

Trophic State Index

to assess aquatic ecosystem health

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Trophic state index is a monitoring tool to assess the state (oligotrophy, mesotrophy, eutrophy and hypereutrophy) of an aquatic ecosystem which indeed serves as baseline for measuring biological integrity and interface between human and water environment. This tool is comprehensively used for formulating climatic model base which helps in developing rehabilitation and restoration strategies of the various aquatic ecosystems. Thus, it is effective for climate researchers for use of lentic and lotic environment in the long run.

Key words: Aquatic ecosystem, Climate change, Fisheries, Trophic state index

CLIMATIC variability marked by increased temperature, erratic and abnormal pattern of rains, droughts etc. have adversely impacted biological diversity and living pattern of fishers. Fisheries sector generates employment to over 14.5 million people who directly and indirectly involved in fisheries for their livelihood. Therefore, it is necessary to understand the ecological status and vulnerability of aquatic ecosystem for developing adaptation and mitigation strategies for dealing with the impacts. Determination of trophic state in an aquatic ecosystem depends upon wide criterion such as amplitude of oxygen curve, microalgal diversity and composition, concentration of nutrients and other measures of biomass production (Carlson, 1977). The Trophic State Index (TSI) was initially developed for temperate environments which considers secchi disk transparency, concentration of chlorophyll *a* and total phosphorus. Lamparelli (2004) suggested a modified index based on the Carlson's (1977) index. This index works in combination of both limnological and biological factors

which enables a better response for assessment of eutrophic status of an aquatic ecosystem. Most recently (2015) the eutrophic potential of lake Sumidouro has been characterized in the central region of the state of Minas Gerais through integrated analysis of morphometric and limnological parameters, land use and land occupation in the watershed. The lake is classified as oligotrophic to hypereutrophic with subsequent inflammation of water nutrient during rainy months. The present paper deals with the potential role of TSI and other approaches in assessing the vulnerability of inland open water in relation to different climatic variability for their sustainable utilization and management.

Importance of TSI

Assessing the trophic state of wetland ecosystem can play a vital role in management and restoration. It serves as baseline to measure biological integrity, check human induced interferences, and helps in formulating rehabilitation and restoration strategies in an aquatic ecosystem. The complex nature of eutrophication is influenced by both

anthropogenic and natural factors. Hence, it is worth to conduct integrative approach including physical and chemical parameters and, trophic state indices but also their relationship with morphology, land use, and land occupation. Morphological geometry of a water body together with land use pattern has quantitative impact on limno-chemical factors as well as magnitude of nutrient concentration and trophic state. Moreover, agriculture or urban dominated watershed have greater influence of land nutrients export to water bodies in comparison to undisturbed watersheds and thus, land use is one of the prime influential parameter for assessing eutrophication.

Trophic state is a fundamental property of ecosystem because it describes the potential food base. Distribution of trophic state also provides a baseline to measure biotic integrity and a point of comparison for efforts to document and manage human influences, as well as providing goal for restoration efforts. In the trophic states, the efforts have mainly focussed on the planktonic chlorophyll, degree of water

transparency and total mass of nutrients in the lake water columns which are very useful determinants of the trophic states of lakes that are directly or indirectly linked related to the potential C source: autochthonous inputs. Furthermore, the heterotrophy has implications for carbon flux to the entire food web, food web and ecosystem stability may be enhanced by reliance on allochthonous carbon sources. The characterization of trophic state in aquatic ecosystem now has been expanding and distinguished between heterotrophic and autotrophic conditions in rivers and streams. A comprehensive system of trophic characterization would emphasize both autotrophic and heterotrophic state across all ecosystem types (Table 1).

Linking with climatic variation

A strong impact on lakes of inter annual climatic variability, with direct and indirect effects, as altered air and water temperature, cause variations in the thermal structure, in chemical and physical characteristics, in food web, and in features of the community assemblage such as phytoplankton and zooplankton. Direct and indirect effects of climatic variability on freshwater zooplankton and shown a variation in distribution, abundance and phenology. On this view, the large scale climatic indices represent a useful tool in ecology, providing a framework for the interpretation of community and species level response to altered climatic conditions. Climate is considered a one of the major drivers of change of population phenology that directly and indirectly influencing seasonal cycles in marine and freshwater organisms. The food web in lakes characterized by different trophic levels responded differently to climatic variation.

Estimation of Trophic State Index for wetlands

Method of TSI estimation has been accepted widely for lentic systems and for reservoirs. Firstly, the trophic classification based on the relationship of total phosphorous (TP) content and chlorophyll *a* (Chl-

Table 1. Potential autotrophic and eutrophic states, and the separation of autotrophic and heterotrophic states based on autochthonous and allochthonous inputs

	Low Allochthonous	High Allochthonous
Low Autotrophy	Oligo-autotrophic Oligo-heterotrophic	Oligo-autotrophic Eu-heterotrophic (dystrophic)
High Autotrophy	Eu-autotrophic Eu-heterotrophic	Eu-autotrophic heterotrophic

Source: Expanding the concept of tropic steain aquatic ecosystems; It's not just the autotrophs. Walter K. Dodds, Jonathans J Cole, 2007.

a) of temperate lakes, was used for comparative evaluation of trophic status. Secondly, carlson trophic state index (TSI) is based on the basis that doubling of algal biomass causes halving of Secchi disk depth (SDD), were used to quantify the trophic state of non-perennial reservoirs. Following this, an index is developed for tropical environments based upon water transparency which is regularly influence by turbidity. Later on, a modified index was developed. The modified formula is as follows:

$$TSI(S) = 10\{6-[0.64+\ln S/\ln 2]\}$$

$$TSI(P) = 10\{6-[\ln (80.32/P)/\ln 2]\}$$

$$TSI(Cl) = 10\{6-[(2.04-0.695 \ln Cl)/\ln 2]\}$$

Where, TSI(S) for, Secchi disk depth (m); TSI (P) for Total phosphate (mgm⁻³); TSI (Cl) for Chlorophyll-a (µg/L).

Lamparelli (2004) modified TSI index for tropical wetland/ reservoir is TSI, < 24, 24-< 44, 44-< 54, 54-< 74, >74, for Ultraoligotrophic, oligotrophic, mesotrophic, eutrophic, and hypereutrophic, respectively.

Estimation of TSI for rivers

Generally, a running water body with minimum discharge or flow velocity along with heavy nutrient load will turn the system into eutrophic condition. Carlson (1977) described Chla (CA) as basic reference to define the trophic state along with other variables such as, secchi depth (SD) and total phosphate (TP) related to aquatic environment. The trophic categorization will vary based upon hydrological regime coupled with anthropogenic stress and also as per river geomorphology. Though early water quality and nutrient enrichment studies in lotic systems focused on the C sources the current concerns of the stream eutrophication

mainly focus on nitrogen and phosphorous enrichment. Though production of lake has often been linked to chlorophyll biomass, it can be net heterotrophic and highly influenced by terrestrial C inputs. As rivers and streams are likely to be more dominated by heterotrophic processes than lakes, the trophic state division allows consideration of the influence of external C sources as well as nutrients such as nitrogen and phosphorous. It is also observed that phosphorous and nitrogen are most important nutrient regulating autotrophic state in flowing waters and that benthic algal biomass which is positively correlated to gross primary production in streams. It is imperative which nutrient might be expected to control trophic state in lotic systems of tropical environment. There is ample scope to study for assessing key nutrients which are responsible for controlling the trophic state in flowing waters. A survey pointed the presence of phosphorus concentration in combination with smaller particulate was responsible for lake turbidity resulting into eutrophic nature in the Upper lake of Madhya Pradesh.

The Carlson trophic state index (TSI) of was calculated using the following formulae:

$$TSI \text{ for Chlorophyll-a (CA) } TSI = 9.81\ln \text{ Chlorophyll-a (}\mu\text{g/l)} + 30.6$$

$$TSI \text{ for Secchi depth (SD) } TSI = 60-14.41\ln \text{ Secchi depth (Meters)}$$

$$TSI \text{ for Total phosphorus (TP) } TSI = 14.42 \ln \text{ Total phosphorous (}\mu\text{g/l)} + 4.15$$

$$\text{Carlson's trophic state index (CTSI) } = [TSI (TP) + TSI (CA) + TSI (SD)]/3$$

Recent Studies of ICAR-Central Inland Fisheries Research Institute (ICAR-CIFRI)

ICAR-CIFRI undertook some studies on trophic status of inland

water bodies viz. flood plain wetlands and reservoirs of Asom, West Bengal, Odisha, Jharkhand, Bihar, Tamil Nadu etc. and river Mahanadi of Odisha. Studies revealed that most of the wetlands are under mesotrophic to eutrophic state and reservoirs are under oligo to mesotrophic state. Similarly, different stretches of river Mahanadi reflected eutrophic in middle and lower stretch and mesotrophic state in the upper stretch. In a recent study, it observed significant relationship of chlorophyll level and quantity and diversity of trophic guild in a reservoir. Further, trophic state index is also linked with climato-environmental parameters to establish the interactive relationships for development of modelling framework (ongoing) and ecological vulnerability assessment for fisheries management under NICRA project. A comprehensive information on the trophic state of various inland water bodies (India) is shown in Table 4 and Fig. 1.

Modelling approaches

Efforts have been made to propose numerous indices for quantifying the state of eutrophication in lentic and lotic environment. Most of the indices developed or modified considering conventional trophic state indices (e. g., Carlson trophic state index) or pre-specified ranges of cause and response variables (e.g. index proposed by OECD) where a strong correlation structure must exist among cause and response variables. The eutrophication process is complex in nature with many cause and response variables; hence it is multidimensional and multivariable indexing allows for a more thorough investigation of water quality and a more continuous description of the eutrophication process than a single variable index system. CTSI is the most common multivariate trophic indexing methods based on the variables; total phosphorus, chlorophyll *a* concentration and secchi disc transparency. This multivariate index has several inherent problems. Firstly, the geographical and atmospheric factor influence eutrophication, causing the standards for each area to differ.



Fig. 1. A typical eutrophic floodplain wetland in West Bengal

Table 2. Assessing trophic state index of various inland water bodies, an initiative by ICAR-CIFRI

Name of the water body	Trophic status
47 Morkolung Beel, Asom	Mesotrophic
Krishnagiri reservoir, Tamil Nadu	Eutrophic
Maithon, West Bengal	Oligotrophic
Patratu dam, Jharkhand	Oligotrophic
Panchet dam, West Bengal	Oligotrophic
Derjang reservoir, Odisha	Mesotrophic
Palair reservoir, Telengana	Mesotrophic
Chandil dam, Jharkhand	Oligotrophic
Mahanadi river, Odisha	Eutrophic in middle and lower stretch and mesotrophic in upper stretch
Barpetabeel, Assam	Eutrophic

Table 3. Trophic status of inland water bodies in India

Sl. No.	Name of the water body	Longitude	Latitude	TSI Status	References
1.	Kabar wetland	86°55'	25°30'	Mesotrophic	Sharma and Shandendu, 2012
2.	Mandakalli Lake	89°09'	25°32'	Mesotrophic	Murthy <i>et al.</i> , 2008
3.	Mansi Ganga lake	77°27'49.13"	27°29'55.91"	Mesotrophic	Sharma <i>et al.</i> , 2010
4.	Sphatikshila river	80°51'25.1"	25°84'6.5"	Oligotrophic	Chaurasia and Gupta, 2016
5.	Arogyadham river	80°51'51.4"	25°9'25.9"	Mesotrophic	
6.	Jankikund river	80°52'1.1"	25°9'31.6"	Mesotrophic	
7.	Pramodvan river	80°52'15.9"	25°10'15.2"	Mesotrophic	
8.	Ramghat river	85°6'0"	25°10'40.8"	Mesotrophic	
9.	Chilika lagoon	76°28'	19°28'	Eutrophic	Ganguly <i>et al.</i> , 2015
10.	Bhindawas Lake	76°49'	28°28'	Hypereutrophic	Saluja and Garg, 2017
11.	Sukhana Lake	73°40'	30°44'	Hypereutrophic	Dhillon and Mishra, 2014
12.	Rankala Lake	77°57'	17°17'	Hypereutrophic	Patil <i>et al.</i> , 2018
13.	Bellandur Lake	75°5'11.5"	12°95'	Hypereutrophic	Ramesh and Krishnaiah, 2014
14.	Mansar lake	75°2'30"	32°40'58.25"	Mesotrophic	Singh <i>et al.</i> , 2007
15.	Surinsar	74°21'	32°46'30"	Eutrophic	
16.	Dal lake	78°12'51"	34°5'	Eutrophic	
17.	Tsomoriri	79°5'32"	32°48'16"	Eutrophic	
18.	Tsokar lake	77°27'	33°4'14"	Hypertrophic	
19.	Renuka Lake	86°5'	30°36'	Hypereutrophic	

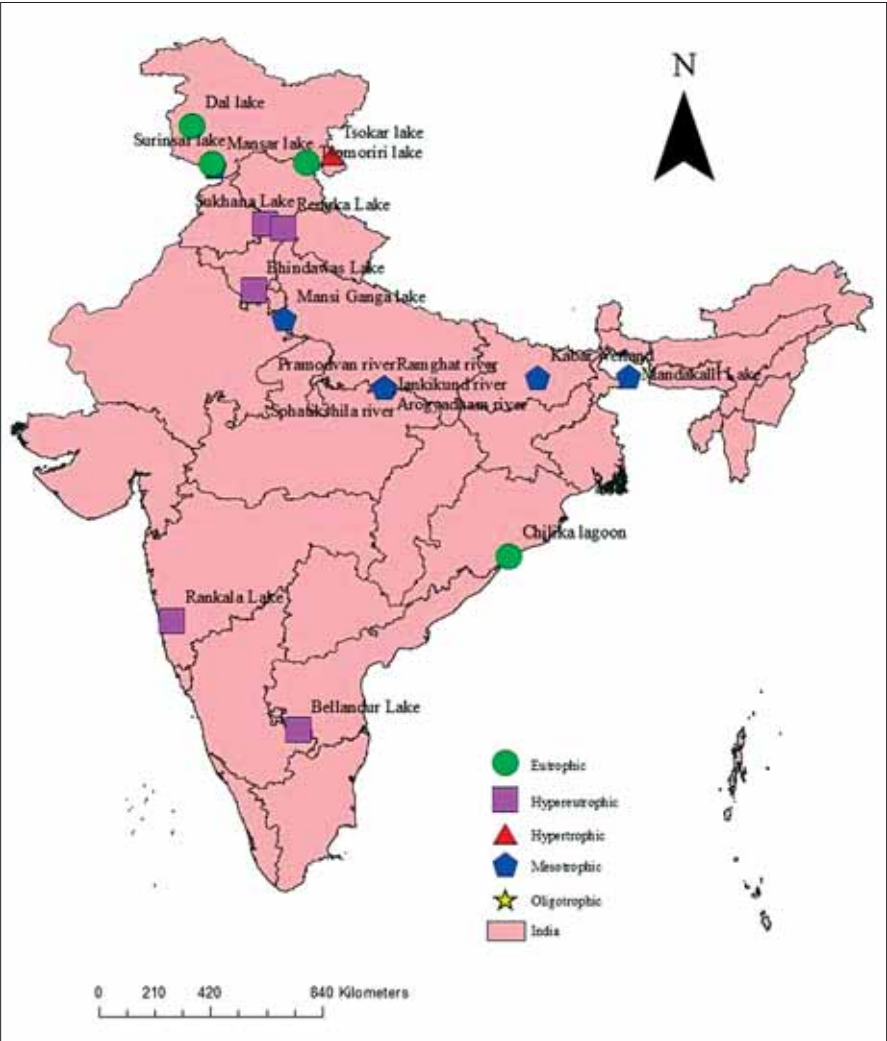


Fig. 2. Graphical representation of trophic status of inland water bodies in India

Secondly, unreasonable categorization of standards, e.g., values between 49 and 50 are in two different classification which the range between 41 - 49 are classified as mesotrophic status while those equal to 50 or higher than 50 as eutrophic status. The range CTSI = 49 and 50 are in two different category though the difference between two are small, but CTSI = 41 and 49 are in same trophic states, even though the difference between them are large.

The modelling approaches on trophic state level may concise the

impreciseness of trophic status. The fuzzy Synthetic Evaluation (FSE), analytic hierarchy process (AHP) and the concept of statistical entropy is extensively used since many decades for the assessment of trophic state. Fuzzy set theory was developed by the Zadeh (1965) which incorporates the specifications of uncertainty by membership functions (Table 5) that was used by Silvert (2000) to develop environmental indices. Fuzzy based techniques can provide a mean for measuring the intensity of exceeding regulated thresholds with

the help of memberships functions of various water quality levels and the water quality indicators weighed by both objective (Entropy method) and subjective (AHP) criteria. In this regard, the entropy method is used to determine the amount of useful information from the data set and subjective weight is determined by AHP using a pair-wise comparison done by the expert judgement; which has been applied extensively in water quality classification.

SUMMARY

Trophic state index (TSI) is an ecosystem based monitoring tool which exclusively considers physical and limnological factor of a water body to determine the nutrient base and functional productivity. The tool has its intensive use throughout the ecological horizon irrespective of temperate, sub-tropics and for tropics with modified equation. This tool being emerged for assessing the temperate lakes, its implications has spread over lotics and estuarine waters especially for developing ecosystem health card for *Chilika* lagoon. The climatic variables have direct and indirect effect on primary production and trophic status. The modelling approaches extensively used towards assessing the appropriate trophic state Index ensure the current scenario of lotic and lentic ecosystems which will help to mitigate the issues raised related to the climatic variability and undertake the various policy issues. To ensure sound health and ecosystem functionality in this era of changing climatic variability, it is imperative to understand the ecosystem monitoring tools with predictive modelling framework which will provide the suitable measures for sustainable management and utilization of ecosystem services.

Table 4. Key values defining the fuzzy limits of the membership functions

Trophic Indicator	a (Oligotrophic)	b (Mesotrophic)	c (Eutrophic)
Ch-a (µg/L)	1.7	4.7	14
TP (µg/L)	8	27	84
TN (µg/L)	661	753	1875

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