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Comparative Evaluation of Trophic State Index of the Gharni Reservoir, Udgir, Dist: Latur Using Selected TSI Models

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Abstract

Availability of good-quality water is a growing global concern and access to safe freshwater is increasingly recognized as a universal human right. Water resources in Maharashtra are unevenly distributed spatially and temporally, and specifically the Marathwada region lies in a rain-shadow zone and frequently experience water scarcity, making effective water resources management essential for addressing deficits in rainfall-dependent areas. In this study, the trophic status of the Gharni Reservoir, Maharashtra, India, was assessed using different Trophic State Index (TSI) models. Surface water samples were collected from August 2019 to January 2021, and key parameters—Secchi Disk Depth (SDD), chlorophyll-a (Chl-a), and total phosphorus (TP)—were analyzed using the TSI models proposed by Carlson (1977), Cheng and Lei (2001), and Markad, Landge, Nayak, Inamdar, and Mishra (2019). The Carlson (1977) model underestimated the trophic status of the Gharni Reservoir, yielding TSI values in the range of 50-60. In contrast, Cheng and Lei's (2001) model overestimated the trophic state, with TSI(SDD) values exceeding 100, indicating its unsuitability for this reservoir. The model developed by Markad et al. (2019) provided the most reliable assessment, showing peak performance, with TSI values ranging between 70 and 80. Overall, the Gharni Reservoir exhibits mesotrophic to hypereutrophic conditions on a seasonal basis. While increased productivity can enhance fish yield, excessive nutrient enrichment poses a risk to the long-term ecological balance of the reservoir.

Keywords: Trophic State Index, eutrophication, Gharni reservoir

Introduction

Increasing population growth and rapid urbanization are exerting significant pressure on global freshwater resources (Schmutz & Moog, 2018). Although freshwater availability is inherently limited, demand continues to rise for agricultural, domestic, and industrial uses (Tundisi & Tundisi, 2011). As a result, water quality deterioration has emerged as a major global concern, particularly in reservoirs that serve as critical sources of drinking water, irrigation, and fisheries. Anthropogenic activities have increasingly contributed to the degradation of reservoir ecosystems, posing risks to both human health and ecological sustainability (Teshome, 2020).

India possesses substantial freshwater resources; however, their spatial and temporal distribution is highly uneven. The country comprises 19,134 small reservoirs (<1,000 ha) covering 1,485,557 ha, 180 medium reservoirs (527,541 ha), and 56 large reservoirs (1,140,268 ha) (Gopal, Chandrasekar, & Geethalakshmi, 2021). Despite this, regional disparities in rainfall and climate strongly influence water

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availability. Maharashtra, particularly the Marathwada region, lies in a rain-shadow zone and frequently experiences drought conditions, making water quality monitoring especially critical.

Intensification of agriculture to meet growing food demand has led to increased use of fertilizers and pesticides. Residual nutrients from these inputs are transported into water bodies through surface runoff, especially during the monsoon, resulting in elevated nutrient levels and declining water quality (Hughes et al., 2014; Knight, 2021; Yang, 2022). Consequently, many freshwater ecosystems are now under ecological stress or degradation (Gonzaìlez & Roldán, 2019; Le Moal et al., 2019).

A major outcome of nutrient enrichment is eutrophication, characterized by excessive nitrogen and phosphorus that stimulate rapid algal and aquatic plant growth (Bali & Gueddari, 2019; Sonarghare et al., 2020; Zeng et al., 2022). Under favourable conditions, this leads to increased primary productivity and often results in harmful cyanobacterial blooms, which disrupt food webs and threaten ecosystem stability (Haberman & Haldna, 2014; Havens, 2014; Jeppesen et al., 2015; Glibert, 2017; Zhang, Chen, & Haffner, 2023).

Given these challenges, effective water resource management requires reliable assessment tools. The Trophic State Index (TSI) is widely used to evaluate nutrient status and biological productivity in freshwater systems (Markad et al., 2024). While Carlson's (1977) TSI is globally recognized, it was developed for temperate, phosphorus-limited systems and may not be directly applicable to regions with different climatic conditions (Carlson & Havens, 2005). Therefore, modified indices tailored to local environments have been proposed (Cheng & Lei, 2001; Markad et al., 2019), and selecting an appropriate model is crucial, as different indices can yield varying trophic classifications (Pomari, Kane, & Nogueira, 2018).

The Gharni Reservoir supports an active inland fishery that contributes to local livelihoods and regional fish production. The fishery is primarily dominated by Indian Major Carps, along with contributions from exotic species and catfishes, reflecting a typical multi-species reservoir fishery system. Despite its productive potential, the reservoir exhibits yield lower than the national average for small reservoirs (174 kg/ha/year), indicating scope for improved management through scientific stocking, conservation measures, and water quality enhancement.

In this context, the present study focuses on the Gharni Reservoir in Latur district, located in the drought-prone Marathwada region of Maharashtra, India. Considering its importance for irrigation, fisheries, and local livelihoods, the study aims to estimate and compare TSI values using different models to identify the most suitable approach for effective reservoir management and long-term sustainability.

Materials and Methods

The study was conducted at the Gharni Reservoir (Fig. 1), located at 18°222′49″ N and 76°49′35″ E in Shirur Anantpal Tahsil of Latur district, Maharashtra, India. The reservoir is situated on the Gharni River, a sub-tributary of the Manjara River in the Godavari basin. It has a water spread area of 525 ha at full reservoir level, a catchment area of 243.66 km², and an irrigation potential of approximately 2,834 ha. The reservoir water is primarily utilized for agricultural and domestic purposes.

Monthly water samples were collected from August 2019 to January 2021 from five pre-defined sampling stations (Fig. 1). Laboratory analyses were carried out at the Aquatic Environment Management Laboratory, College of Fishery Science, Udgir. Chlorophyll-a (Chl-a) and total phosphorus (TP) were estimated following standard protocols described in American Public Health Association [APHA] (2005), while Secchi disk depth (SDD) was measured in situ using a 20 cm diameter Secchi disk (Table 2). Statistical analyses were performed using Microsoft Excel and IBM SPSS Statistics (version 23).

Trophic status of freshwater was accessed by Trophic State Index (TSI). TSI rates water health according to its biological productivity in the scale of 0-100 and the productivity of water is positively correlated with increasing values in the 0-100 scale. The water bodies having TSI value in the range of 0-40 are considered as oligotrophic, while TSI values in the range of 40-60 are regarded as mesotrophic with fair condition TSI values in the range of 60-100 are taken as eutrophic to hypereutrophic condition of the water. The different indices that were used are as follows:

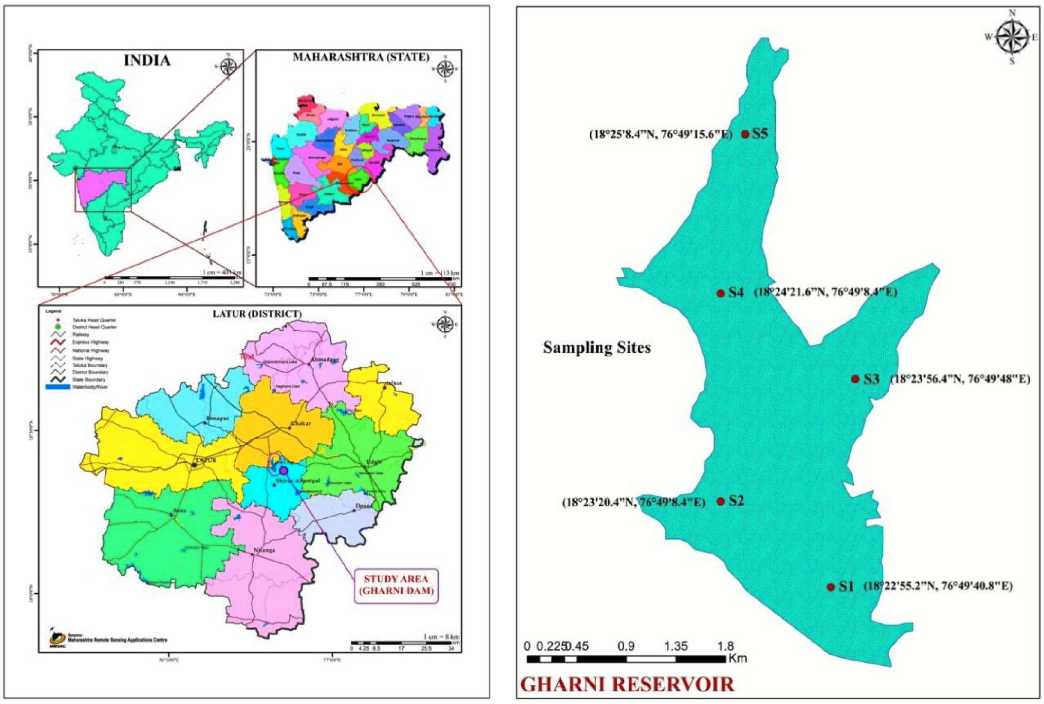

Fig. 1. Location map and sampling sites of Gharni reservoir

A) Carlson's (1977) TSI:

Carlson's (1977) TSI for estimation of health status of water body is most extensively used and the interrelationship among SDD, Chl-a, and TP is considered (Saluja and Garg, 2017). Carlson's (1977) models for TSI estimation based on SDD, TP, and Chl-a is derived as per:

$$\text{TSI (SDD)} = 10 \text{ X } \left(6 - \frac{\ln \text{(SDD)}}{\ln (2)}\right)$$

$$\text{TSI (Chl} - \text{a)} = 10 \text{ X } \left(6 - \frac{2.04 - 0.68 \text{ x } \ln \text{(Chl)}}{\ln (2)}\right)$$

$$\text{TSI (TP)} = 10 \text{ X } \left(6 - \frac{\ln \text{(48/TP)}}{\ln (2)}\right)$$

Many researchers consider Carlson's 1977 trophic state index estimate model to be the simplest and most often used method for assessing reservoir productivity. (Nalamutt & Karmakar, 2014).

B) Markad et al. (2019) TSI:

TSI model proposed by Markad et al. (2019) is constructed based on the native geographical parameters of the Tiru reservoir which is located in the vicinity of the Gharni dam (60 km). Chl-a, TP, and SDD values are used as inputs to determine trophic status of the reservoir. This model estimates TSI as:

$$\text{TSI (SDD)} = 10 \text{ X } \left(5.3354 - \frac{\ln \text{(SDD)}}{\ln (1.3119)}\right)$$

$$\text{TSI (Chl} - \text{a)} = 10 \text{ X } \left(5.3354 - \frac{-0.341 - 0.143 \text{ X } \ln \text{(Chl-a)}}{\ln (1.3119)}\right)$$

$$\text{TSI (TP)} = 10 \text{ X } \left(5.3354 - \frac{-0.025 - 0.162 \text{ X } \ln \text{(TP)}}{\ln (1.3119)}\right)$$

Final TSI = [TSI (Chl-*a*) + TSI (SDD) + TSI (TP)]/3.

C) Cheng and Lei (2001) TSI:

Cheng and Lei (2001) TSI is as given below:

$$\text{TSI (SDD)} = 10 \text{ X } \left(8.605 - \frac{\ln \text{(SDD)}}{\ln (1.544)}\right)$$

$$\text{TSI (Chl} - \text{a)} = 10 \text{ X } \left(8.605 - \frac{1.8751 - 0.3264 \text{ X } \ln \text{(Chl-a)}}{\ln (1.544)}\right)$$

$$\text{TSI (TP)} = 10 \text{ X } \left(8.605 - \frac{2.1775 - 0.4230 \text{ X } \ln \text{(TP)}}{\ln (1.544)}\right)$$

Generally, three classes as oligotrophic, mesotrophic, and eutrophic are taken into account while classifying TSI. Cheng and Lei (2001) simplified the classification method and subdivided some of these classes into slightly and fully-eutrophic, very-eutrophic, hypereutrophic, and dystrophic. Although the trophic status estimation of water body can be estimated by different TSI indices, ground truthing must be carried out by visual observation by verifying the appearance of the selected location.

Trophic Classes suggested by different studies and used in this study for classification is given in Table 1.

Results and Discussion

To evaluate the trophic status and overall health of the Gharni Reservoir, Trophic State Index (TSI) models proposed by different researchers were applied to the measured water quality parameters (Table 3). Seasonal variations in TSI values, calculated as the mean of TSI (Chl-a), TSI (TP), and TSI (SDD), indicated a consistently eutrophic condition across all seasons according to the Carlson (1977) model (Fig. 2). The TSI values were 53.17 during monsoon 2019, 53.08 in winter 2019, 58.73 in summer 2020, 55.19 in monsoon 2020, and 52.60 in winter 2020.

In contrast, the model proposed by Markad et al. (2019) (Fig. 3) indicated a higher trophic status, classifying the reservoir as polyeutrophic during monsoon 2019 (72.63), winter 2019 (74.47), monsoon 2020 (73.62), and winter 2020 (73.74), and hypereutrophic during summer 2020 (75.46).

Similarly, the Cheng and Lei (2001) model (Fig. 4) reflected a more severe trophic condition, recording polyeutrophic status in monsoon 2019 (91.18), winter 2019 (91.92), monsoon 2020 (92.64), and winter 2020 (91.37), while indicating a hypereutrophic condition during summer 2020 (95.25).

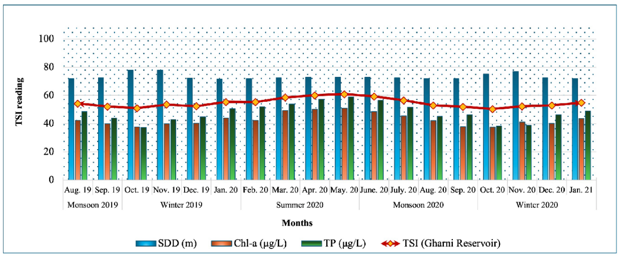

Fig. 2. Trophic State Index (TSI) estimation of Gharni reservoir by Carlson's (1977) TSI model

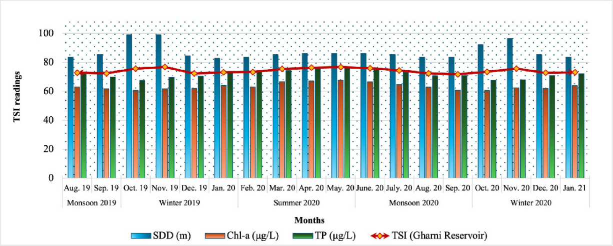

Fig. 3. Trophic State Index (TSI) estimation of Gharni reservoir by Markad et al. (2019) TSI model

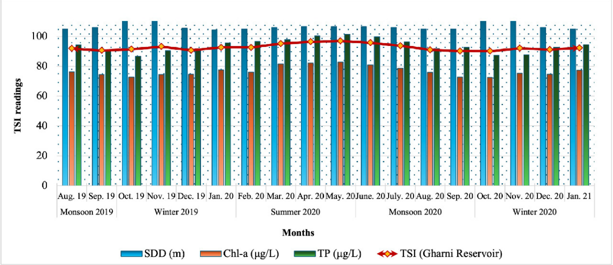

Fig. 4. Trophic State Index (TSI) estimation of Gharni reservoir by Cheng and Lei (2001) model

Table 1. Trophic Classes suggested by different researchers

Sl. No.	TSI	Carlson (1977)	Cheng and Lei (2001)	Markad et al. (2019)
1	Oligotrophic	> 30 - 40	< 53	> 30 - 40
2	Mesotrophic	40 - 50	53 - 61	40 - 50
3	Meso-eutrophic	—	61 - 66	50 - 65
4	Eutrophic	50-70	66 - 78	65 - 70
5	Poly-eutrophic	—	78 - 94	70 - 75
6	Hyper-eutrophic	70 - 100	94 - 100	75 - 100

Table 2. Spatio-temporal fluctuation in SDD (m), Chl-α (μg/L) and TP (μg/L)

Season		Secchi Disc Depth (m)						Chlorophyll-*a* (μg/L)						Total Phosphorus (μg/L)					
	Location Month	01	02	03	04	05	Mean	01	02	03	04	05	Mean	01	02	03	04	05	Mean
Monsoon	Aug.-19	0.44	0.44	0.43	0.44	0.43	0.44	3.24	3.21	3.35	3.29	3.41	3.30	19.70	21.40	22.60	21.80	23.20	21.74
2019	Sep.-19	0.42	0.41	0.43	0.43	0.41	0.42	2.62	2.55	2.51	2.69	2.67	2.61	17.50	16.20	15.40	14.60	14.80	15.70
	Average						0.43						2.96						18.72
Winter	Oct.-19	0.32	0.32	0.32	0.27	0.25	0.29	2.12	2.08	2.06	2.04	2.07	2.07	11.20	11.32	9.23	9.62	8.92	10.06
2019	Nov.-19	0.29	0.29	0.29	0.29	0.28	0.29	2.62	2.55	2.41	2.67	2.69	2.59	13.24	14.42	15.67	14.86	15.13	14.66
	Dec.-19	0.44	0.44	0.43	0.42	0.42	0.43	2.64	2.62	2.69	2.71	2.74	2.68	14.53	13.43	17.46	18.73	19.77	16.78
	Jan.-20	0.46	0.46	0.47	0.44	0.44	0.45	3.86	3.88	3.89	3.92	3.96	3.90	23.42	24.26	27.33	26.35	24.26	25.12
	Average						0.37						2.81						16.66
Summer	Feb.-20	0.44	0.44	0.44	0.45	0.43	0.44	3.23	3.19	3.24	3.27	3.31	3.25	25.36	30.54	28.72	26.53	26.27	27.48
2020	Mar.-20	0.42	0.42	0.43	0.42	0.41	0.42	6.67	6.64	6.71	6.76	6.84	6.72	28.65	29.37	31.46	33.58	34.49	31.51
	Apr.-20	0.42	0.41	0.41	0.42	0.41	0.41	7.19	7.23	7.32	7.44	7.52	7.34	37.47	38.41	41.22	40.73	42.35	40.04
	May.-20	0.41	0.41	0.42	0.41	0.41	0.41	7.87	7.91	7.98	8.03	8.12	7.98	45.31	44.57	43.65	44.71	46.17	44.88
	Average						0.42						6.32						35.98
Monsoon	Jun.-20	0.41	0.41	0.41	0.42	0.41	0.41	6.04	6.13	6.21	6.28	6.36	6.20	41.13	38.94	36.54	35.46	36.43	37.70
2020	Jul.-20	0.42	0.42	0.41	0.42	0.41	0.42	4.33	4.42	4.53	4.67	4.72	4.53	28.75	27.42	26.47	25.67	26.72	27.01
	Aug.-20	0.44	0.44	0.43	0.44	0.43	0.44	3.13	3.08	3.17	3.24	3.36	3.20	18.75	17.34	16.78	15.64	17.34	17.17
	Sep.-20	0.44	0.44	0.44	0.44	0.44	0.44	2.03	2.01	1.97	2.16	2.24	2.08	16.77	17.46	18.63	19.48	20.37	18.54
	Average						0.43						4.00						25.11
Winter	Oct.-20	0.34	0.35	0.35	0.34	0.34	0.35	1.86	1.92	2.04	2.13	2.24	2.04	12.21	11.41	11.42	9.47	9.13	10.73
2020	Nov.-20	0.32	0.31	0.31	0.32	0.31	0.31	2.84	2.87	2.93	2.98	3.04	2.93	10.24	11.14	9.86	11.58	12.37	11.04
	Dec.-20	0.42	0.42	0.41	0.43	0.42	0.42	2.57	2.62	2.66	2.72	2.74	2.66	16.43	17.37	18.72	19.77	20.14	18.49
	Jan.-21	0.44	0.43	0.44	0.44	0.44	0.44	3.77	3.73	3.82	3.86	3.89	3.81	23.64	22.45	24.16	21.21	19.87	22.27
	Average						0.38						2.86						15.63

Seasonal variations in individual TSI components revealed distinct patterns across the study period. The highest TSI (SDD) values (Fig. 5) were recorded during the winter season, which can be attributed to reduced water transparency caused by increased turbidity associated with dense phytoplankton growth. In contrast, TSI (SDD) values declined during the summer and reached their lowest levels during the monsoon, likely due to increased water volume and dilution effects that enhanced transparency.

TSI (Chl-a) values were highest during the summer season, primarily due to elevated temperature and light intensity, which enhance photosynthetic activity and promote phytoplankton growth. Additionally, reduced water levels during summer may concentrate nutrients, further contributing to higher chlorophyll-a levels. In winter, lower light intensity and temperature resulted in reduced chlorophyll-a concentrations, indicating relatively lower productivity. During the monsoon, TSI (Chl-a) values showed a moderate increase, possibly due to nutrient influx from surface runoff. Overall, the chlorophyll-based trophic status of the Gharni Reservoir remained within the mesotrophic range during the study period. Similar observations have been reported by James, Havens, Zhu, and Qin (2009), Gupta (2014) and Saluja and Garg (2017).

TSI (TP) values were highest during the summer season, likely due to reduced water levels and higher temperatures that promote nutrient concentration, indicating a meso-eutrophic condition as per the classification proposed by Markad et al. (2019). During the monsoon, TSI (TP) values were moderate, reflecting nutrient inputs from agricultural runoff. In contrast, lower values observed during winter may be attributed to the uptake of nutrients by phytoplankton. Similar seasonal trends have been reported by James et al. (2009) Saluja and Garg (2017), and Markad et al. (2019) in reservoirs of the Marathwada region. Comparable patterns during rainy periods have also been documented by Elmaci,

Table 3. Monthly variation in Trophic State Index (TSI) of Gharni reservoir by different TSI models

	MODELS	Carlson (1977)			Markad et al. (2019)			Cheng and Lei (2001)		
MONTH		TSI (SDD)	TSI (Chl-*a*)	TSI (TP)	TSI (SDD)	TSI (Chl-*a*)	TSI (TP)	TSI (SDD)	TSI (Chl-*a*)	TSI (TP)
Monsoon 2019	Aug. 19	71.82	42.31	48.55	83.60	63.05	71.98	104.95	76.27	94.26
	Sep. 19	72.49	40.01	43.86	85.31	61.82	70.04	106.02	74.51	91.09
Monsoon 2019 (Average TSI)		72.16	41.16	46.21	84.46	62.44	71.01	105.49	75.39	92.68
Monsoon TSI = [TSI(SDD) + TSI(TP) + TSI(Chl-a)] / 3			53.17			72.63			91.18	
Winter 2019	Oct. 19	77.83	37.74	37.44	98.95	60.60	67.38	114.55	72.77	86.76
	Nov. 19	77.83	39.94	42.87	98.95	61.78	69.63	114.55	74.45	90.42
	Dec. 19	72.15	40.27	44.82	84.44	61.96	70.43	105.48	74.71	91.74
	Jan. 20	71.50	43.95	50.64	82.77	63.93	72.84	104.43	77.53	95.67
Winter 2019 (Average TSI)		74.83	40.48	43.94	91.28	62.07	70.07	109.75	74.87	91.15
Winter TSI = [TSI(SDD) + TSI(TP) + TSI(Chl-a)] / 3			53.08			74.47			91.92	
Summer2020	Feb. 20	71.82	42.16	51.93	83.60	62.97	73.38	104.95	76.16	96.54
	Mar. 20	72.49	49.29	53.90	85.31	66.80	74.19	106.02	81.61	97.87
	Apr. 20	72.84	50.15	57.36	86.20	67.26	75.62	106.58	82.28	100.21
	May. 20	72.84	50.97	59.00	86.20	67.70	76.30	106.58	82.91	101.32
Summer 2020 (Average TSI)		72.50	48.14	55.55	85.33	66.18	74.87	106.03	80.74	98.99
Summer TSI = [TSI(SDD) + TSI(TP) + TSI(Chl-a)] / 3			58.73			75.46			95.25	
Monsoon2020	June. 20	72.84	48.50	56.49	86.20	66.37	75.26	106.58	81.01	99.62
	July. 20	72.49	45.42	51.68	85.31	64.72	73.27	106.02	78.65	96.37
	Aug. 20	71.82	42.01	45.15	83.60	62.89	70.57	104.95	76.04	91.96
	Sep. 20	71.82	37.78	46.26	83.60	60.62	71.03	104.95	72.80	92.71
Monsoon 2020 (Average TSI)		72.24	43.43	49.90	84.68	63.65	72.53	105.63	77.13	95.17
Monsoon TSI = [TSI(SDD) + TSI(TP) + TSI(Chl-a)] / 3			55.19			73.62			92.64	
Winter2020	Oct. 20	75.12	37.59	38.37	92.02	60.52	67.76	110.22	72.66	87.38
	Nov. 20	76.87	41.15	38.78	96.50	62.43	67.93	113.01	75.38	87.66
	Dec. 20	72.49	40.20	46.22	85.31	61.92	71.01	106.02	74.65	92.68
	Jan. 21	71.82	43.72	48.90	83.60	63.81	72.12	104.95	77.35	94.49
Winter 2020 (Average TSI)		74.08	40.67	43.07	89.36	62.17	69.71	108.55	75.01	90.55
Winter TSI = [TSI(SDD) + TSI(TP) + TSI(Chl-a)] / 3			52.60			73.74			91.37	

Ozengin, Teksoy, Þaðban, and Baskaya (2009), Sheela, Letha, Joseph, Ramachandran, and Sanalkumar (2011), Ghashghaie, Maralan, Ostad-Ali-Askari, Eslamian, and Singh (2018), and Kaur, Abubakr, and Hassan (2018).

The TSI values obtained from the models proposed by Carlson (1977), Cheng and Lei (2001), and Markad et al. (2019), were compared to evaluate their suitability for assessing the trophic status of the Gharni Reservoir (Table 3 and 4; Fig. 6). The model outputs were further examined against the observed physical and ecological conditions of the reservoir to determine their accuracy.

The Carlson (1977) model indicated TSI values in the range of 50–60, thereby underestimating the trophic status of the reservoir. This discrepancy may be attributed to the fact that the model was originally developed under temperate climatic conditions and for deeper lakes with higher Secchi disk depth values. In contrast, the Gharni Reservoir is a shallow tropical water body with a maximum depth of approximately 17 m, where environmental conditions differ significantly from those assumed in the Carlson model.

Similarly, the Cheng and Lei (2001) model tended to overestimate the trophic status, with TSI (SDD)

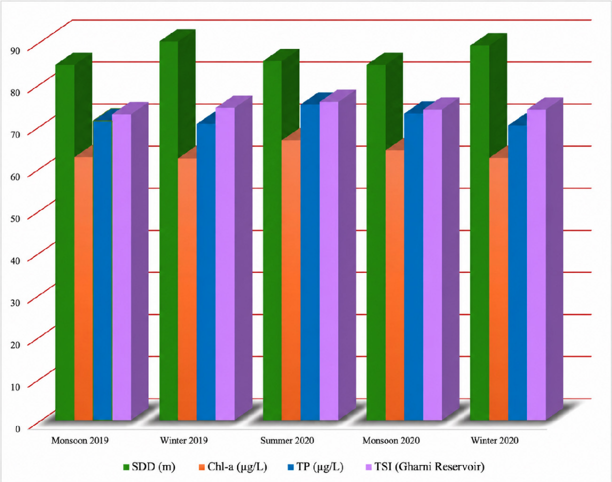

Fig. 5. Seasonal fluctuation in TSI of Gharni reservoir

values exceeding 100, making it less suitable for the present study. The overestimation may be related to differences in model assumptions regarding transparency and nutrient dynamics.

In comparison, the model developed by Markad et al. (2019) provided more realistic and consistent estimates of trophic status. This model is specifically designed for shallow reservoirs under tropical climatic conditions, closely matching the agro-climatic characteristics of the Gharni Reservoir. Therefore, it was found to be the most appropriate model for assessing trophic status in the present study.

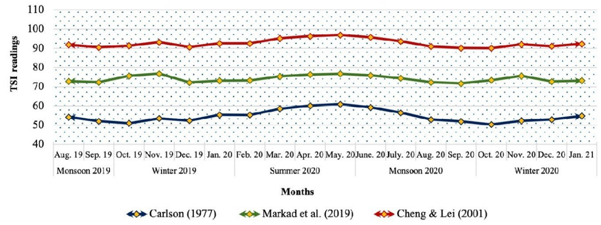

Fig. 6. Comparison of Trophic State Index (TSI) of Gharni reservoir by different TSI model

Fish harvest data from the Gharni Reservoir (Table 5) indicate a steady increase in production during the study period, rising from 57.2 tonnes (108.96 kg/ha/year) in 2018–19 to 65.2 tonnes (124.22 kg/ha/year) in 2020–21. Indian Major Carps dominated the catch, contributing approximately 67–70% of the total annual biomass, followed by exotic fishes (10–11%) and non-air-breathing catfishes (4.7–5%). Other groups, including minor carps, murrels, perches, eels, featherbacks, air-breathing catfishes, and weed fishes, contributed relatively smaller proportions.

Seasonal trends revealed that fish production peaked during the summer months, while winter showed moderate catches and the monsoon season recorded the lowest yields. Despite the nutrient-rich and productive nature of the reservoir, overall fish yield remained below the national average for small

Table 4. Comparison of TSI and corresponding values of SDD, Chl-*a*, and TP by Carlson (1977), Markad et al. (2019), and Cheng and Lei (2001) models

MODELS	Carlson (1977) model for Minnesota's Lake			Markad et al. (2019) Model for Tiru reservoir			Cheng and Lei (2001) model for Te-Chi reservoir		
TSI	SDD (m)	Chl-*a* (µg/L)	TP (µg/L)	SDD (m)	Chl-*a* (µg/L)	TP (µg/L)	SDD (m)	Chl-*a* (µg/L)	TP (µg/L)
0	64	0.04	0.75	4.2	0.00002	0.0013	64	0.001	0.01
10	32	0.12	1.5	3.25	0.00015	0.0045	32	0.008	0.05
20	16	0.34	3	2.5	0.001	0.016	16	0.064	0.24
30	8	0.94	6	1.9	0.006	0.059	8	0.53	1.26
40	4	2.6	12	1.45	0.04	0.22	4	4.47	6.49
50	2	6.4	24	1.1	0.3	0.79	2	37	33
60	1	20	48	0.83	1.8	2.88	1	313	172
70	0.5	56	96	0.63	11.3	10.6	0.5	2613	886
80	0.25	154	192	0.48	90	43.9	0.25	21851	4560
90	0.125	427	384	0.37	501	161	0.125	182705	23475
100	0.064	1183	768	0.28	3345	520	0.0625	1527652	120853

Table 5. Yearly season wise fish production (kg)

Season	Summer		Monsoon				Winter				Summer		Total (kg)	Yield kg/ha/yr
Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar		
2018-19	9031	9529	0	0	0	3070	3773	4474	5352	6234	7252	8494	57209	108.96
2019-20	9509	9932	0	0	0	3135	3685	4628	5461	6632	7742	8523	59247	112.85
2020-21	10149	10795	0	0	0	3615.5	4364	4965	6087	7330.5	8243	9670	65219	124.22

reservoirs. This suggests potential for further enhancement through improved stocking strategies, better resource management, and control of eutrophication.

In the Gharni Reservoir, the increasing nutrient load is largely influenced by surface runoff carrying nitrogen and phosphorus from surrounding agricultural fields, particularly through the application of chemical fertilizers. These nutrients accumulate in the reservoir and contribute to higher TSI values, promoting algal growth and accelerating the eutrophication process. To maintain a sustainable fishery and healthy aquatic ecosystem, it is important to regulate nutrient inputs into the reservoir. Effective measures may include adopting better agricultural practices to reduce fertilizer runoff, establishing buffer vegetation around the reservoir to filter nutrients, and implementing regular water quality monitoring programs. By managing nutrient enrichment and maintaining a moderate trophic state, the reservoir can support improved fish production while preventing the negative impacts associated with excessive eutrophication.

The present study demonstrated that the Trophic State Index (TSI) model developed by Markad et al. (2019) most accurately represented the trophic status of the Gharni Reservoir when compared to the models of Carlson (1977) and Cheng and Lei (2001). The reservoir exhibited seasonal variation in trophic condition, ranging from mesotrophic to hypereutrophic states, reflecting significant fluctuations in nutrient dynamics, primary productivity, and water transparency. Elevated TSI values during summer were primarily driven by increased temperature, reduced water levels, and higher nutrient concentrations, whereas monsoon conditions were influenced by dilution and nutrient influx through runoff.

The high nutrient status of the reservoir supports considerable biological productivity, which is reflected in the observed fish yields. However, despite a steady increase in fish production from 57.2 tonnes (108.96 kg/ha/year) in 2018–19 to 65.2 tonnes (124.22 kg/ha/year) in 2020–21, the overall yield remains below the national average for small reservoirs. This indicates that the reservoir has untapped potential for enhanced fish production. The dominance of Indian Major Carps in the catch further suggests that the system is conducive to carp-based fisheries, but requires optimized management interventions.

At the same time, the observed meso- to hypereutrophic conditions raise concerns regarding long-term ecological sustainability. Excessive nutrient enrichment increases the risk of algal blooms, oxygen depletion, and habitat degradation, which may ultimately affect fish health and productivity. Therefore, a balanced approach is required to harness the productive potential of the reservoir while preventing further ecological deterioration.

Enhancement of fish production can be achieved through scientifically planned stocking programs, species diversification, and improved fishery management practices. Controlling nutrient inputs from agricultural runoff, regulating anthropogenic activities in the catchment, and maintaining optimal water quality are essential to sustain ecosystem health. Regular monitoring of trophic status using region-specific indices, such as the Markad et al. (2019) model, is recommended for effective management.

In conclusion, while the Gharni Reservoir exhibits favourable conditions for fisheries development, sustainable exploitation will depend on integrating productivity enhancement measures with effective nutrient management and ecosystem-based approaches.

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