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Baseline

Imprints of COVID-19 lockdowns on total petroleum hydrocarbon levels in Asia's largest brackish water lagoon

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Abstract

India successfully executed one of the strictest lockdowns in the world during the height of the COVID-19 pandemic in early 2020, which provided unique opportunities to analyze the second-largest populous country's anthropogenic footprint on its natural systems. India's first Ramsar site and the world's second-largest brackish water system Chilika lagoon experienced a substantial decline (64%) in the total petroleum hydrocarbon (TPHC) level in water, which was attributed to the massive declines or, at times, an abrupt complete halt of motorized boat operations for fishing and tourism. Using the TPHC values during the lockdown period, our study recommends a TPHC baseline threshold of 2.02 μg L⁻¹ and 0.91 μg g⁻¹ for Chilika waters and sediment, respectively. These baseline values can be used to quantify oil pollution and to formulate policy and management action plans for Chilika lagoon as well as for other similar ecosystems by local environmental agencies.

Assessment of TPHC and its derivatives in inland and estuarine aquatic environments has received considerable attention in recent times due to their toxic, mutagenic, and carcinogenic characteristics and because they readily transform into hydrophilic metabolites and accumulate into the aquatic environment (i.e., fish, shellfish, etc.) (Mohanty et al., 2017; Hemalatha et al., 2020). Coastal lagoons are also vulnerable to TPHC and derivatives as they could be sourced from natural or anthropogenic activities that include point discharges and urban runoff, with a significant contribution from boat activities for fishery and tourism. Assessment of the status of the TPHC with respect to the controlling factors is vital in such ecosystems as the local population depends on them for their livelihood (Chouksey et al., 2004; Li et al., 2010; Mohanty et al., 2016; Hemalatha et al., 2020). Expanded literature on the impacts and dynamics of TPHC in natural waters is provided in the Supplementary section and tables (S.1; S. T1 and S. T2). Several past studies from Indian coastal environments have studied TPHC magnitude and dynamics (Venkatachalapathy et al. 2012; Mohanty et al., 2017; Hemalatha et al., 2020). However, so far, there have been no reports on the impact of the lockdown (due to the COVID-19 pandemic) on the variability of TPHC in those systems.

SARS-CoV-2 or COVID-19 pandemic has created an unprecedented global crisis and profoundly affected all aspects of our daily lives. The effect of this pandemic has been severe on public health but mostly beneficial to the environment. Several studies in the recent past have highlighted the net positive effect of the lockdown on natural environments in India, such as a decline in greenhouse gas emission, improved air and water quality, and reduction in urban heat (Mishra et al., 2020; Garg et al., 2020; Mukherjee, 2020; Muduli et al., 2021; Nanda et al., 2021). At the beginning of the pandemic, a strict nationwide lockdown was imposed in India on 24th March 2020, initially for three weeks and further extended up to 30 May 2020, through phases, with slowly easing up restrictions in each phase and with differing rules for specific activities such as commercial and recreational fishery and tourism in coastal ecosystems (Ray and Subramanian, 2020). Fishing and tourism was also restricted for about two months in Chilika lagoon, the second largest brackish water system of the world, on which 0.2 million people depend for their livelihood (SRCO, 2021). Additional details on the COVID-19 impact on the study region can be found in the Supplementary section.

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Despite fishing activities being exempted under the latter phases of lockdowns, the fisherfolk of Chilika could not operate the boat similar to the pre-lockdown period due to major disruptions in the workforce, logistics, and down-market situations in the wake of COVID-19 (First post, 2020).

Every day, there are roughly 7300 motorized boats operated in Chilika for fishery (5900) and tourism (1400) (Kumar et al., 2020). Apart from these boats, there are also ferry services in the lagoon for transporting people and goods, which were halted for about seven months, much longer than the halt on fisheries. Restriction on ferrying tourists also resulted in many boats anchored near the shore. In previous studies, Mohanty et al. (2016 and 2017) found that the operation and maintenance of motorized boats inside Chilika have led to consistent seepage of oil into the lagoon, which drives the changes in the TPHC level in water and sediment. Since all boat operations were halted due to the lockdowns, the TPHC level was expected to be reduced; therefore, an assessment of the fluctuations was necessary to develop baseline conditions. TPHC baseline is a value (TPHC concentration) with which the status quo can be compared for studying the influencing drivers and factors. A baseline is often region specific, and from a management point of view, it is crucial to establish such baselines for large, complex, and diverse ecosystems such as Chilika lagoon (CPCB, 1993, 1986). Till date, there have been no TPHC baseline conditions established for the lagoon, and the lockdowns provided a unique opportunity to establish them, which can be used in future to assess pollution status and analyze the long-term trends, for targeted policy formulation. To bridge the gap, the specific objectives of this study were to i) establish a baseline value for TPHC in water and sediments of Chilika lagoon and ii) understand the impact of lockdown on TPHC variability in different hydro-ecological sectors of the Chilika lagoon. This study is novel because, for the first time, we report TPHC variability in the water and sediment compartment of a heavy-traffic coastal lagoon during a period of negligible anthropogenic inputs.

Although the countrywide strict lockdown provided a rare opportunity to collect water samples to analyze the impact on the water quality of the lagoon, strict government-mandated social distancing and stay-at-home guidelines severely restricted logistical support for field sampling trips and laboratory analysis. Despite the difficulties, sampling was carried out from 13 to 18 May 2020 during the peak of the lockdown period following COVID-19 safety measures. This dataset was used to derive the baseline by fixing up a percentile that was corroborated with the excellent health status of the lagoon (details are provided in the baseline discussion section). Because of the shallow nature of the lagoon, there was no vertical stratification (mixed water column) observed between the surface and bottom waters. Hence, only subsurface water samples were collected from 7 a.m. to 2 p.m. from 33 locations covering different sectors of the lagoon (Fig. 1) using a 5 L Niskin sampler for the analysis of various biogeochemical parameters. The samples were analyzed in the laboratory within 24 h of collection. The pH of the samples was measured with a ROSS combination (reference electrode) glass electrode (Metrohm pH meter). The total suspended matter (TSM), salinity, dissolved oxygen (DO), and nutrients (viz. NO\textsubscript{2}\textsuperscript{-}, NO\textsubscript{3}\textsuperscript{-}, NH\textsubscript{4}\textsuperscript{+}, SiO\textsubscript{2}, and PO\textsubscript{4}\textsuperscript{3-}) were sampled, preserved, and analyzed following standard protocols described by Grasshoff et al. (1999). Alkalinity analysis was performed following the procedure of Dickson et al. (2003). Sample collection and analysis of chlorophyll-a (Chl-a) were carried out following the methods proposed by Parsons et al. (1984).

Two liters of water samples were collected for the TPHC analysis

![Fig. 1. The distribution of 33 TPHC sampling locations in the four sectors: southern, northern, central, and outer channel.](image-url)
from each location in pre-cleaned amber-colored glass bottles, extracted with n-hexane, and dried over anhydrous Na$_2$SO$_4$. Then, the fluorescence of the extract was measured at 360 nm (excitation at 310 nm) using UVF spectroscopy (Hitachi 7000) following the protocols of the Intergovernmental Oceanographic Commission – United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO, 1984). Top 5 cm surface sediment samples were collected using a Van Veen grab (KC Denmark), and the sediment from the center part of the grab was used to avoid any metallic contamination. Vegetation fragments, animal shells, and other physically visible debris were removed. The collected samples were wrapped in aluminum foil immediately and stored in polyethylene bags at 20–4°C until analysis. After thawing, 50 g of wet samples were Soxhlet-extracted (with KOH-methanol mixture) for 2 h, further extracted with n-hexane, and dried over anhydrous Na$_2$SO$_4$. The final extract was separated on a silica–alumina column, the fluorescence was measured, and the concentration was expressed on the wet weight basis (IOC-UNESCO, 1982).

Unfortunately, we did not have the TPHC data for the immediate pre-lockdown period (April 2020) for comparison. However, the Chilika Development Authority (CDA) provided the data from August 2019 when the TPHC levels for water and sediment were recorded as part of a monthly monitoring program implemented by the CDA. We also obtained the data for May 2019 and August 2018 for comparative analysis. May and August were considered as summer and monsoon seasons, respectively. Since boating and tourism activities are region specific in the lagoon (Mohanty et al., 2016), we considered four well-established ecological sectors: southern sector (SS), central sector (CS), northern sector (NS), and the outer channel (OC) for comparison and discussion. All the statistical analyses such as Pearson’s correlation, homogeneity of variance (Levene Statistic), and analysis of variance (ANOVA) were performed using a statistical package SPSS 20.0 (IBM).

During the study period (from Aug 2018 to May 2020), the water temperature (WT) ranged between 26.5°C and 34°C (31.26 ± 1.32°C). The depth of the lagoon varied between 0.54 and 3.50 m with an average depth of 1.73 m and with sectoral variation in the order OC > SS > CS > NS. The water column transparency varied between 0.07 and 1.82 m, with an average of 0.68 m, and with sectoral variation in the order SS > CS > OC > NS. The lowest transparency in the NS was due to the highest turbidity maintained in the sector. Because of shallow depth, the NS experiences sediment resuspension by wind action, which makes the water turbid (see Supplementary Section, S. T3) (Kumar et al., 2016; Muduli and Pattnaik, 2020). The pH level plays a vital role in the spatio-temporal dynamics of biogeochemical processes in coastal environments (Muduli et al., 2012, 2013). During the study period, the lagoon’s overall pH varied between 6.94 and 9.88, with an average of 8.27 ± 0.49 and was found to vary significantly between sectors (S. T3). The pH level of water influences the ability of the microbes to degrade hydrocarbons (Mohanty et al., 2016), and we found a significant negative correlation between pH and TPHC ($r = -0.215$, $p < 0.05$). This indicated that the water with a higher TPHC level enhanced the respiration process, resulting in a reduction in the pH value. Similar observations with low pH associated with higher TPHC and vice versa were also reported by Mohanty et al. (2016) for Chilika lagoon and elsewhere (Sharma et al., 2016; Schwartz et al., 2012). During the study period (except for August 2018), the highest TPHC was recorded in the NS, which corroborates with the findings of the study by Muduli et al. (2012), who reported the highest bacterial respiration in the NS compared with the levels observed in the other sectors of the Chilika lagoon. Alkalinity varied from 80 to 218 (avg. 131.94 ± 29.51 mgl$^{-1}$), which showed a significant negative correlation with the TPHC, indicating that higher alkaline water contained higher TPHC (see Supplementary Section, S. T4).

Salinity is a major factor that controls the microbial community structure in Chilika (Mohapatra et al., 2020) and plays a significant role in controlling the TPHC levels in pelagic and benthic compartments (Shiaris, 1989). As reported by many previous studies and also recorded in the present study, in summer, salinity in the lagoon is comparatively higher than that in monsoon and post-monsoon seasons due to the reduction in riverine freshwater discharge to the lagoon. The salinity recorded in this study ranged between 0.07 and 35.62, with an average of 8.29 ± 8.04. However, it did not show any significant correlation with the TPHC level, in contrast with the observations made by Mohanty et al. (2016). Chilika lagoon maintained a normal DO level in all the sectors ranging from 3.94 to 12.66, with an average of 7.48 ± 1.49 mg L$^{-1}$ (S. T3) and did not show any significant relationship with TPHC (S. T4) in either water or sediment. We theorize that the oxygen consumed for the degradation of TPHC by biotic/abiotic components was compensated by oxygen production through primary productivity and, therefore, did not decline with higher TPHC (Robin et al., 2016). Nutrient availability controls the growth of microbial communities and react with other elements to degrade TPHC (Cooney, 1984; Walker and Colwell, 1974). Nutrient concentrations in Chilika showed a significant variability with respect to months and sectors ($p = 0.05$, $n = 462$), supporting the observations made in earlier studies (Barik et al., 2017; Muduli et al., 2017). It showed a significant negative correlation with NH$_3$ and DIN ($r = -0.269$, $p < 0.01$ and $-0.219$, $p < 0.05$; S. T4), which could be due to the utilization of DIN-nitrogen (preferably NH$_3$) by the microbial community in order to degrade the large and complex TPHC molecules, increasing the TPHC concentration in the lagoon.

During the lockdowns of 2020, the TPHC in the Chilika waters substantially declined to its lowest ever recorded level, an average of 1.4 µg L$^{-1}$. It showed a decline of 64% compared with that observed in the same season in the previous year (2019). This drastic change during the lockdown period was attributed to the sudden and abrupt reduction in tourism and fishing activities in the Chilika lagoon. The decline in the TPHC level was substantial in all sectors compared with the rest of the study periods before the lockdown. Compared with the same season and month in the previous year (May 2019), the highest mean percentage decline of TPHC was observed in the NS (70%), followed by SS (63.49%), CS (55.45%), and OC (35.4%). The insignificant difference in rainfall recorded for May 2019 and 2020 (148 mm and 134 mm, respectively; SRC, 2021) also indicated that the decline was due to factors other than rainfall. During the study period, a significant sectoral variation was observed in the distribution of TPHC in the surface waters. Irrespective of the season, the highest mean concentration of TPHC in the water column was recorded from the NS followed by the SS, CS, and OC, except during the monsoon of 2018 (S. T3, Fig. 2). The highest concentration of TPHC in the NS was attributed to a complex interaction among several factors such as shallow depth, vertical mixing of surface waters, sediment resuspension, and the highest number of operational fishing boats (Mohanty et al., 2016). Since boat operations were halted completely in April–May 2020, NS encountered the highest decline compared with other sectors. Also, turbidity showed a significant positive correlation with TPHC in water ($r = 0.327$, S. T4), indicating that the TPHC in the water column could either be sourced directly from wind-driven sediment resuspension or the oil seepage from boats.

SS usually exhibits the second-highest TPHC levels in the lagoon due to seepage from boat painting activities in that sector (Mohanty et al., 2016) (Fig. 2). Similarly, high TPHC levels due to painting activities have also been observed at other places such as in Setiu wetland, South China Sea (Suratman et al., 2012). Therefore, when there was a sudden halt in the boat painting activities during the lockdowns, SS showed the second-highest decline in the TPHC levels. Lower concentrations of TPHC in the other two sectors (i.e., CS and OC), both during the lockdown period and the other periods, resulted in dilution by saline water intrusion into the Chilika through the OC from the Bay of Bengal (Panigrahy et al., 2014). Despite this, the two sectors CS and OC exhibited a decline of 55% and 35% in the TPHC levels during the height of the lockdown.

Several past studies have reported that seasonal variations of TPHC in aquatic environments are significant. For instance, Reddy et al. (2005) found that the Gulf of Cambay, Gujarat coast, showed a seasonal trend where a high concentration of TPHC was observed during winter compared with summer and monsoon seasons. A similar trend was
reported from Tianjin Bohai Bay by Li et al. (2010). Except during the summer of 2020, i.e., the lockdown period, in the summers of other years such as 2019 and 2014, the TPHC values in Chilika lagoon are typically higher compared with monsoon (Mohanty et al., 2016). That is due to the high residence time of water during summer, which ultimately increases the rate of accumulation and retention time of TPHC in the water column (Reddy et al., 2005). Sediment resuspension into the water column is also greater due to heavier wind action in summer, which was evident from the positive correlation between TPHC and turbidity ($r = 0.372$, S. T4). In addition, the summer season sees a spike in boat operations because it is the peak season for tourism and fishing activities in the lagoon (Mohanty et al., 2016). In contrast, the lower TPHC levels during monsoon are due to the dilution of freshwater inflows from the catchment areas (Mohanty et al., 2016; Reddy et al., 2005).

We conclude that across all factors, both natural and anthropogenic, the halt in boating activities was the main driver for the decline in the TPHC level in the lagoon. Similar patterns have been observed in other places. For example, Van Dam (1998) found a significant increase in the TPHC levels due to a spike in boating activities in the Yellow River in Kakadu National Park, Australia.

The TPHC concentrations in surface waters varied from 0.19 to 10.61 μg L$^{-1}$, with an average of 2.33 ± 2.28 μg L$^{-1}$ during the study period (S. T3). On comparing these TPHC levels with the levels reported by the limited number of previous studies conducted in India, we found that a significantly higher TPHC level was observed by Mohanty et al. (2017) (S. T1) in the Chilika lagoon (0.45–44.03 μg L$^{-1}$), whereas a similar range of TPHC had been reported from the coastal waters off Chennai (Veerasingham et al., 2011) and a comparatively low TPHC level (0.04–1.58 μg L$^{-1}$) was recorded in the coastal waters off Chilika in the Bay of Bengal (Panigrahy et al., 2014). Overall, the TPHC concentrations in the surface waters of Chilika lagoon from the present study are well below the threshold limits (PHC > 100 μg L$^{-1}$) prescribed for the sustainability of biotic life of aquatic and marine environments by the Central Pollution Control Board, Government of India (CPCB, 1986, 1993), and the U.S Environmental Protection Agency (USEPA, 1986). Also, the TPHC level in Chilika during the study period was significantly lesser than the threshold value (140 μg L$^{-1}$) prescribed by the ASEAN marine water quality criterion for the protection of aquatic life (AMWQC, 1999). Even though the TPHC level in Chilika waters was not above the proposed thresholds in the past, we had no prior knowledge about the baseline conditions for the TPHC levels in the lagoon. Through this analysis, we now know the baseline conditions, which would be crucial to quantify the pollution levels in the future.

Before the lockdowns, the average sediment TPHC was 0.9 μg g$^{-1}$, which declined to 0.6 μg g$^{-1}$ during the peak of the lockdown. Decline in the sediment TPHC level in the in the summer of 2020, although substantial, did not show a clear seasonal influence when compared with the summer (30%) and monsoon (33%) of 2019 and the monsoon (17%) of 2018. However, ANOVA analysis of the entire data (for all stations) recorded before and after lockdown revealed a statistically insignificant relationship. This implies that, unlike pelagic compartment TPHC levels, the impact of lockdown on the TPHC level in the benthic compartment was minimal. During the study period, the TPHC concentrations varied from 0.02 to 2.97 μg g$^{-1}$, with an average of 0.79 μg g$^{-1}$ (S. T3). The observed sediment TPHC concentrations were in a similar range as recorded for other ecosystems in India, including Pondicherry coastal waters (Kamalakannan et al., 2017), the Southeast coast of India (Bouloubassi et al., 2001), Pulicat Lake (Hemalatha et al., 2020) and elsewhere such as Bizerte lagoon, Tunisia, and Changjiang estuary, China (Mzoughi et al., 2005) (S. T2). The TPHC concentrations of Chilika sediments were much lower than those found for the Mandovi Estuary, India (5.4–12.34 μg g$^{-1}$) and other coastal water bodies around the globe, as listed in S. T2. As classified by the U.S National Academy of Sciences (US NAS, 1975), >70 μg g$^{-1}$ is considered as an indication of pollution, and as per the Food and Agriculture Organization (FAO), <100 μg g$^{-1}$ is classified as the threshold (FAO, 1982). The sediment TPHC levels recorded in our study were far below these thresholds and posed no risk to the biota of the Chilika lagoon (S. T2).

Similar to the observed sectorwise variability in the water TPHC levels, the differential impact of the lockdowns was analyzed in the sediments from different sectors. The sectoral ANOVA of sediment TPHC during lockdown revealed an insignificant variation (Fig. 2). The same

![Fig. 2. Sectoral variations of TPHC concentrations (with standard error bar) (a) in water and (b) in the sediments of Chilika lagoon during the lockdown period (May 2020) and in the past, Aug 2019, May 2019, and Aug 2018.](image-url)
was also observed for all the months during the pre-lockdown period. Overall, the sediment TPHC was neither statistically significant with months and seasons nor with sectors. This could be because the active mineralization process in the benthic compartment of the lagoon disintegrates the TPHC that settles on the water column, similar to what was observed in several ecosystems. For instance, Trosa Archipelago, Sweden (Ståhlberg, 2006), and Boreal Lake, California, USA (Gudasz et al., 2015), revealed higher organic remineralization in sediments compared with water, and it was primarily controlled by both physical and microbial processes. Although there was almost no anthropogenic input of TPHC to the lagoon during the lockdown, the preexisting TPHC in the water column could have settled on the benthic compartment, become demineralized, and nullified the differences across space (sectors), and time (pre- and post-lockdown). This process could be the reason for the three-times lower TPHC concentration in the sediment than in the water observed in the lagoon. Similar differences between sediment and water TPHC levels have been observed for the South China Sea by Wongnapapan (1991). The Chennai coast, India, also experienced than in the water observed in the lagoon. Similar differences between sediment and water TPHC levels have been observed for the South China Sea by Wongnapapan (1991). The Chennai coast, India, also experienced

During and before the lockdowns, except for the summer of 2019, the highest sectoral mean concentration of sediment TPHC was observed in the OC, followed by the CS, NS, and SS. The OC is the estuarine zone of the Chilika lagoon (Fig. 2), and it acts as the major depository for all the sectors to dispose of the domestic effluents/discharges and dredged materials to the coast. Also, it is a dynamic zone where the retention time of the material fluxes are high along with the high ionic strengths in estuarine waters, which removes the hydrophobic TPHC from the water to the sediment phase (Means, 1995; Brunk et al., 1997; Chapman and Wang, 2001). Furthermore, increasing salinity facilitates the removal of dissolved organic matter from the water to the sediment phase by forming particulate organic matter, which adsorbs hydrophobic chemicals (TPHC) (Brunk et al., 1997). This could be the reason for the higher concentration of TPHC in the sediments of the OC during the lockdown and the rest of the study period.

The TPHC level in the water and sediment of Chilika during the summer of 2020 was found to be the lowest ever recorded in the past. We consider this to be the best-case environmental scenario with the least oil pollution in the lagoon. Therefore, we propose that the TPHC levels in both water and sediment be treated as the new baseline conditions. In order to derive the baseline for water quality parameters for a particular ecosystem, the upper 25th percentile (75th percentile) is preferred as it is likely associated with the minimally impacted conditions and provides management guidance (U.S EPA, 2001). Several studies have recomended considering the lower 75th percentile to demarcate the baseline concentrations. For instance, Smith et al. (2003) derived the natural background concentrations of nutrients by using data from 63 minimally impacted basins in the U.S. As per the U.S EPA (2001), such percentile baselines are considered for water quality references by the Tennessee Department of Environment and Conservation and the New York State Department of Environment and Conservation. Percentiles are also used for deriving baselines for water quality indicators for the preparation of health report cards for aquatic systems (CDA, 2014). In general, the health status of ecosystems is represented by grades such as A, B, C, D, and F (fail), which ranges excellent, good, average, poor, and very poor, respectively. In order to arrive at these gradings, data from the period of interest were considered in the calculation to find the percentage of data that falls within the baseline values, which are either derived particularly for the ecosystem or available in the literature for a similar ecosystem. When 80–100% of the data fall within the baseline, the health status is considered as excellent, and 60–80%, 40–60%, 20–40%, and 0–20% within the baseline are regarded as good, average, poor, and very poor, respectively (CDA, 2012; UMCES, 2016; McIntosh et al., 2019; FBRC, 2019). In order to determine a baseline for Chilika, we considered the dataset of the lockdown period (May 2020), which revealed the lowest levels ever recorded for Chilika and assumed the health status as excellent during that period. Hence, to find the baseline, we selected a threshold value from lockdown period data above which at least 80% of data fall. To do so, we tested the value of 75th and higher percentiles for both water and sediment TPHC data individually. It was observed that the value retrieved from the 82nd percentile fulfilled the criteria of excellent health status (for both water and sediment) and was considered as the TPHC baseline value. Consequently, we propose that the baseline values for the TPHC levels in Chilika waters and sediment be 2.02 µg L⁻¹ and 0.91 µg g⁻¹, respectively, and the level of pollution should be quantified using the deviation from the baseline as a metric.

The past health report cards for Chilika (CHRC) was produced by CDA in collaboration with the University of Maryland (CDA, 2012, 2014, 2016, 2018), and the report cards prepared for other Indian ecosystems such as Paradeep estuary, Dhamara coast, and Gahirmatha coastal stretch also followed similar grading systems (SPCB, 2015). In the present study, we propose to include the TPHC as one of the health indicator parameters (apart from turbidity, Chl-a, and dissolved oxygen used as water quality indicators in earlier report cards) for CHRC using the baseline derived from lockdown period data. Accordingly, the health status of the lagoon was evaluated for all available prior TPHC data recorded in the lagoon. From the oil pollution perspective, Chilika lagoon’s health status was “excellent,” with a score of 81% during the lockdown and “average,” with a score of 55% prior to the lockdowns (37%, 66%, and 63% in May 2019, Aug 2019, and Aug 2018, respectively). However, for Chilika sediment, the health status was “good,” with a score of 65% in pre-lockdown periods (69%, 56%, and 69% in May 2019, Aug 2019, and Aug 2018, respectively) while the status was “excellent” (81%) during the lockdown.

Similar to many ecosystems, lockdown-induced anthropopause produced a positive outcome for Chilika lagoon in terms of oil pollution. The decline in the TPHC level in the entire Chilika lagoon was substantial and occurred due to a sudden halt in all human activities, which used to be dominated by fishing and tourism. The TPHC decline was much more significant for waters compared with that for sediment. The TPHC values recorded during this crucial period could be considered as the baseline data by researchers in future pollution assessment studies. The method adopted to set the baseline in the present study can be regarded as a benchmark for establishing local baselines for other aquatic ecosystems experiencing similar human footprints. As pollution levels continue to increase worldwide, especially in Southeast Asia, this study is timely as it provides a path forward for producing future ecosystem health report cards for the lagoon. Scientific evidence of the environmental pollution status of four hydro-ecological sectors of the lagoon when compared against the baselines would be helpful for the managers and policymakers to formulate appropriate action plans, such as deregistration of boats on fitness grounds (oil spillage), tariff to tourism sectors for using leaky boats, advocating for the usage of electric boats, etc. Although the results show the immediate impact of the lockdown, further monitoring, at least on a monthly or seasonal basis, would reveal the rate of change of the TPHC level with respect to time or increases in human activities.

CRediT authorship contribution statement

Prasannajit Acharya: Field data collection and instrumental analysis, Lab work, TPHC data analysis, writing
Pradipita R. Muduli: Sample analysis, Conceptualization, Data analysis, Writing, Editing, Overall supervision
Deepak R. Mishra: Conceptualization, Data analysis, Writing, Editing, Reviewing
Abhishek Kumar: Data analysis, writing, editing, reviewing
Vishnu Vardhan Kanuri: TPHC data analysis, writing, editing, statistical analysis, Data interpretation
Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A: Supplementary data

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