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# Determination of biogeochemical rate constants for Chilika Lake, a tropical brackish water lagoon on the east coast of India

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**ecosystem models, Chilika lagoon, coefficients, biogeochemistry, eutrophication, rate constant**

## Introduction

Coastal lagoons are the most productive systems in the world because these environments are susceptible to significant nutrient influxes via runoff and direct human waste, which give rise to intricate and unpredictable variations in both spatial and temporal biogeochemical dynamics (Roselli et al., 2009; Tagliapietra et al., 2009). These variations are caused by fluctuations in salinity and temperature gradients, shallow depth, benthic–pelagic interface processes, and restricted connections with the adjacent sea (Torréton et al., 2007). Conversely, shallow-water lagoons exhibit significantly higher ecological diversity than fully marine water bodies due to their diverse biological communities that include freshwater, brackish water, and marine water (Dube et al., 2010). Given these factors, a quantitative mathematical methodology is essential for determining impacts developing solutions to improve water quality, and predicting potential nutrient loads (Jayaraman et al., 2007). This method allows for the assessment of primary, secondary, and tertiary production by anticipating potential outcomes and understanding the impact of local management strategies (Giusti et al., 2010). Understanding ecologically significant processes requires comprehending transformative mechanisms, which necessitate modeling and describing altered biogeochemical cycles.

Previous studies used coefficients derived from field experiments in temperate regions, which have distinct water quality and ecological characteristics compared to tropical areas, such as higher annual solar irradiation, water temperatures exceeding 18°C, and increased primary production (Lewis, 1987; Prasad et al., 2014; Panda et al., 2015). Therefore, the mathematical models employed to predict water quality in tropical water bodies cannot directly adopt the chemical and biological parameters linked to climatic zones (Lin et al., 2001). This limitation stems from variations in local physicochemical properties, diverse tropical biological processes, and models calibrated to specific environmental regimes (Dunlop et al., 2008). Given this context, it becomes imperative to establish a comprehensive modeling framework tailored to tropical coastal water systems.

The present study embodies the culmination of the "Chilika Lake Ecosystem Modeling" project, which provides crucial insights into the prediction of biogeochemical events. In the realm of tropical ecosystems, it is worth noting that there is a significant dearth of research in this area, especially when it comes to the Indian sub-continent. Considering this, a set of objectives has been devised to confront this deficiency in understanding.

i. The determination of rate constants in Chilika Lake holds significant value in terms of predicting and understanding its sustainable biogeochemical processes.
ii. Validation of predictions from a mathematical model on primary and secondary production, which strongly correlate with ecosystem water quality, using *in situ* monitored data.

## Sampling and analysis

### Study area

Chilika Lagoon, a designated Ramsar site in India, features a distinctive pear-shaped, shallow water body with a longitudinal stretch of 64.3 km and an average width of 20.1 km (Pattnaik, 1998) (Figure 1A). Its seasonal variability in total area, ranging from approximately 704 km² in summer to 1,020 km² during the monsoon, is influenced by the confluence of three key tributaries of the Mahanadi River, namely, Daya, Bhargavi, and Nuna. These tributaries play a crucial role in regulating the lagoon's hydrography, along with the 52 streams from the western catchment regions contributing a substantial volume of freshwater ($3.1 \times 10^6$ $m^3$ $d^{-1}$ and $166.8 \times 10^6$ $m^3$ $d^{-1}$ during pre-monsoon and monsoon, respectively) (Gupta et al., 2008). A significant hydrological intervention in September 2000, involving the creation of a new mouth, successfully addressed ecological challenges such as low salinity and macrophyte overgrowth observed in 1996–1997 (Satyanarayana, 1999). Seawater exchange primarily occurs through the Outer channel, supplemented by a discreet connection via the Palur canal in Rambha Bay, resulting in a dynamic interplay of marine water, brackish water, and freshwater ecosystems. Hydrographically, the lagoon is classified into four sectors: the Southern sector, connected to the sea through the Palur canal; the Northern sector, receiving the maximum discharge through rivers; the Outer channel, connected directly to the sea; and the Central sector, serving as the mixing zone of the Northern sector and the Outer channel. The present study was conducted during January 2009 and December 2011 in the lagoon's southern and central sectors, characterized by minimal salinity changes, aimed to derive major coefficients for a comprehensive understanding of its ecological dynamics (Gupta et al., 2008; Muduli et al., 2013) (Figure 1B).

### Biogeochemical parameters and experimental methods

Dissolved inorganic nutrients ($NH_4$, $NO_2$, $NO_3$, and $PO_4$) were estimated using protocols from Grasshoff et al. (1999). The determination of carbonaceous biological oxygen demand (CBOD) was conducted by employing the dissolved oxygen (DO) method with a 5-day incubation period (APHA, 23rd Edition). The MIKE-21 Manual was used to calculate the first-order decay rate at

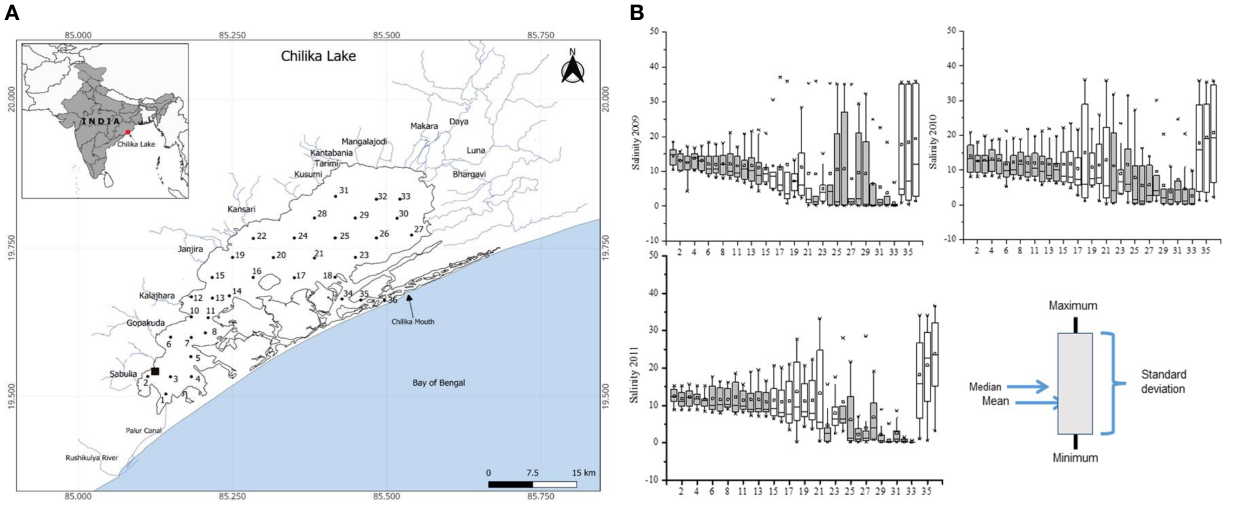

FIGURE 1
**(A)** Map of Chilika lagoon with study locations. The black solid square near station (St.) 2 shows the benthic chamber experiment location. Southern sector: St. no. 1–14; Central sector: St. no. 15–23; Northern sector: St. no. 24–32; and Outer channel: St. no. 34–36. **(B)** Salinity variations across the sampling locations and four sectors of Chilika Lake during the study periods from 2009 to 2011.

20°C, temperature coefficient for decay rate, and half-saturation oxygen concentration. Moreover, the concentrations of ammonia and phosphorus were estimated from the BOD incubated bottles to assess the production of ammonia and phosphorus during the organic matter degradation (i.e., carbonaceous BOD) and their content was calculated following the DHI Manual for WQ-2003. The ammonia in sediments was extracted using the potassium chloride technique (Riley and Vitousek, 1995) and analyzed using the hypochlorite method (Grasshoff et al., 1999). The $H^{14}CO_3^2$ incorporation method was used to measure nitrification rates (Brion and Billen, 1998, 2000), while oxygen demand during nitrification was determined using conversation factors from $NH_4$ to $NO_2$ and $NO_3$ to $NO_2$ (Wezernak and Gannon, 1967).

For new carbon production estimation, the Chlorophyll-*a* (Chl-*a*) measurement before and after 12 h, along with the radioactive carbon ($C^{14}$) technique, is used under *in situ* incubation conditions. Microzooplankton (MZP) grazing experiments were conducted to analyze grazing rates, phytoplankton growth rate, and daily turnover using the dilution technique (Landry and Hassett, 1982). The mass of zooplankton was measured in carbon (C) by filtering 20 ml of culture using a pre-combusted (at 450°C for 4H) 25-mm Whatman GF/F filter (0.7 µm). Similarly, phytoplankton samples were oven dried at 60°C and their organic carbon (de-carbonated by HCl fumes) content was measured using an elemental analyzer on alternate days (Thermo Finnigan, Flash EA1112) (Redalje, 1983). L-Cystine was used as standard and precision of analysis was checked against NIST 1941b and found to be at ±0.1%.

Sediment oxygen demand (SOD) was measured using laboratory-based and *in situ* field methods, using sediment core samples and a submersible benthic chamber where the depth is ~1.5 m, to minimize sediment manipulation and reflect ambient field conditions. The benthic chamber used in this experiment is made up of a height of 30 cm and a diameter of 29 cm, with indigenous fabrication employing a translucent acrylic sheet of 1.3 cm thickness (Abhilash et al., 2012; Muduli et al., 2013). The chamber was equipped with a leakproof design and provisions to replace withdrawn sample volume through side ports. To prevent excessive penetration into sediment, emplacement flanges were attached to two opposite outer walls, with a maximum depth of 15 cm. The chamber was incubated with an artificial bottom current created by generating a mechanical stirring every 10 min to simulate natural processes. DO samples from the chamber water were collected at 3-h intervals for 24 h via Tygon tubing, using a peristaltic pump. Care was taken in avoiding air bubbles and entrapped water in Tygon tube before sampling. For further experiment details, refer to Muduli et al. (2013).

The experiments were conducted during the stable post-monsoon (November to January) and pre-monsoon (March to June) seasons covering all the 3 years (January 2009 and December 2011), and the mean results were used to calculate coefficient derivations, with each experiment performed five times.

## Model formulations

All the model equations, units, and nomenclatures for hydro-chemical, biological, and sediment processes for model requirements were adopted from MIKE 21 Water Quality Temples 2003 in tandem with Hang et al. (2009).

# Results and discussion

BOD is a crucial factor in the aerobic metabolism of various organisms, including pelagic and benthic ones (APHA, 1992; Bhateria and Jain, 2016). In Chilika Lake, the CBOD decay rate constant was measured as 0.24 $d^{-1}$. In general, temperature, hydraulic parameters, and *in situ* processes significantly influence BOD decay rate, with micro-/macro-organisms playing a direct role in governing overall BOD rates within the water column. Despite this, the BOD sources include mass debris, decreased flora and fauna, and mass zooplankton detritus. The dynamics of water quality are exemplified by the difference between clean waters with low BOD values and high organic content with elevated BOD values, which can lead to severe DO depletion and potential fish kills (Penn et al., 2003). This study investigates various BOD processes, the CBOD decay temperature correction factor (1.048 θ), the ratio of ammonium released by BOD decay (0.28 g NH4-N/g BOD), half-saturation concentrations of DO for organic matter degradation (0.38 mg $O_2$/L), and phosphorus content in dissolved BOD (0.6 ± 0.035 g P/g BOD) (Table 1).

In riverine systems, the decomposition of organic matter often hinges on the bacterial populations. For example, in Malaysian river water, CBOD decay rates were found to be higher than BOD decay rates observed during different seawater dilutions, attributed to the suppression of nitrifying bacteria, resulting in reduced oxygen consumption (Nuruzzaman et al., 2018). Our study found that CBOD decay rates in experimental sites were comparable to those in San Francisco Bay Estuary (Chen, 1970), James River (O'Connor, 1981), and Patuxent River Estuary (Lung and Bai, 2003), indicating distinctly brackish waters. The study found that the $NH_4$ release ratio during BOD decay was consistent with Venice Lagoon (Melaku Canu et al., 2001) and Chesapeake Bay (Cerco and Cole, 1994) studies, and the phosphate content in dissolved BOD was lower than Savannah Harbor (NATIONAL BOARD OF WATERS, 1982), indicating that algal growth played a significant role as a regulating factor.

Estimating DO concentrations is crucial for understanding oxidation and reduction processes, nutrient release, and gas production. Oxygen enters water through direct absorption from the atmosphere and photosynthesis, which consumes carbon from the atmosphere by phytoplankton and submerged aquatic vegetation (e.g., *Potamogeton pectinatus*, *Halophila* sp., and *Vallinaria* sp.). This understanding is essential for considerate nutrient release and gas production. Consequently, DO is a helpful indicator of environmental health due to its correlation with phytoplankton biomass (Bhateria and Jain, 2016). DO is also linked to the nutrient cycle through microbial mineralization and demineralization mechanisms. In Chilika Lake, maximum oxygen production at noon was 7.99 ± 0.011$m^2$/d, with submerged plants acting as a major sink for DO at 191.6 $m^2$/d.

Carbon-based primary production measures can be compared to oxygen-based measures, with adjustments based on the photosynthetic quotient (PQ), which represents the molar ratio of

TABLE 1 Comparison of biogeochemical rate constants of Chilika Lagoon with other areas.

| BOD processes | | Value | Study area | Rate constant derivation method | References |
|---|---|---|---|---|---|
| 1 | CBOD decay rate constants (day$^{-1}$) | 0.2 | San Francisco Bay Estuary | Experimental | Chen, 1970 |
| | | 0.1 | New York Bight | Model | O'Connor, 1981 |
| | | 0.2 | James River | Model | O'Connor, 1981 |
| | | 0.2 | Patuxent River Estuary | Field measurements | CercoLung and Bai, 2003 |
| | | 0.01 | Chesapeake Bay | Field measurements/model | Cerco and Cole, 1994 |
| | | 0.007 | Maryland coastal waters | Model | Lung and Hwang, 1994 |
| | | **0.24** | **Chilika Lagoon** | | **This study** |
| 2 | CBOD decay temperature correction factor (θ) | 1.047 | San Francisco Bay Estuary | Experimental | Chen, 1970 |
| | | 1.047 | Venice Lagoon | Model | Melaku Canu et al., 2001 |
| | | 1.05 | Maryland coastal waters | Model | Lung and Hwang, 1994 |
| | | **1.048** | **Chilika Lagoon** | | **This study** |
| 3 | Ratio of ammonium released by BOD decay (g $NH_4$-N/ g BOD) | 0.02–0.29 | In Savannah Harbor | Model | USACE, 2006 |
| | | 1.7–3.2 | Upper Klamath River | Experimental/field | Sullivan et al., 2010 |
| | | **0.28** | **Chilika Lagoon** | | **This study** |
| 4 | Half-saturation concentrations of dissolved oxygen for organic matter degradation (mg $O_2$/L) | 0.1 | Venice Lagoon | Model | Melaku Canu et al., 2001 |
| | | 0.5 | Chesapeake Bay | Field measurements/model | Cerco and Cole, 1994 |
| | | **0.38** | **Chilika Lagoon** | | **This study** |
| 5 | Phosphorus content in dissolved BOD (g P/g BOD) | 0–0.1 | In Savannah Harbor | Model | USACE, 2006 |
| | | **0.06 ± 0.035** | **Chilika Lagoon** | | **This study** |
| Dissolved oxygen (DO) process | | | | | |
| 1 | Maximum oxygen production at noon (g $O_2$/m$^2$/d) | 2–7 | Dwaraka | Model | Rohit Goyal, 2011 |
| | | **7.99 ± 0.011** | **Chilika Lagoon** | | **This study** |
| 2 | Carbon-to-oxygen ratio at primary production (mg C/mg O) | 0.2–0.4 | Nova scotia | Field measurements/model | Irwin, 1991 |
| | | **0.31 ± 0.006** | **Chilika Lagoon** | | **This study** |
| 3 | DO-to-Chl-*a* ratio (g DO/mg Chl) | 0.035 | Ariake Sea, Japan | Field measurements/model | Hang et al., 2009 |
| | | 5.9 | Culture experiment | Experimental | Kitajima and Hogan, 2003 |
| | | **1.3691 ± 0.202** | **Chilika Lagoon** | | **This study** |
| 4 | DO-to-mass detritus ratio (mg DO/mg D) | 0.35 | Ariake Sea, Japan | Field measurements/model | Minh Hang et al., 2009 |
| | | **0.0174 ± 0.004** | **Chilika Lagoon** | | **This study** |
| 5 | DO-to-mass zooplankton ratio (mg DO/mg Z) | 0.35 | Ariake Sea, Japan | Field measurements/model | Hang et al., 2009 |
| | | **0.2708 ± 0.11** | **Chilika Lagoon** | | **This study** |
| 6 | Flux rate of DO (kfluxDO) (m/d) | 0.03 | Ariake Sea, Japan | Field measurements/model | Hang et al., 2009 |

*(Continued)*

TABLE 1 Continued

| BOD processes | | Value | Study area | Rate constant derivation method | References |
|---|---|---|---|---|---|
| Dissolved oxygen (DO) process | | | | | |
| | | **0.922 ± 0.023** | **Chilika Lagoon** | | **This study** |
| Ammonia processes | | | | | |
| 1 | $NH_4$–N in sediment (mg/m$^3$) | 10–400 | Ariake Sea, Japan | Field measurements/model | Hang et al., 2009 |
| | | 2,756 | River Seine | Field measurements/ experimental | Brion and Billen, 2000 |
| | | 70–12,400 | Nhue River model | Model | Reichert et al., 2001 |
| | | **284.8** | **Chilika Lagoon** | | **This study** |
| 2 | Nitrification rate of $NH_4$–N (μmol N/L/d) | 0.011 | Mediterranean Lagoon | Model | Chapelle et al., 2000 |
| | | 0–5.4 | Pearl River Estuary | Field measurements/ experimental | Dai et al., 2008 |
| | | 0.05 at 20°C | Temperate lagoon, Ria de Aveiro | Field measurements/model | Lopes et al., 2010 |
| | | **3.001** | **Chilika Lagoon** | | **This study** |
| Nitrification processes | | | | | |
| 1 | N-to-mass detritus ratio (yN/D) | 0.15 | Ariake Sea, Japan | Field measurements/model | Hang et al., 2009 |
| | | 0.043 | Westerschelde estuary | Field measurements/model | Soetaert and Herman, 1995 |
| | | **0.12** | **Chilika Lagoon** | | **This study** |
| 2 | N-to-Chl-*a* ratio (yN/Chl) | 0.014 | na | Field measurements/model | Aminot et al., 1997 |
| | | 0.012 | English Channel | Model | Cugier et al., 2005 |
| | | 0.0033 | Experimental data | Experimental data | Geider et al., 1998 |
| | | **0.019** | **Chilika Lagoon** | | **This study** |
| Phosphorus process | | | | | |
| 1 | P-to-Chl-*a* ratio (g P/mg Chl) | 0.0012 | Ariake Sea, Japan | Field measurements/model | Hang et al., 2009 |
| | | 0.0025–0.002 | Mesotrophic waters | Field measurements/model | Jørgensen and Bendoricchio, 2001 |
| | | **0.0036 ± 0.001** | **Chilika Lagoon** | | **This study** |
| 2 | P-to-mass detritus ratio (mg P/mg D) | 0.012 | Ariake Sea, Japan | Field measurements/model | Hang et al., 2009 |
| | | 0.0074 | Coastal zone in China | Model | Nobre et al., 2010 |
| | | **0.000321 ± 0.00001** | **Chilika Lagoon** | | **This study** |
| 3 | P-to-mass zooplankton ratio (mg P/mg Z) | 0.012 | Ariake Sea, Japan | Field measurements/model | Hang et al., 2009 |
| | | 0.02 | Lake Michigan | Field measurements/model | Chen et al., 2002 |
| | | 50 | Kjelsasputten, Norway | Experimental | Hessen and Lyche, 1991 |
| | | 50 | Oslo Fjord | Experimental | Sterner et al., 1992 |
| | | **100.9 ± 52.7** | **Chilika Lagoon** | | **This study** |

*(Continued)*

TABLE 1 Continued

| | BOD processes | Value | Study area | Rate constant derivation method | References |
|---|---|---|---|---|---|
| **Chlorophyll to carbon processes** | | | | | |
| 1 | Chl-*a*-to-carbon ratio (g/g) | 0.03 | Laboratory experiment | Experimental | Cloern et al., 1995 |
| | | 40 | Créteil Lake | Field measurements | Gamier et al., 1989 |
| | | 0.005–0.065 | California coastal water | Field measurements/model | Qian et al., 2010 |
| | | 0–0.03 | California coastal water | Experimental | Qian et al., 2011 |
| | | **0.007–0.02 (± 0.004)** | **Chilika Lagoon** | | **This study** |
| **Sediment processes** | | | | | |
| 1 | Sediment oxygen demand (SOD) (µmol/$m^2$/h) | 0–30 | Hiroshima bay | Experimental | Seiki et al., 1994 |
| | | 0.549–0.986 | Cochin Backwater | Field and Laboratory | Abhilash et al., 2012 |
| | | **5.01** | **Chilika Lagoon, India** | | **This study** |
| 2 | Temperature coefficient for SOD (SODT) (g $O_2$/$m^2$/d) | 1–1.2 | Semariang Batu River | Field and Laboratory | Ling et al., 2009 |
| | | 1.024 | Lake Vegoritis | Model | Antonopoulos and Gianniou, 2003 |
| | | **0.87** | **Chilika Lagoon, India** | | **This study** |

Bold values means present study.

oxygen and carbon production. PQ can vary depending on inorganic nitrogen source, with higher values used for nitrate utilization. The carbon-to-oxygen ratio at primary production in the lagoon was 0.31 ± 0.006 mg C/mg O. The study determined the DO-to-Chl-*a* ratio, DO-to-mass detritus ratio, and DO-to-mass zooplankton ratios in all lagoon sectors and mean values are 0.1391 ± 0.202 g DO/mg Chl, 0.0174 ± 0.004 mg DO/mg D, and 0.2708 ± 0.11 mg DO/mg Z, respectively (Table 1). The mean water to air oxygen flux rate was calculated as 0.0008 mM/$m^2$/d. These results indicate that the fluctuations in water quality are linked to algal growth. For instance, during peak photosynthetic production, Chl-*a* concentrations coincide with DO and pH values (Lindenberg et al., 2008), making the DO-to-Chl-*a* ratio crucial for estimating ecosystem health. DO-to-detritus and mass zooplankton ratios indicate the lagoon's biological stability.

The non-humic dissolved organic matter production can be related to chlorophyll-a as well as bacteria–chlorophyll concentrations (Khan and McKnight, 2010; Harvey et al., 2015; del Giorgio and Peters, 1993). The bacterial degradation of organic matter results in the production of inorganic molecules, including $NH_4$ in sediment, which is an important indicator of organic load and its conversion into an inorganic state. The $NH_4$ concentration in lagoon sediment was quantified as 284.6 mg/$m^3$, providing valuable insights into nutrient regeneration from the bottom sediment. The study measured the increase in dissolved $NH_4$ concentration in a lagoon using benthic chamber experiments, which revealed a mean value of 0.0041 mM/$m^2$/d (Table 1), where the variations in chlorophyll content were linked to the dissolved organic nitrogen and $NH_4$, especially in the northern part, due to active *in situ* mineralization of POC-rich SPM (Patra et al., 2016). Additionally, the re-suspension of bottom sediment during the pre-monsoon period due to high wind action increased SPM levels, which could also affect the lagoon's $NH_4$ concentration (Ganguly et al., 2015).

The nitrification process involves the microbial transformation of $NH_4$ to $NO_2$ and $NO_3$ is important in the nitrogen (N) cycle. The nitrification rate was observed as 3.001 (k Ni NH) and is comparable to the South China Sea (0–5.2 kNiNH) (Dai et al., 2008). In the Mediterranean Lagoon and Ria de Aveiro (temperate lagoon), the nitrification rates were reported as 0.011 kNiNH and 0.05 kNiNH (at 20°C) (Chapelle et al., 2000; Lopes et al., 2010), and the nitrification and de-nitrification processes are subject to the distinctive environmental parameters prevailing in the local context. The N-to-mass detritus ratio and N-to-Chl-*a* ratio were shown as 0.12 yN/D and 0.019 yN/Chl, respectively, which are in agreement with other studies (Cugier et al., 2005; Hang et al., 2009).

Phosphorus is a key nutrient in ecosystem dynamics, limiting algal development. Sediment in shallow water systems regulates P levels in the water column. The complex processes of P transformation, preservation, and recycling at the sediment–water interface are influenced by the reactivity of P forms and diverse biological, physical, and geochemical factors, with estuarine and coastal environments serving as vital P sinks and filters (Liu et al., 2016). Furthermore, previous studies suggested that the mineralization of organic matter and the reduction of iron oxide affect P release into the water column (Ruttenberg, 1992). The P cycle in turbid waters is still unknown due to its reliance on other elements. Studies using spatiotemporal data from lagoon ecosystems aim to understand phosphate involvement and its relationship with primary producers, consumers, and detritus. The estimated mean sediment to water of $PO_4$-P flux rate was recorded as 0.00437 mM/$m^2$/d. The mean ratios of P to Chl-*a*, mass detritus, and mass zooplankton in Chilika Lake were measured as 0.0036 ± 0.001 g P/mg Chl, 0.000321 ± 0.00001 mg P/mg D, and 100.94 ± 52.7 mg P/mg Z, respectively. These results are comparable (Table 1) with the previous studies conducted elsewhere (Chen et al., 2002; Nobre et al., 2010); however, the P-to-mass zooplankton ratio showed a high value, which may be due to the high productivity nature of Chilika Lake.

The complex and non-linear relationship between phytoplankton carbon biomass and chlorophyll concentration is influenced by light, nutrients, and temperature within the euphotic zone, as documented in various studies (Brown et al., 2003; Le Bouteiller et al., 2003; Armstrong, 2006). Under nutrient-rich conditions, the phytoplankton carbon-to-chlorophyll (C:Chl) ratio decreases as light levels decrease, a phenomenon known as "photoacclimation" (Dubinsky and Stambler, 2009). The natural death rate of Chl-*a* in laboratory conditions is 0.7 $d^{-1}$ (Table 1), indicating that chlorophyll concentrations, which are indicators of phytoplankton populations, are influenced by nutrient availability. In general, nitrogenous nutrients enter through oxygen-demanding processes like nitrification, while phosphorus is released through cellular processes, excretions, and river runoff. Conversely, total suspended matter (TSM) includes all living, non-living, organic, and inorganic materials, including chlorophylls and suspended planktons, and is significantly related to chlorophyll concentrations, highlighting the interconnectedness of environmental factors.

MZP are primarily composed of ciliates, are the primary consumer of nanoplankton, and serve as an important link between small primary producers and larger consumers in aquatic feed webs (Burkill et al., 1993). The lagoon has a mean grazing rate of 0.305 $d^{-1}$, and the mean mass of zooplankton to Chl-*a* was calculated to be 0.341g Z/mg Chl, based on extensive spatiotemporal data collection. The decline in phytoplankton biomass is influenced by factors like water quality, zooplankton grazing, and their life cycle, while zooplankton abundance is regulated through secondary grazing and natural mortality mechanisms (Ger et al., 2014). Greater grazing values indicate higher rates of zooplankton domination, possibly measured by zooplankton-to-chlorophyll ratios.

Oxygen depletion in aquatic ecosystems is primarily caused by sediment organic material oxidation and invertebrate anaerobic respiration, affecting a significant portion of water column oxygen consumption, thus making measuring the rate of change in DO concentration essential for understanding oxygen flux changes (Akomeah and Lindenschmidt, 2017). Consequently, the study estimated the change in column DO concentration in a chamber-entrapped water volume and analyzed the SOD, revealing that temperature, water flow velocity, residence time, and sediment composition are key factors influencing SOD (Zeledon-Kelly, 2009).

The designed experiment calculated the temperature coefficient for SOD, the half-saturation concentration for SOD, and the DO sediment exchange rates. The results showed a temperature coefficient of 0.87 g $O_2$/$m^2$/d and a half-saturation concentration of 0.46 mg/L, with a mean SOD of 1.45 mg/$m^2$/d (Table 1). The mean DO exchange rate between water column and sediment is 1.082 mg/L, which controls the benthic community and nutrient leaching from sedimentary pore water, but has a significant impact on shallow-water aquatic bodies. The high SOD of 5.01 µmol/$m^2$/h in Chilika Lake may be attributed to the high benthic primary production resulting in increased benthic oxygen demand. Algae usually consume oxygen during nighttime respiration, while during daylight photosynthesis, they generate and release oxygen (Akomeah and Lindenschmidt, 2017).

## Conclusion

The findings from this study indicate that the lagoonal ecosystem possesses a noteworthy level of resilience in the face of environmental fluctuations, comparable to other tropical shallow ecosystems worldwide. These determined rate constants mark a significant step towards establishing an ecosystem model tailored to the lagoon. Such a model would be instrumental in forecasting ecosystem alterations in response to variations in chemical and biological elements. In the northern part of the lagoon, where nutrient, SPM (suspended particulate matter), and chlorophyll-*a* levels are notably high, it is apparent that this region exerts a dominant influence over the entire lagoon. Further investigations into this northern region are necessary. It is worth noting that the derived rate constants may exhibit variations contingent upon species composition, abundance, decomposition processes, and evolving environmental conditions. It is important to note that although this study was conducted in saline to semi-saline conditions, the insights obtained may be applicable to the vast majority of tropical brackish water lagoons.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

SP: Conceptualization, Supervision, Writing – original draft, Writing – review & editing. BK: Data curation, Validation, Writing – review & editing. PM: Data curation, Methodology, Writing – review & editing, Validation. KV: Data curation, Methodology, Writing – review & editing, Validation. RR: Data curation, Investigation, Methodology, Writing – review & editing, Validation. DG: Data curation, Investigation, Writing – review & editing. AK: Data curation, Methodology, Writing – review & editing. AL: Data curation, Methodology, Writing – review & editing. UP: Validation, Writing – review & editing. SD: Writing – review & editing, Validation. MR: Project administration, Supervision, Writing – review & editing.

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## Conflict of interest

## Publisher's note

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