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Locally Calibrated Algal Indicators and a Five-Metric Bio-monitoring Index for Tropical Monsoonal Water Bodies: Limitations of Palmer's and Nygaard's Indices in Vidarbha, India

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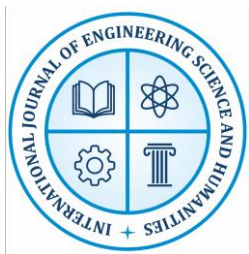
Abstract

Temperate algal pollution and trophic indices are routinely applied to Indian water bodies without local testing. This study checked Palmer's genus pollution index, Nygaard's phytoplankton quotients and Carlson's trophic state index against measured water quality in six reservoirs, tanks and ponds of Amravati District, Maharashtra, and used the same data set to build a locally calibrated bio-monitoring index. Littoral and open-water stations were sampled monthly from July 2024 to June 2026 (288 samples). Palmer's score put 61.1 per cent of samples in the high organic pollution class, yet it ranked the perennial lake (27.73) and the irrigation tank (26.17) above the urban tank (19.83), which had the lowest oxygen and highest oxygen demand. Nygaard's quotients calculated from pooled species lists were identical at every site and season (compound quotient 5.00), and sample-level quotients could not be calculated for the 32.3 per cent of samples that contained no desmids. Carlson's chlorophyll-based index ranked the sites correctly, from mesotrophic (S1, mean 49.25) to hypereutrophic (S5, 72.65), but non-algal turbidity raised its Secchi-based counterpart by 8.07 units in the monsoon. Indicator value analysis with a cross-year consistency test identified nine enrichment indicators led by *Euglena viridis* and *Microcystis aeruginosa*, and eleven low-enrichment indicators led by *Volvox aureus*, *Closterium moniliferum* and *Pinnularia gibba*. A five-metric index built from cyanobacterial share, Shannon diversity, pollution-tolerant taxa, Zygnematophyceae share and chlorophyll-based trophic state correlated strongly with phosphate-P ($\rho = 0.894$) and BOD ($\rho = 0.882$), although neither variable enters its calculation. At five of the six sites it placed 79 to 98 per cent of samples in the expected class.

Keywords: bioassessment; indicator species; Palmer's index; Nygaard's quotients; trophic state index; phytoplankton; Maharashtra

1. Introduction

Chemical monitoring describes the water at the moment of sampling; algae integrate conditions over the preceding weeks. Algae occur in almost every water body, include many taxa with different tolerances and respond quickly to nutrients and organic matter, so they have become one of the main tools of biological water-quality assessment (Stevenson, 2014; Bellinger &



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Sigee, 2015). Assessment schemes use lists of tolerant or sensitive taxa, ratios between algal groups, diversity measures and pigment-based trophic indices.

Two indices have dominated Indian practice. Palmer (1969) compiled records of algae from organically polluted waters and gave twenty genera pollution-tolerance scores from 1 to 5. The scores of the genera present in a sample are added, and 20 or more indicates high organic pollution. Nygaard (1949) proposed ratios of species numbers between algal groups as indicators of trophic state, with desmids in the denominator of the myxophycean, chlorophycean and compound quotients. Both indices are simple, need only a species or genus list, and appear widely in surveys of Indian ponds, reservoirs and wastewater-fed waters (Shekhar et al., 2008; Das et al., 2018). Carlson's (1977) trophic state index converts Secchi depth, chlorophyll a or total phosphorus to a common scale of 0 to 100 and is the most widely used continuous trophic metric.

The problem is that these indices were calibrated elsewhere. Palmer's list rests largely on North American and European records and scores presence rather than abundance. Nygaard's reference values came from soft-water Danish lakes in which desmids are naturally abundant. Reviews of algal bioassessment agree that indicators moved between regions work better after local calibration against measured environmental gradients (Lobo et al., 2016; Pandey et al., 2017; Wu et al., 2017). In the hard, alkaline waters of the Deccan basalt, desmids can be scarce for geological reasons, and turbid monsoon inflow can lower transparency regardless of algal biomass. Neither effect has been tested systematically in Indian standing waters. Indian studies relating phytoplankton to water chemistry have mostly described single water bodies (Giripunje et al., 2013). Recent work has identified local indicator genera by statistical analysis (Sharma & Tiwari, 2018; Kumar et al., 2020), and toxic cyanobacteria have been documented in urban lakes of Vidarbha (Maske et al., 2010).

Using two years of data from six sites in Amravati District, this paper asks three questions. Do Palmer's index, Nygaard's quotients and Carlson's index rank the water bodies in the same order as independently measured oxygen, oxygen demand and nutrients? Which algal taxa can serve as locally tested indicators of enriched and unenriched conditions, and do their associations hold in two separate annual cycles? And can a small set of abundance-based metrics be combined into a practical index that a district laboratory could apply with a microscope and standard glassware?

2. Materials and Methods

2.1 Study sites and sampling

Amravati District (12,210 km²) lies on Deccan Trap basalt and Purna alluvium in the Vidarbha region of Maharashtra, and most of its rain falls during the south-west monsoon (Lamsoge, 2013). Six water bodies covering a gradient of catchment condition were grouped into three



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catchment types: forested reservoirs (S1 Shahanur Reservoir, S2 Chandrabhaga Reservoir), agricultural water bodies (S3 minor irrigation tank at Nandgaon Khandeshwar, S4 Sawanga Lake) and settlement-influenced water bodies (S5 Chhatri Lake, an urban tank receiving storm-drain inflow, and S6 a village pond at Bhatkuli used for washing and watering cattle). A littoral and an open-water station at each site were sampled monthly between 07:00 and 10:00 h from July 2024 to June 2026. With the year divided into monsoon (June to September), winter (October to January) and summer (February to May), the design gave 288 station-month samples: 48 per site and 144 per annual cycle.

2.2 Laboratory analysis

Dissolved oxygen, BOD₅, nitrate-N, phosphate-P, chloride and chlorophyll a (acetone extraction) were determined by standard methods (American Public Health Association et al., 2017), and Secchi transparency was measured in the field. For phytoplankton, 1 L of each 5 L surface sample was fixed with Lugol's iodine, concentrated to 20 mL by sedimentation and counted in a Sedgewick-Rafter cell in three fillings. Taxa were identified from Lugol- and formalin-preserved material using standard monographs and Bellinger and Sigee (2015), and densities were expressed as organisms per litre. In all, 28 taxa in seven classes were recorded.

2.3 Pollution and trophic indices

Palmer's index. Thirteen of the recorded genera appear in Palmer's (1969) list (Table 1), so the highest possible score for a sample was 32. A genus counted as present when at least one unit was found. Samples were classed as lower (< 15), probable (15 to 19) or high ($\geq$ 20) organic pollution.

Table 1. Recorded genera included in Palmer's (1969) pollution index and their scores

Genus in Palmer (1969)	Taxon recorded in this study	Class	Score
Oscillatoria	Oscillatoria limosa	Cyanobacteria	5
Euglena	Euglena viridis	Euglenophyceae	5
Scenedesmus	Scenedesmus quadricauda	Chlorophyceae	4
Chlorella	Chlorella vulgaris	Chlorophyceae	3
Navicula	Navicula cryptocephala	Bacillariophyceae	3
Nitzschia	Nitzschia palea	Bacillariophyceae	3
Synedra	Ulnaria ulna (formerly Synedra ulna)	Bacillariophyceae	2



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Genus in Palmer (1969)	Taxon recorded in this study	Class	Score
Phacus	Phacus pleuronectes	Euglenophyceae	2
Anacystis	Microcystis aeruginosa	Cyanobacteria	1
Phormidium	Phormidium tenue	Cyanobacteria	1
Gomphonema	Gomphonema parvulum	Bacillariophyceae	1
Cyclotella	Cyclotella meneghiniana	Bacillariophyceae	1
Closterium	Closterium moniliferum	Zygnematophyceae	1
Maximum attainable score			32

2.4 Selection of indicator taxa

Indicator value (IndVal) analysis (Dufrêne & Legendre, 1997) was run for the three catchment groups, with significance tested by 999 permutations. Because an indicator that works in only one year is of little use in monitoring, a second criterion was added. The density of each taxon was correlated (Spearman) with phosphate-P and BOD separately in each annual cycle ($n = 144$ per cycle). A taxon was accepted as a candidate indicator if it had a significant IndVal and its correlations with both variables were significant and of the same sign in both cycles.

2.5 Construction and testing of the bio-monitoring index

Five metrics that can be obtained from one preserved sample and a chlorophyll extract were chosen: the percentage of cyanobacteria, the Shannon-Wiener index (H'), the percentage of pollution-tolerant taxa, the percentage of Zygnematophyceae and TSI(Chl). Each metric was scored 1, 2 or 3 with thresholds set from the observed range, so that the forested reservoirs fell mainly in the first band and the settlement-influenced sites in the third. The five scores were added (range 5 to 15). The index was tested by its Spearman correlation with phosphate-P and BOD, neither of which enters the calculation, and by the proportion of samples from each site that it placed in the expected class. Kruskal-Wallis and Mann-Whitney tests compared the tolerant-taxa share among catchment groups, and two-way ANOVA with annual cycle as an additional factor tested site and season effects on index values. Significance was set at $p < 0.05$.

3. Results

3.1 Palmer's pollution index

Palmer's score ranged from 6 to 32, with a mean of 21.25 ± 6.96 . Site had a strong effect ($F(5, 269) = 89.28$, $p < 0.001$) and season a weak one ($F(2, 269) = 4.27$, $p = 0.015$), and the interaction was significant ($F(10, 269) = 8.37$, $p < 0.001$). The order of the sites did not follow the water-



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quality gradient, however (Table 2; Figure 1). The perennial lake S4 (27.73) and the irrigation tank S3 (26.17) had the highest mean scores, with 97.9 and 95.8 per cent of their samples in the high pollution class. The urban tank S5 had the lowest dissolved oxygen (3.43 mg/L) and the highest BOD (7.07 mg/L) of the six sites, yet it scored only 19.83, and half of its samples fell below the high pollution threshold. Its summer score (15.56) was close to the values of the forest-fringe reservoir S2, even though summer was the season of lowest oxygen at S5.

Table 2. Palmer's pollution score by site and season, and distribution of samples among pollution classes

Site	Monsoon	Winter	Summer	Overall (mean $\pm$ SD)	Tukey group	Lower < 15 (n)	Probable 15–19 (n)	High ≥ 20 (n)
S1	14.88	12.31	13.31	13.50 $\pm$ 4.16	e	30	13	5
S2	16.88	15.44	16.69	16.33 $\pm$ 4.74	d	19	15	14
S3	26.19	24.44	27.88	26.17 $\pm$ 3.87	ab	0	2	46
S4	27.94	26.88	28.38	27.73 $\pm$ 3.76	a	0	1	47
S5	18.25	25.69	15.56	19.83 $\pm$ 6.05	c	11	13	24
S6	21.94	28.56	21.31	23.94 $\pm$ 5.25	b	3	5	40
All	21.01	22.22	20.52	21.25 $\pm$ 6.96	—	63	49	176

Source: Computed from the data of the present study; n = 16 samples per site-season and 48 per site. Sites sharing a letter do not differ (Tukey HSD, $p > 0.05$).



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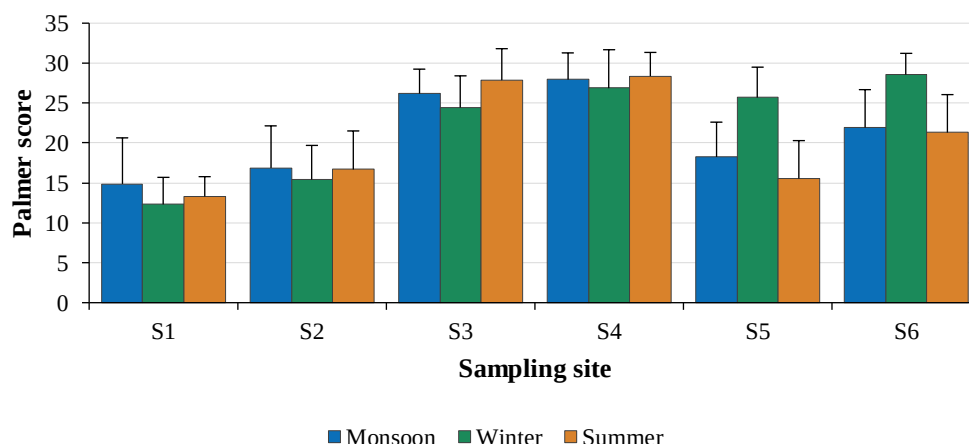


Figure 1. Season-wise mean Palmer's pollution score at the six sites

The distribution of samples among Palmer's classes (Figure 2) shows the same inversion. S1 was mostly in the lower class (62.5 per cent), and S2 was spread across all three. S3, S4 and S6 fell almost entirely in the high class, while S5 was split between lower (22.9 per cent), probable (27.1 per cent) and high (50.0 per cent). Over all samples, Palmer's score was only moderately correlated with measured water quality. Its strongest association was with COD ($\rho = 0.384$), followed by BOD ($\rho = 0.37$) and phosphate-P ($\rho = 0.36$).

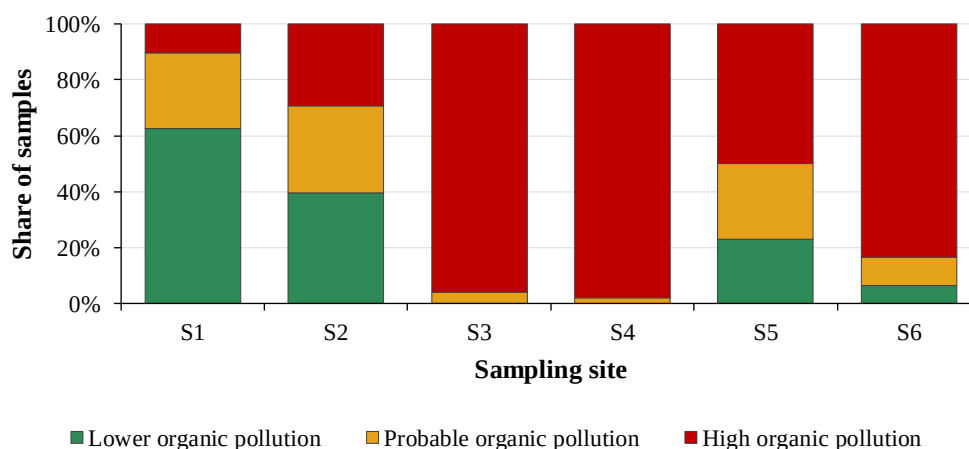


Figure 2. Percentage of samples in Palmer's pollution classes at the six sites

3.2 Abundance-weighted share of pollution-tolerant taxa

Weighting the same tolerant genera by density instead of scoring their presence changed the ranking of the sites (Figure 3). The tolerant-taxa share rose from 8.09 per cent at S1 and 11.38 per cent at S2 to 30.10 and 29.48 per cent at S3 and S4, and to 41.76 and 39.92 per cent at S5 and



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S6, an order that matches the chemical gradient. Site had a very strong effect ($F(5, 269) = 133.93$, $p < 0.001$), but season did not ($F(2, 269) = 1.60$, $p = 0.204$). By catchment group, the share averaged 9.74 per cent in the forested reservoirs, 29.79 per cent in the agricultural water bodies and 40.84 per cent at the urban tank and village pond, and the groups differed significantly (Kruskal-Wallis $H = 203.30$, $df = 2$, $p < 0.001$). The share at S5 and S6 was higher than at the other four sites (Mann-Whitney $U = 16,382.0$, $p < 0.001$). It was strongly correlated with BOD ($\rho = 0.81$), COD ($\rho = 0.80$), phosphate-P ($\rho = 0.79$) and chloride ($\rho = 0.78$), and negatively with dissolved oxygen ($\rho = -0.78$).

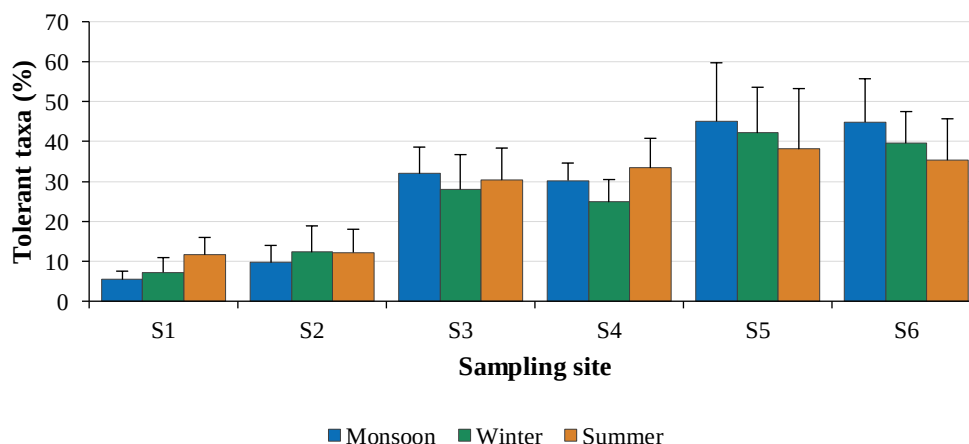


Figure 3. Season-wise mean share of pollution-tolerant taxa in total density at the six sites

3.3 Nygaard's quotients

Almost every site-season combination contained at least one record of every taxon in every group, so the pooled species lists were nearly identical. As a result, the pooled quotients were the same for 17 of the 18 combinations: myxophycean 2.00, chlorophycean 1.67, diatom 0.20 (0.25 at S4 in the monsoon), euglenophycean 0.27 and compound 5.00. Every site, the forested reservoirs included, fell in the eutrophic range, and the pooled quotients could not tell any of the water bodies apart.

Sample-level compound quotients were more informative (Table 3). They were lowest at S1 (2.55) and S2 (3.91) and highest at S4 (11.04) and S3 (10.77). The quotient could not be calculated, however, for 93 samples (32.3 per cent) in which no desmid was counted, and all of these came from S3 to S6. At S6 more than half the samples (27 of 48) were excluded, so the quotients for the enriched sites rest on their less enriched samples and understate their condition, and, as with Palmer's score, S5 ranked below S3 and S4.



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Table 3. Mean sample-level compound quotient of Nygaard (1949) by site and season

Site	Monsoon	Winter	Summer	Overall	Samples without desmids (n)	Samples excluded (%)
S1	2.56	2.11	2.96	2.55	0	0.0
S2	4.66	2.77	4.30	3.91	0	0.0
S3	10.00	10.82	11.30	10.77	21	43.8
S4	13.57	9.68	10.64	11.04	23	47.9
S5	6.25	10.12	7.88	8.54	22	45.8
S6	9.57	12.83	7.46	9.70	27	56.3

Source: Computed from the data of the present study; samples without desmids were excluded from the means.

3.4 Carlson's trophic state index

The chlorophyll-based index ranked the water bodies in the same order as the chemistry (Table 4; Figure 4). Mean TSI(Chl) rose from 49.25 at S1 and 53.73 at S2, through 63.87 and 64.42 at S3 and S4, to 69.34 at S6 and 72.65 at S5. Both site ($F(5, 269) = 523.30$) and season ($F(2, 269) = 130.02$) were highly significant ($p < 0.001$), and every site had its lowest values in winter. By modal class, S1 was mesotrophic (29 of 48 samples), S2, S3, S4 and S6 were eutrophic, and S5 was hypereutrophic (35 of 48 samples) (Figure 5). No sample was oligotrophic.

Table 4. Carlson's trophic state index based on chlorophyll a and Secchi depth, and trophic classification

Site	TSI(Chl) monsoon	TSI(Chl) winter	TSI(Chl) summer	TSI(Chl) overall	TSI(SD) overall	Meso (n)	Eu (n)	Hyper (n)	Modal class
S1	50.02	46.94	50.80	49.25	55.22	29	19	0	Mesotrophic
S2	53.43	51.35	56.42	53.73	57.38	8	40	0	Eutrophic
S3	68.13	58.94	64.54	63.87	64.66	0	44	4	Eutrophic
S4	66.14	60.48	66.65	64.42	65.40	0	46	2	Eutrophic
S5	74.68	68.02	75.24	72.65	76.14	0	13	35	Hypereutrophic
S6	70.77	65.52	71.73	69.34	72.06	0	26	22	Eutrophic

Source: Computed from the data of the present study using Carlson (1977); classes from TSI(Chl), n = 48 samples per site.



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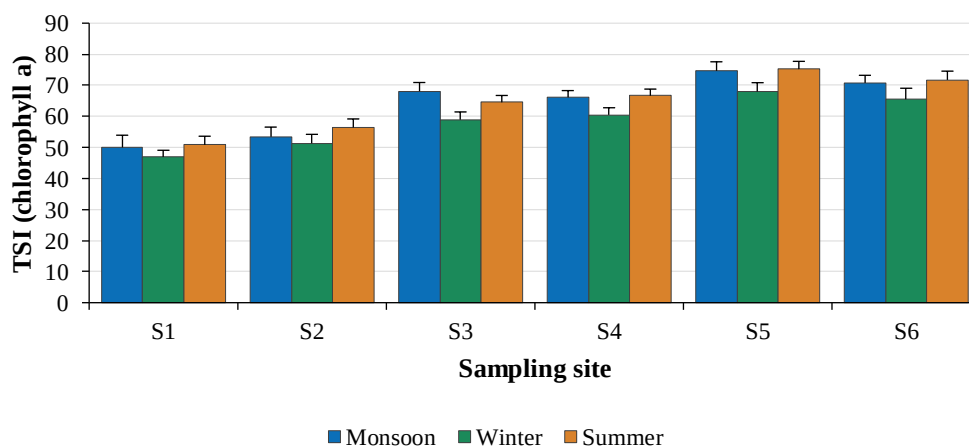


Figure 4. Season-wise mean Carlson's trophic state index based on chlorophyll a
Source: Computed from the data of the present study. Error bars show +1 SD.

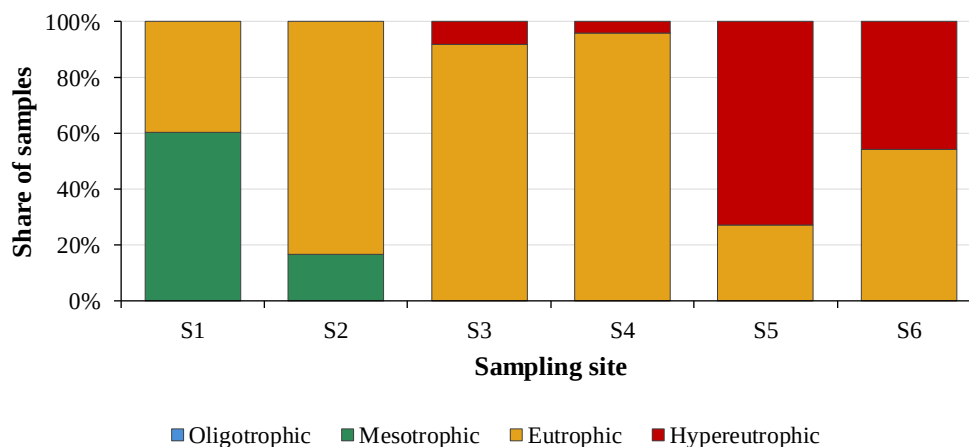


Figure 5. Distribution of samples among trophic state classes based on TSI(Chl)

The Secchi-based index put the sites in the same order but was consistently higher. TSI(SD) exceeded TSI(Chl) by an average of 8.07 units in the monsoon and 2.55 units in winter, and fell 1.82 units below it in summer. In the monsoon the gap was largest at S6 (11.30 units) and S5 (9.49 units), where TSI(SD) reached 82.07 and 84.17; over the whole year it was largest at the clear reservoir S1 (5.97 units). The monsoon excess shows that suspended silt from runoff, not algae, was the main cause of low transparency in that season.

3.5 Agreement among indices

Table 5 compares the ranks of the six water bodies on the chemical variables and on each index. DO, BOD, phosphate-P, the tolerant-taxa share, TSI(Chl) and TSI(SD) all gave the same order,



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with S1 least and S5 most enriched; they differed only over the closely matched pair S3 and S4. Palmer's score and the sample-level Nygaard quotient disagreed at the enriched end, where both placed S4 and S3 above S5. The cause was richness: the urban tank averaged 12.52 taxa per sample against 19.58 and 19.73 at S3 and S4, so fewer of Palmer's genera and more desmid-free samples occurred there.

Table 5. Rank of the six water bodies (1 = least enriched) on chemical variables and algal indices

Measure	S1	S2	S3	S4	S5	S6	Agrees with chemistry
Dissolved oxygen (reversed)	1	2	3	4	6	5	—
BOD ₅	1	2	3	4	6	5	—
Phosphate-P	1	2	4	3	6	5	—
Palmer's score	1	2	5	6	3	4	No
Nygaard compound quotient (sample level)	1	2	5	6	3	4	No
Pollution-tolerant taxa (%)	1	2	4	3	6	5	Yes
TSI (chlorophyll a)	1	2	3	4	6	5	Yes
TSI (Secchi depth)	1	2	3	4	6	5	Yes
Bio-monitoring index (this study)	1	2	3	4	6	5	Yes

Source: Ranks derived from site means of the present study.

3.6 Locally tested indicator taxa

All 28 taxa had a significant indicator value for one catchment group ($p < 0.05$): eleven for the forested reservoirs, fifteen for the agricultural water bodies and two for the urban tank and village pond. The forested indicators had the highest values, led by *Volvox aureus* (84.9), *Closterium moniliferum* (83.4), *Pinnularia gibba* (81.6) and *Staurostrum gracile* (81.4), because they were frequent at S1 and S2 and nearly absent elsewhere. Desmids dominated individual samples only at the reservoirs; *Closterium moniliferum* and *Staurostrum gracile* each made up at least 10 per cent of density in 18 samples from S1. The enrichment indicators had lower values because tolerant taxa were widespread. *Euglena viridis* (52.4) and *Microcystis aeruginosa* (44.4) marked the urban and village group, and each was dominant in 20 to 26 samples at S5 and S6.



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In all, 23 taxa passed the cross-year test, with correlations with both phosphate-P and BOD that were significant and of the same sign in both annual cycles. Combining the two criteria gave 20 candidate indicators, nine of enrichment and eleven of low enrichment (Table 6). *Merismopedia glauca* and *Gomphonema parvulum* failed because their correlations were weak and not significant, and *Dolichospermum circinale* and *Cyclotella meneghiniana* because their associations appeared in only one cycle. *Navicula cryptocephala* belongs to a Palmer genus with a score of 3, yet it was consistently negatively associated with enrichment ($\rho = -0.34$ and -0.36 with phosphate-P), so it was not accepted as an enrichment indicator. *Navicula*, *Coelastrum microporum* and *Cryptomonas ovata* did pass the cross-year test with negative associations, but they were excluded because their maximum indicator value lay with the agricultural group and not with the forested reservoirs.

Table 6. Candidate indicator taxa: indicator value and cross-year Spearman correlations with phosphate-P and BOD

Taxon	Group	IndVal (%)	PO ₄ -P cycle 1	PO ₄ -P cycle 2	BOD cycle 1	BOD cycle 2
<i>Euglena viridis</i>	Urban/village	52.4	0.68	0.62	0.67	0.63
<i>Microcystis aeruginosa</i>	Urban/village	44.4	0.61	0.58	0.66	0.57
<i>Phormidium tenue</i>	Agricultural	51.0	0.39	0.35	0.42	0.33
<i>Chlorella vulgaris</i>	Agricultural	48.9	0.47	0.40	0.46	0.39
<i>Oscillatoria limosa</i>	Agricultural	46.8	0.56	0.52	0.53	0.48
<i>Spirulina major</i>	Agricultural	46.8	0.53	0.45	0.58	0.47
<i>Trachelomonas volvocina</i>	Agricultural	44.4	0.52	0.47	0.44	0.45
<i>Phacus pleuronectes</i>	Agricultural	43.0	0.55	0.46	0.56	0.45
<i>Nitzschia palea</i>	Agricultural	40.9	0.40	0.37	0.46	0.44
<i>Volvox aureus</i>	Forested	84.9	-0.72	-0.74	-0.73	-0.72
<i>Closterium moniliferum</i>	Forested	83.4	-0.77	-0.73	-0.73	-0.74
<i>Pinnularia gibba</i>	Forested	81.6	-0.69	-0.73	-0.67	-0.74
<i>Staurastrum gracile</i>	Forested	81.4	-0.68	-0.68	-0.64	-0.67
<i>Cosmarium botrytis</i>	Forested	76.5	-0.62	-0.60	-0.65	-0.60



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Taxon	Group	IndVal (%)	PO ₄ -P cycle 1	PO ₄ -P cycle 2	BOD cycle 1	BOD cycle 2
Ceratium hirundinella	Forested	75.5	-0.67	-0.65	-0.68	-0.69
Spirogyra sp.	Forested	66.0	-0.66	-0.72	-0.67	-0.69
Oocystis lacustris	Forested	51.0	-0.59	-0.60	-0.55	-0.59
Peridinium cinctum	Forested	43.3	-0.53	-0.60	-0.46	-0.51
Pediastrum duplex	Forested	37.7	-0.40	-0.45	-0.42	-0.39
Ulnaria ulna	Forested	35.0	-0.43	-0.51	-0.35	-0.44

Source: Computed from the data of the present study; all correlations $p < 0.05$ ($n = 144$ per cycle); IndVal $p \leq 0.003$ (999 permutations).

At the class level, the two most diagnostic groups mirrored each other (Figures 6 and 7). Zygnematophyceae made up 31.96 per cent of density at S1 and 20.12 per cent at S2 but less than 2.3 per cent at S3 to S6. Their share was correlated with dissolved oxygen ($\rho = 0.82$) and transparency ($\rho = 0.77$) and negatively with phosphate-P ($\rho = -0.84$). Euglenophyceae formed less than 2.3 per cent at the reservoirs but 27.62 per cent at S6 and 30.12 per cent at S5, and they were most closely correlated with nitrate-N ($\rho = 0.85$) and phosphate-P ($\rho = 0.84$).

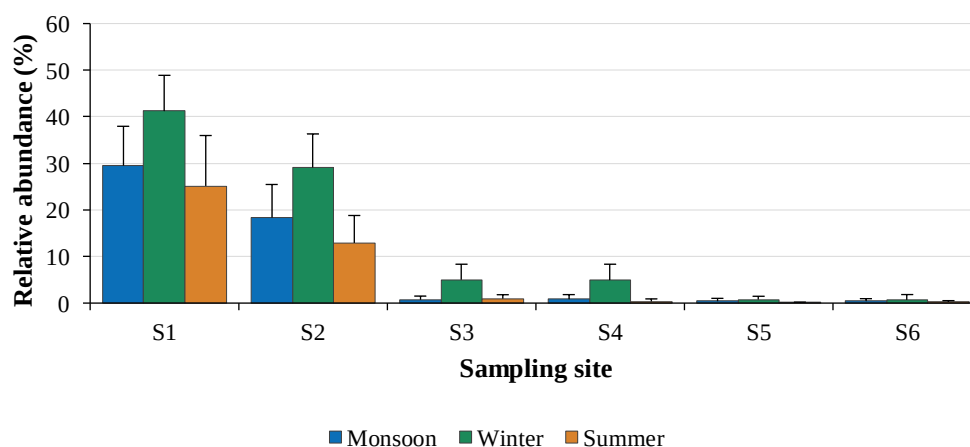


Figure 6. Season-wise mean relative abundance of Zygnematophyceae at the six sites



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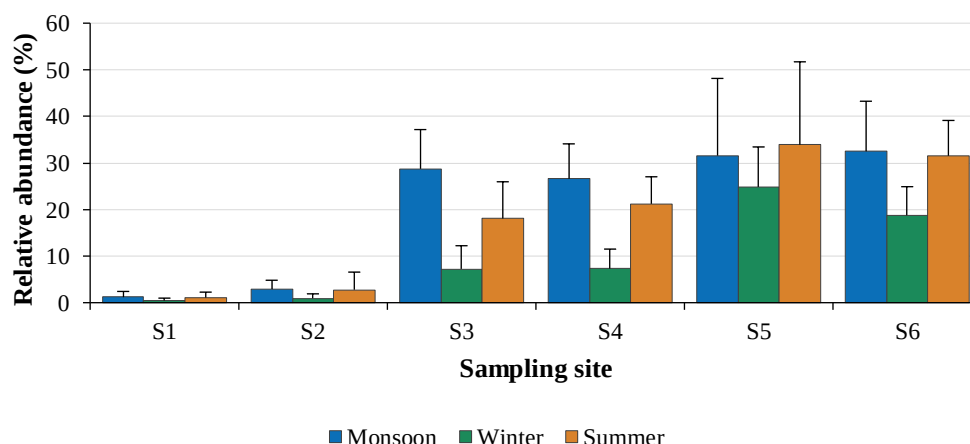


Figure 7. Season-wise mean relative abundance of Euglenophyceae at the six sites

3.7 Five-metric bio-monitoring index

Table 7 gives the metrics, thresholds and classes of the index. Across all 288 samples, the total score correlated strongly with phosphate-P ($\rho = 0.894$, $p < 0.001$) and BOD ($\rho = 0.882$, $p < 0.001$). Mean scores rose from 5.58 at S1 and 6.17 at S2 to 10.08 and 10.27 at S3 and S4, and to 12.40 at S6 and 13.08 at S5, so every site mean fell in its expected class (Table 8; Figure 8). The index classified individual samples correctly in 97.9 per cent of cases at S1, 83.3 per cent at S2, S4 and S5, and 79.2 per cent at S3. The village pond was the least stable site, with one sample in three classed as moderate rather than severe enrichment.

Table 7. Metrics, thresholds and scores of the five-metric bio-monitoring index

Metric	Score 1	Score 2	Score 3
Cyanobacteria (% of total density)	< 15	15–35	> 35
Shannon-Wiener index (H')	≥ 2.5	2.2 to < 2.5	< 2.2
Pollution-tolerant taxa (% of total density)	< 15	15–35	> 35
Zygnematophyceae (% of total density)	≥ 10	1 to < 10	< 1
TSI (chlorophyll a)	< 55	55–70	> 70
Total score and class	5–7: low enrichment	8–11: moderate enrichment	12–15: severe enrichment



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Note: Pollution-tolerant taxa are Oscillatoria, Euglena, Scenedesmus, Chlorella, Navicula and Nitzschia (Palmer score ≥ 3).

Table 8. Classification of the study samples by the bio-monitoring index

Site	Catchment	Mean score	Low (%)	Moderate (%)	Severe (%)	Class of mean score
S1	Forested	5.58	97.9	2.1	0.0	Low enrichment
S2	Forested	6.17	83.3	16.7	0.0	Low enrichment
S3	Agricultural	10.08	4.2	79.2	16.7	Moderate enrichment
S4	Agricultural	10.27	0.0	83.3	16.7	Moderate enrichment
S5	Urban	13.08	0.0	16.7	83.3	Severe enrichment
S6	Village	12.40	0.0	33.3	66.7	Severe enrichment

Source: Computed from the data of the present study; n = 48 samples per site.

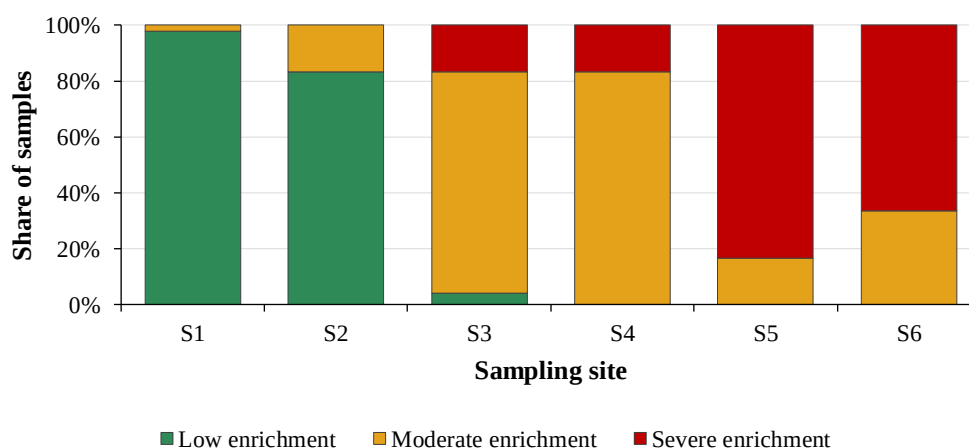
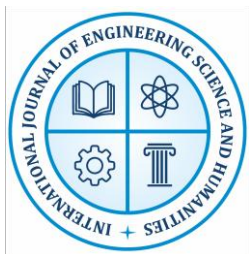


Figure 8. Percentage of samples in each enrichment class of the bio-monitoring index

Source: Computed from the data of the present study.

Season affected how well the index separated the sites. Summer samples spread them most widely, with mean scores from 5.69 at S1 to 14.12 at S5. Winter samples compressed the range and understated the condition of S5 and S6, because cyanobacterial dominance eased and diversity peaked in that season. A littoral sample from S5 in April 2025 shows how the scoring works. Cyanobacteria formed 47.53 per cent of density (score 3), H' was 1.833 (3), tolerant taxa formed 30.32 per cent (2), no Zygnematophyceae were counted (3), and chlorophyll a of 120.0



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$\mu\text{g/L}$ gave $\text{TSI(Chl)} = 77.57$ (3). The total of 14 put the sample in the severe class, which agrees with the dissolved oxygen (2.40 mg/L) and phosphate-P (0.544 mg/L) measured on the same visit.

4. Discussion

4.1 Why Palmer's index misranked the most polluted water body

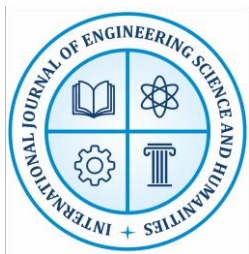
Palmer's (1969) index adds up the scores of the genera present, however many cells of each are found. A sample with a few cells of many listed genera therefore scores higher than one dominated by one or two of them. Here the moderately enriched S3 and S4 were rich in taxa and held most of the listed genera in most samples, whereas the urban tank supported fewer taxa per sample and was dominated by *Euglena*, *Microcystis* and filamentous cyanobacteria. The index therefore ranked S5 below S3 and S4, with its lowest values in summer, when the tank's oxygen was lowest. Weighted by density, the same genera ranked the sites as the chemistry did, and the tolerant share correlated with BOD at $p = 0.81$, compared with 0.37 for Palmer's score. In India, Palmer's index has mainly been used to separate polluted from less polluted waters (Shekhar et al., 2008; Das et al., 2018). The present results suggest that it separates clean from enriched waters reasonably well but cannot grade severity once enrichment reduces richness. *Navicula cryptocephala*, a Palmer genus that was negatively associated with enrichment here, adds a second caution: genus-level tolerance scores taken from temperate records do not always describe the local species (Lobo et al., 2016; Pandey et al., 2017).

4.2 Nygaard's quotients in hard-water Deccan systems

The quotients failed in two ways. Pooled over a season, every site held at least one species of each group and so received the same eutrophic value; the forested reservoirs, with the clearest and best-oxygenated water, were classed as eutrophic simply because the regional flora contains only three desmid species. At the sample level the quotients did separate the reservoirs, but desmids were absent from a third of samples, which left the quotients undefined exactly where enrichment was greatest. Nygaard's (1949) reference values came from soft-water Danish lakes with a rich desmid flora. In the alkaline, calcium-rich waters of the Deccan basalt, desmid scarcity is partly geological, and this inflates the quotients regardless of nutrient status. General reviews of algal indicators have noted the same problem with transferring group ratios between regions (Bellinger & Sigee, 2015; Wu et al., 2017). In these systems the quotients can serve at most as a supplement, and they should always be reported with the species counts behind them.

4.3 Carlson's index and non-algal turbidity

The chlorophyll-based trophic index was the most reliable of the borrowed indices and ranked the sites exactly as the chemistry did. This is expected, since chlorophyll a measures algal biomass directly and the index was designed as a continuous scale rather than a list of taxa



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(Carlson, 1977). The Secchi-based index ordered the sites correctly but overstated trophic state in the monsoon by about eight units. In tropical reservoirs the monsoon brings silt and clay that lower transparency even when algal density is low, so Secchi depth should be read together with chlorophyll a rather than on its own. The seasonal gap between the two indices is itself diagnostic: a large positive difference points to mineral turbidity from runoff, whereas agreement in summer shows that algae are the main cause of low transparency.

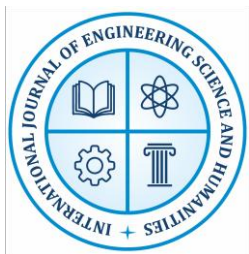
4.4 Ecological basis of the indicator taxa

The selected indicator taxa agree closely with the known ecology of their groups. Desmids such as *Closterium*, *Cosmarium* and *Staurostrum* are associated with clear, weakly enriched water, and dinoflagellates such as *Ceratium* with stable, well-lit water columns (Reynolds et al., 2002; Padisák et al., 2009). *Euglena* and *Phacus* can use dissolved organic substrates and thrive where domestic and cattle wastes enter shallow ponds (Bellinger & Sigee, 2015). *Microcystis* has a competitive advantage in warm, nutrient-rich, stable water, and its presence carries a potential toxin hazard (Huisman et al., 2018). Apart from *Navicula*, the same genera were reported as pollution indicators in Nachiketa Tal (Sharma & Tiwari, 2018), and *Microcystis* dominated the urban lakes of Nagpur (Maske et al., 2010). This suggests that the enrichment indicators found here can be transferred within Indian monsoonal waters. The cross-year test was an important safeguard: four taxa with significant indicator values in the pooled data were rejected because their associations did not hold in both years, and a one-year study would have accepted them.

Low-enrichment taxa had higher indicator values than enrichment taxa. Tolerant *Chlorella* and *Oscillatoria* were widespread and differed among sites mainly in abundance, whereas desmids and dinoflagellates were concentrated at the reservoirs. For monitoring, the loss of the sensitive assemblage is therefore a sharper signal than the arrival of tolerant taxa, and tolerant taxa should be judged by their share of density rather than by presence. When species identification is uncertain, morphological traits such as size, motility and colony formation offer another route to classification (Kruk et al., 2010).

4.5 Use and limits of the five-metric index

The index combines two measures of sensitive taxa (*Zygnematophyceae* share and diversity), two of tolerant taxa (cyanobacterial and tolerant-taxa share) and one of biomass (TSI(Chl)). Each comes from a single preserved sample and a chlorophyll extract, and each ranked the sites in the same order as the chemistry. The total score correlated strongly with phosphate-P and BOD, although neither enters the calculation, so the index captures the nutrient and organic gradient. It should be applied in summer, when the classes separated most clearly, with a winter round in support, and a water body should be classified from the mean of at least two stations, preferably over two rounds. Any sample in which cyanobacteria exceed half of total density or form visible



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scums should trigger precautionary advice against drinking, bathing and watering livestock, in line with risk-based guidance for toxic cyanobacteria (Chorus & Welker, 2021).

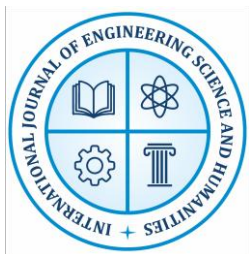
The main limitation is circularity. The thresholds came from the same data used to test the index, so it probably performs better here than it would on independent water bodies. The study also covered only six sites, omitted the saline Purna alluvium, measured only dissolved nutrients and did not measure toxins. Before regulatory use it should be validated on an independent set of Vidarbha water bodies, including intermediate and saline sites, and its thresholds should be reviewed as data accumulate (Stevenson, 2014).

5. Conclusions

Temperate indices borrowed without calibration gave misleading results in Deccan water bodies. Palmer's presence-based score ranked the most polluted urban tank below two moderately enriched water bodies because enrichment reduced the number of taxa present. Nygaard's quotients were either identical at every site or undefined where desmids were absent. Carlson's chlorophyll-based index ranked the sites correctly, while its Secchi-based form was inflated by monsoon silt. Abundance-weighted metrics did better: the density share of Palmer's tolerant genera followed the chemical gradient closely. Twenty taxa that passed both an indicator value test and a cross-year consistency test form a locally tested indicator list, and a five-metric index based on routine microscopy and chlorophyll *a* reproduced the phosphate and BOD gradient ($\rho \approx 0.89$). Once validated on independent data, the index can give district laboratories an inexpensive, summer-focused tool for classifying reservoirs, tanks and ponds by enrichment.

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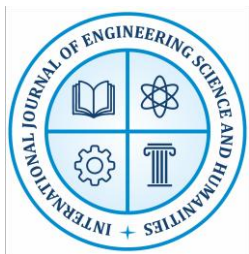
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