Considers metabolites as indicator, • Could give precise result (+). • Lengthy evaluation makes it a time consuming (-).

The literature review reveals that the little work has been done on assessment of ecological health of water bodies in India [12, 17 & 18], but significant work in other countries as shown in Table 1. Out of several indices, only EHIM is found as a useful tool to evaluate the health of any water body; as it is less time consuming, require thermodynamic parameter (eco-exergy) and provide satisfactory results to assess ecological health of the water body quantitatively as well as qualitatively; accordingly only EHIM is discussed below:

4. Ecosystem Health Index Methodology (EHIM)

The EHIM was initially proposed by Xu et al. [11] and applied to assess the ecological health of 30 Italian lakes. The EHIM can be used to assess the lake health ecosystem of any geographical region. The step by step procedure to evaluate EHI is performed, which consists of selecting the basic and additional indicators to determine the correlation; calculating SUBEHIs for all selected indicators; determining weighting factors for all selected indicators; calculating a EHI using the SUBEHIs and weighting factors for all selected indicators; assessing ecosystem health based on EHI values. The EHI ranges from 0-100, where 0 indicate less polluted and 100 indicates severely polluted river shown in Table 3.

Table 3: Comparison of EBI, EHI and TSI to Classify Ecological Health of Water Body

Sl.No.	EBI	EHI	TSI	Attributes of water body
1	Poor (6.0-6.2)	Worst (0-20)	Very High (80-100)	Hypereutrophic: algal biomass relatively very high, highly nutritive, significantly reduced oxygen levels and prevent life functions at lower depths, zooplankton (only Microzooplankton) biomass very less, Ex high, Exst and buffer capacity low.
2	Moderate (6.2-6.8)	Bad (20-40)	High (60-80)	Eutrophic: high biological productivity, able to support abundance of aquatic plants, devoid of oxygen, zooplankton biomass less (Macrozooplankton biomass relatively very less, Microzooplankton biomass high), moderately life supporting activity.
3		Middle (40-60)	Moderate (40-60)	Mesotrophic: algal biomass relatively low, zooplankton biomass high (Macrozooplankton biomass less, Microzooplankton biomass very high). Ex, and Exst high but low buffer capacity, little life support of aquatic flora and fauna.
4	Good (>6.8)	Good (60-80)	Low (20-40)	Oligotrophic (Hypolimnia become anoxic): algal biomass relatively low, low algal production, and very clear water, with high drinking-water quality, zooplankton biomass very high (Macrozooplankton biomass high, Microzooplankton biomass less), ample oxygen with moderate life support ability.
5		Best (80-100)	Very Low (0-20)	Oligotrophic (Hypolimnia remain oxygenated throughout the year): Algal biomass very low, zooplankton biomass very high, (macrozooplankton biomass relatively very high, microzooplankton biomass very less). Ex, Exst and buffer capacity relatively high, more oxygen, high life supporting ability to sustain aquatic flora and fauna.

The above Table 3 shows that more TSI is than EBI and EHI is an indication of worst quality of water and vice versa and provides important information about the ecological health of a water body. These indices are also used to assess quality of water suitable for drinking, recreation, irrigation, and aquatic life. The water bodies with slight increase in phytoplankton density as indicated by chlorophyll ‘a’ i.e. more Chl-a indicates more phytoplankton biomass showing of worst ecological health.

The SUBEHI and EHI indices were calculated by following equation:

$$\mathrm{SUBEHI} = 10(\mathrm{a} + \mathrm{b}\ \ln \mathrm{C_x}) \quad \text{(Equation 1)}$$

Where, C_x is the measured indicator value; ‘a’ and ‘b’ is constants evaluated using C_{min} and C_{max} by equation 2 and 3 as:

$$\mathrm{a} = -10 \times \frac{\ln C_x}{\ln C_{max} - \ln C_{min}} \quad \text{(Equation 2)}$$

$$\mathrm{b} = 10 \times \frac{1}{\ln C_{max} - \ln C_{min}} \quad \text{(Equation 3)}$$

Where, C_{max} is the measured maximum value when sub EHI is 0; C_{min} is the measured value when the measured SUB EHI is 100.

$$w_i = \frac{r_{i1}^2}{\sum_{i=1}^{m} r_{i1}^2} \quad \text{(Equation 4)}$$

w_i is the weightage factor for i^{th} indicator; r_{i1} is the Pearson correlation coefficient between the i^{th} indicators and basic indicator; m is the total number of indicator considered.

$$\mathrm{EHI} = \sum_{i=1}^{n} w_i \times \mathrm{SUBEHI}_i \quad \text{(Equation 5)}$$

Where; SUBEHI is the ecological health index of i^{th} indicator; i^{th} indicators are phytoplankton biomass (BA), zooplankton biomass (BZ), eco-exergy (Ex) and structural eco-exergy (Ex_{st}).

ISSN: 2028-2508
CODEN: JMESCN

5. Ecological Health Assessment of Baiyangdian Lake Case Study

The Baiyangdian Lake, one of the biggest lakes in the North China, is located in the range of 115º45′–116º07′E and 38º43′–39º02′N, with an area of 366 km^2. It consists of 143 small and shallow lakes linked by thousands of ditches. Generally, the lake is regarded to be partly dry at water level of 6.5m, and is totally dry at water level 5.5m. In the past 50 years, the water depth varied between 5.2 – 9.26 m [34].

From literature review, it is observed that the ecological health of Baiyangdian Lake was assessed using eco-exergy based index (EBI) by Xu et al. [9] but in the present study, the concept of EHIM has been applied to assess the ecological health of the said Baiyangdian Lake. The data on phytoplankton biomass (BA), zooplankton biomass (BZ), tropic state index (TSI), eco-exergy (Ex), and structural eco-exergy (Ex_{st}) as indicators were obtained from the work of Xu et al. [9]. The details of sampling locations in lake are also given in the paper of Xu et al. [9]. The calculated SUBEHI index of each indicator and overall EHI at 14 different sites of the lake is given in Table 6. For calculation of EHI, the value of 'a' and 'b' constant were evaluated using equation 2 and 3 respectively, and the weightage factor of each indicator was calculated using equation 4 and is given in Table 4. The Pearson Correlation coefficient (r) between different indicators is given in Table 5.

Table 4: 'a' and 'b' constants and weightage factor (w_i) value of indicators

Indicators	**BA**	**BZ**	**BA/BZ**	**Ex**	**Ex_{st}**
w_i	0.78	0.04	0.01	0.00	0.16
A	-8.20	8.50	20.21	-93.24	-107.75
B	3.84	3.62	3.30	12.17	59.86

Table 5: Pearson Correlation coefficient between BA and other indicators

Correlation	BA-BA	BA-BZ	BA-BA/BZ	BA-Ex	BA-Ex_{st}
r_{ij}	1	0.23	-0.11	0.07	-0.45
r_{ij}^2	1	0.05	0.01	0.01	0.20

Table 6: Ecological health status of Baiyangdian Lake, China using EHI methodology

Sampling sites	**SUBEHI (BA)**	**SUBEHI (BZ)**	**SUBEHI (BZ/BA)**	**SUBEHI (Ex)**	**SUBEHI (Ex_{st})**	**EHI**	**Health status range**
1	65.07	50.35	43.96	78.47	16.60	56.98	Middle
2	60.60	81.78	76.44	11.64	28.98	56.37	Middle
3	70.92	69.13	56.02	36.13	27.09	63.55	Good
4	00.00	11.70	64.73	99.99	99.99	17.49	Worst
5	68.11	99.96	79.03	67.51	00.01	58.67	Middle
6	14.70	14.08	54.23	40.95	12.74	14.84	Worst
7	8.17	00.17	47.15	00.00	17.56	9.66	Worst
8	34.33	69.63	87.97	72.84	61.10	40.75	Middle
9	26.87	43.87	70.89	76.73	62.88	33.96	Bad
10	36.97	21.70	42.00	42.09	53.91	39.10	Bad
11	27.25	76.14	99.99	35.67	28.98	30.30	Bad
12	99.95	35.10	00.00	73.65	21.39	83.62	Best
13	31.06	43.18	66.68	46.73	69.96	38.18	Bad
14	11.05	73.70	35.74	84.29	86.47	26.29	Bad
Overall avg. EHI of lake						**40.69**	**Middle**

The Pearson correlation coefficient of each indicator is used to evaluate the weightage factor (wi) as per equation 4. SUBEHI for each indicator are multiplied with their weightage factor (wi) and finally averaged to get the EHI at all 14 sites using equation 5. The EHI of all 14 sites of various sampling locations are averaged to get the overall EHI of lake. The graphical representation of ecological health of the lake is shown in Figure 1.

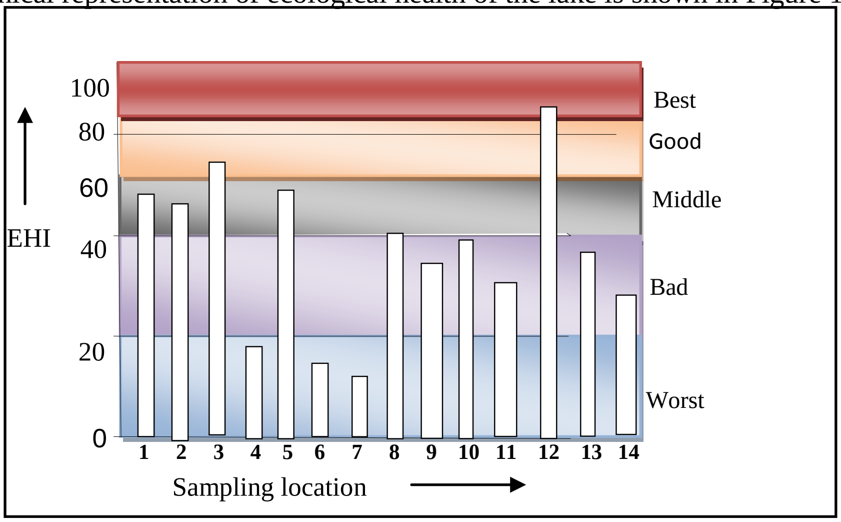

Figure 1: Ecological health of Baiyangdian Lake at all sampling locations

In the Figure 1, the red portion depicts that the value of EHI is high (80-100), hence it can be said that water in these regions are free from polluted i.e. fit for drinking purpose. The EHI for the region which is orange reads from 60-80, reveals that the water quality in these regions is good. The Water Quality Index for the region showed in blue (0-20) confirms that the water in these regions has been contaminated with high pollutant level which is unsuitable for drinking.

6. Result and Discussions

Literature review reveals that assessment of ecological health of any water body requires appropriate indices and indicators. The concept of eco-exergy can be applied to all water bodies to assess its health. The benthic macro-invertebrates are essential indicators as most of indices reviewed require benthos data for ecological health assessment. It is also found that almost all the indices reviewed can be used to assess the ecological health of water body in all geographical regions, except IBMA and ISI due to being region specific, while EFAI and SSMI are restricted to hyaline water bodies only. Table 1 and 2 shows that though the indices like HEHI, EBLE etc. cover all the aspects of ecosystem for assessing the ecological health but involve complicated evaluation. The EHIM is, therefore, selected as an appropriate tool for ecological health assessment of water bodies, and is applied to assess the ecological health of Baiyangdian Lake. EHI of 40.69, is an indication of bad quality of water (EHI: 40-60) with no life support. Table 7 compares the results obtained from EBI used by Xu et al. [9] with the results of EHI obtained in present study.

Table 7: Comparison of Results on Ecological Health of Baiyangdian Lake

Features	**Xu et al., 2011**	**Present study**
Methodology	Based on comparative analysis of eco-exergy and structural eco-exergy i.e. EBI.	Based on EHIM
Findings	• Overall lake health is found as moderate.	• Overall lake health is in middle status, but overall average EHI (40.69) is very close to bad health.

The above table shows that the results of EHIM are in good agreement with EBI indicating the bad health of lake and bad quality of water with no life supporting ability. It could be due to various anthropogenic activities in undergoing nearby area. Graphical presentation of EBI, TSI and EHI of Baiyangdian Lake has been shown in Figure 2.

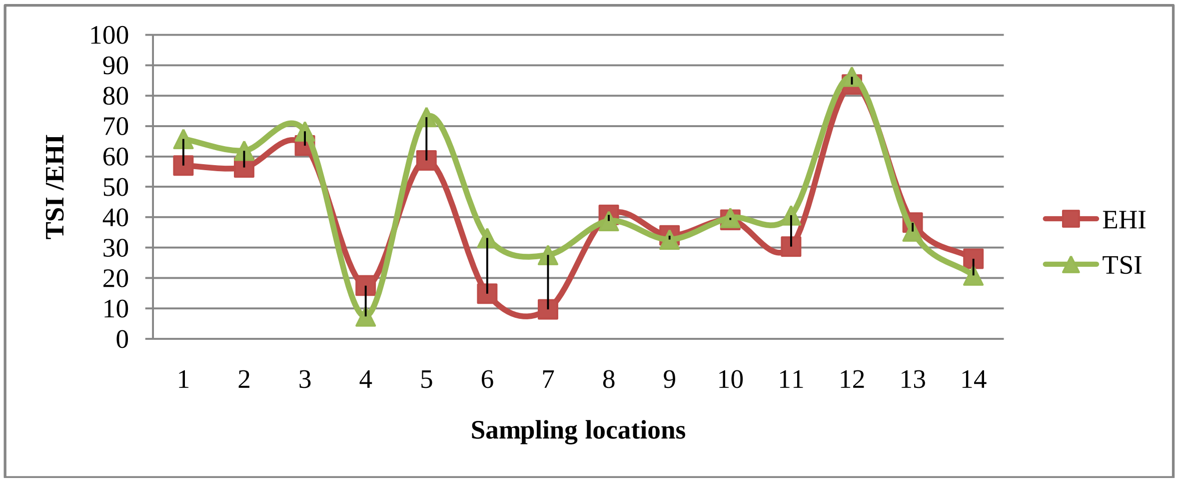

Figure 2: Comparison of Ecological Health Status based on EHI & TSI

Figure 2 shows that, the overall ecological health of Baiyangdian Lake is found as medium showing medium quality and medium health with little life support. Xu et al. [9] evaluated that trend of EBI with tropic state index (TSI) found as reciprocal. To further validate the results of EHI, TSI was calculated for all 14 sampling locations and results are to show a positive trend as suggested by Xu et al. [9] i.e. low EBI, EHI and TSI is higher, is an indication of bad quality, nutritive lake with no life support and vice versa. These results reveal in addition to EBI, EHIM can also be used to know the health of a water body. From the above, it is concluded that both EBI & EHIM and TSI can be used to assess t health of water body and therefore, EHIM can also be recommended to be used as a best tool to assess the ecological health of any water bodies and for undertaking appropriate preventive measures to restore the health of water bodies.

Conclusions

The literature reveals that the physiochemical and biotic parameters like plankton, benthos, fishes etc. are the indicators of the health of aquatic ecosystems. Although, the hydrological, geographical and social characteristics are considered for health assessment and also for minimize the impacts of anthropogenic disturbances. Out of several indices reviewed, indices like IBMA & ISI are region specific, while EFAI & SSMI are restricted to hyaline water bodies. The EHIM is found as the only indexes which can be applied in very less time and give precise results for health of water bodies. In the paper, EHIM applied for assessment of health of Baiyangdian Lake China, and results similar to EBI used by Xu et al. [9] are obtained. As per the EHIM, the EHI of Baiyangdian Lake has EHI: 40-60, which indicates bad water quality with no life support capability which may be due to significant anthropogenic activities surrounding the lake. To further validate the results of EHI, TSI was calculated for all 14 sampling locations and results are to show a positive trend as suggested by Xu et al. [9] i.e. low EBI, EHI and TSI is higher, is an indication of bad quality, nutritive lake with no life support and vice versa. The indices like P-IBI, SDM etc. require limited indicators and do not cover all the aspect of ecosystem, while, indices like HEHI, FMM etc. covers almost all aspects of ecosystem health, but are time consuming, and have complex calculation procedure and yields enormous results. The work concluded that EHIM can also be used as an important to assess the ecosystem health in addition to EBI used by Xu et al. [9].

Acknowledgement-One of the authors (SM) is thankful to MHRD, Government of India for financial assistance in the form of academic scholarship during his Master of Technology programme in Environmental Management of Rivers and Lakes.

References

1. Fry A., Haden E., Martin M., Martin R., Facts and trends of water. World business council for sustainable development. Report. (2005), *ISBN.* 2-940240-70-1.
2. Royo C.L.Y., Casazza G., Martin P.C., Pergent G., *Ecol. Ind.* 10 (2010) 380–389.
3. Su M., Fath B.D., Yang Z., *Sci. of the Total Environ.* 408 (2010) 2425–2434.
4. Clements F.E., Weaver J.E., Plant ecology. New York, McGraw-Hill, (1929).
5. Huang Y., Wen H., Cai J., Cai M., Sun J., Procedia *Environ. Sci.* 2 (2010) 868–880.
6. Paukert C.P., Pitts K.L., Whittier J. B., Olden J.D., *Ecol. Ind.* 11 (2011) 304–310.
7. Cacadora I., Netob J.M., Duartea B., Barrosob D.V., Pintoa M., Marquesb J.C., *Ecol. Ind.* 25 (2013) 141.
8. Kane D.D., Gordon S.I., Munawar M., Charlton M.N., Culver, D.A., *Ecol. Ind.* 9 (2009) 1234–1247.
9. Xu F., Yang Z.F., Chen B., Zhao Y.W., *Ecol. Modl.* 222 (2011) 201–209.
10. Zhang J., Gurkan Z., Jørgensen S.E., *Ecol. Modl.* 221 (2010) 693–702.
11. Xu F.L., Zhao Z.Y., Zhan W., Zhao S.S., Dawson R.W., Tao S., *Ecol. Modl.* 188 (2005) 327–339.
12. Yadav N.S., Kumar A., Sharma M.P., *J. of Integr. Sci. and Tech.* 2 (2014) 52-56.
13. Williams M., Longstaff B., Buchanan B., Llansó R., Dennison W., *Marine Poll. Bull.* 59 (2009) 14–25.
14. Pinilla G., *Ecol. Ind.* 10 (2010) 848–856.
15. Jiang M., Chen H., Chen Q., Wu H., Chen P., *Ecol. Ind.* 48 (2014) 252–262.
16. Cardoso I., Fonseca L. C., Cabral H. N., *Marine Poll. Bull.* 64 (2012) 1136–1142.
17. Huang Y., Wen H., Cai J., Cai M., Sun J., Procedia *Environ. Sci.* 2 (2010) 868–880.
18. Shah R. D. T., Shah D.N., *Ecol. Ind.* 23 (2012) 447–452.
19. Poncet H. T., Bernadet C., Compin A., *Limnologica.* 47 (2014) 34–43.
20. Haase R., Nolte U., *Ecol. Ind.* 8 (2008) 599 – 613.
21. Duarte B., Freitas J., Couto T., Valentine J., Dias J. M., Silva H., Marques J.C., Cacador I., *Ecol. Ind.* 29 (2013) 390-397.
22. Villamarín C., Rieradeval M., Paul M. J., Barbour M. T., Prat N., *Ecol. Ind.* 29 (2013) 79–92.
23. Marzin A., Delaigue O., Logez M., Belliard, J., Pont, D. *Ecol. Ind.* 43 (2014) 195–204.
24. Cabral H. N., Fonseca V. F., Gamito R., Goncalves C. I., Costa J. L., Erzini K., Goncalves K., Martins J., Leite L., Andrade J. P., Ramos S., Bordalo A., Amorim E., Neto J. M., Marques J. C., Rebelo J. E., Silva C., Castro N., Almeida P. R., Domingos I., Gordo L. S., Costa M. J., *Ecol. Ind.* 19 (2012) 144–153.
25. Zheng T., You X.Y., *Ocean and Coastal Mgmt.* 95 (2014) 1-10.
26. Zhang F., Liu J., Yang Z., Li Y., *Environ. Sci. Engg.* 2 (2008) 209–217.
27. Yang T., Liu J., Chen Q., *Ecol. Modl.* 268 (2013) 37– 47.
28. Wiegand J., Raffaell D., Smart C. R., White P.C.L., *J. of Environ. Mgmt.* 91 (2010) 1446-1455.
29. Kim J.H., Yeom D.H., An K.G., *Chemosphere.* 108 (2014) 376–382.
30. Tlili S., Minguez L., Giamberini L., Geffard A., Boussetta H., Mouneyrac C., *Ecol. Ind.* 32 (2001) 285– 293.
31. Kumar A., Chaudhary Om, *J. Emerg. Techn. Adv. Engg*. 3(201)574-577.
32. Kumar A., Sharma M.P., Yadav N.S., *J. Mater. Environ. Sci.* 5(2014) 1781-1785.
33. Yadav N.S., Sharma M.P., Kumar A., *J. Mater. Environ. Sci.* 6(2015)613-618.
34. Zhang Y., Cuia B., LanY., Han Z., Wang T., Guo A., *Environ. Sci.* 13 (2012) 645–654.

(2015) ; http://www.jmaterenvironsci.com