Changes in physicochemical, heavy metals and air quality linked to spot *Aplocheilus panchax* along Mahanadi industrial belt of India under COVID-19-induced lockdowns

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Abstract Positive effects of COVID-19-induced lockdowns on environment are well documented although pre-planned experiments for such analyses and appearance of fish species are lacking. We hypothesize that spotting the fish *Aplocheilus panchax* along the industrial belt of Mahanadi River near Cuttack in a never seen manner could be due to the regenerated environment. Heavy metals, water and air qualities along with spotting *A. panchax* in up, mid and downstream of Mahanadi River near Jagatpur industrial basins were analysed during pre-(end of March 2020) and after 60 days of lockdowns (last week of May 2020). An overall 45, 61, 79, 100, 97 and 90% reduction of Fe, Cu, Ni, Cd, Pb and Zn was recorded in the studied area after lockdowns, respectively. Similarly, dissolved oxygen and pH were elevated by 26 and 7%, respectively. Water temperature, conductivity and total dissolved solute levels were reduced by 7, 46 and 15%, respectively, which were again elevated during post-lockdowns during 2021 as observed from the Landsat-8 OLI satellite data. Air NO₂, SO₂, NH₃, PM₂.₅, PM₁₀ and CO levels were alleviated by 58.75, 80.33, 72.22, 76.28, 77.33 and 80.15%, respectively. Finally, for the first time, about 12 *A. panchax* fish per 100 m shore line in the area were spotted. The observed lockdown-induced environmental healing at the studied area could contribute to the appearance of *A. panchax* in the study site and therefore a stringent environmental audit is suggested during post-COVID-19 periods to make the regenerated environmental status long lasting in such habitats.

Keywords *Aplocheilus panchax* · COVID-19-induced lockdown · Environmental regeneration · Fish reappearance · Heavy metal pollution · Stringent global environmental audit
Introduction

An intricate positive relation between Coronavirus (SARS-CoV-2) Disease (COVID-19) outbreak-induced lockdowns or shutdowns and environmental auto-regeneration is reportedly documented (Arora et al., 2020; Child, 2020; Mack, 2020; Mousazadeh et al., 2021; Saadat et al., 2020). For the first time, ultra-modern human species lifted the weight of nurturing nature by doing nothing but only keeping themselves off the street and locked inside home to get rid of COVID-19 infection. Our previous studies indicate that the health of ecosystems and associated events in most of the urban and sub-urban areas were unexpectedly damaged due to high anthropogenic, vehicular and industrial activities or climate change issues (Bal et al., 2021; Paital et al., 2015, 2016; Paital, 2016a, 2016b; Chainy et al., 2016). In the former case, it is pertinent that environmental audits were not stringent in India and in many other countries (Supplementary Fig. S1) to keep the habitats pollution free near industrial belts. Perhaps for this reason, drastic diminish in fossil fuel burning by industry and vehicular operations under COVID-19-induced lockdowns was responsible for the reduction of water, air and noise pollution across many cities (Chauhan & Singh, 2020; Jayaweera et al., 2020; Paital, 2020; Paital & Agrawal, 2020; Paital et al., 2020; Panda et al., 2020; Panda et al., 2020).

Industries are the only major sources of effluent discharges into many river basins (Mohanty & Samanta, 2016). Although all industries usually went through environmental audit, it seems execution of environmental protection rules are not performed accurately. It clearly indicates that environmental audit need be transparent for industrial effluent discharges as a result water bodies and air will not be polluted and, this could be the fact in places where pollution is pre-dominant. So, adaption of local, national and global stringent environmental audit is required for the sustenance of the everlasting regenerated nature that has been noticed under COVID-19-induced lockdowns (Bhumireddy et al., 2021; Coccia, 2021; Dutheil et al., 2020; Pei et al., 2021; Sharma et al., 2021). Post-COVID-19 time period were the best to employ such stringent environmental audit rules because all the industries opened and started working aggressively to gain the loss they have incurred during shutdowns (Arora et al., 2020; Child, 2020; Das et al., 2021; Gholizadeh et al., 2016; Mack, 2020; Saadat et al., 2020; Yunus et al., 2020). As a result, it leads to the pollution level back as observed in pre-COVID-19 timings. So, focusing on how to handle the current situation and planning for the post-COVID-19 timings seems to be the need of the hour. Therefore, to have ever lasting nurtured nature, amendment of such stringent action will lead to pollution-free environment. First-hand information from field studies always provide clues, therefore, water quality (physicochemical and heavy metal distribution) of Mahanadi River, and air quality in the nearby industrial area has been studied along with spotting a fish species Aplocheilus panchax in pre- and during COVID-19-induced lockdown periods in 2020. The data could be used as spotlight to formulate post-COVID environmental policies in several places (Mohanty & Samanta, 2016).

Data on pre-designed sampling for analyses of environmental health of any ecosystem just before implementation and after substantial period of full and stringent lockdowns, and its effects on the inhabitants are lacking (Arora et al., 2020; Child, 2020; Das et al., 2021; Gholizadeh et al., 2016; Mack, 2020; Saadat et al., 2020; Yunus et al., 2020). It is because all such studies are performed after observing COVID-19-induced lockdowns and its impact on self-nurtured nature (Arora et al., 2020; Child, 2020; Mack, 2020; Saadat et al., 2020). While conducting such analyses at the highly polluted basin of Mahanadi river near Jagatpur industrial basin of the 1000 years old Cuttack city (20°30’14.5” N 85°54’14.5” E), we have observed abundance in three stations (up, down and mid basin) at Mahanadi River near Cuttack Jagatpur industrial area of India during the last week of March and May 2020. Therefore, we hypothesize that the lockdown-induced alleviation in pollution could be a reason for the appearance of the fish A. panchax in the study site. To answer the hypothesis, we have analysed the heavy metal contents, water quality, air quality and the fish A. panchax abundance in three stations (up, down and mid basin) at Mahanadi River near Cuttack Jagatpur industrial area of India during the last week of March and May 2020. Also, we have studied the water qualities from the Landsat-8 OLI satellite bands from 2020 to 2021. Results could be useful in environmental toxicology and policy making purpose (Paital & Das, 2021).
Materials and methods

This experiment did not include sacrifice of fish; however, all experimental protocols including counting of fish were done following the Institutional ethical committee guidelines of Odisha University of Agriculture and Technology, Bhubaneswar, India.

Chemicals

All essential analytical grade chemicals for this study were purchased from Sigma-Aldrich Chemical Company, USA and from HiMedia and SD Fine chemicals, Mumbai, India.

Sampling site and their status before and after lockdown

Mahanadi River system is the 3rd largest in the peninsula of India and has a long history of fisheries and agricultural irrigation to the state Chhattisgarh and Odisha, India. It is the largest river in the state of Odisha that serves as the source of domestic water supply to many cities including Sambalpur (population 0.2 million), Cuttack (population 0.5 million, 1000 years old city) and Paradeep (contains a major port of the country and population of 0.15 million) besides many officially undocumented number of rural and minor urban settlements. Additionally, its basin near Choudwar–Jagatpur industrial belt (N: 20° 28′ 34.43″; E: 85° 48′ 15.13″ and N:20°29′46.80″; E:85°53′32.76″) harbours mainly steel, ferroalloys, charge chrome, textile, polythene, plastic, paper and pharmaceutical industries and in return it receives the discharges from these industries (Mohanty & Samanta, 2016).

So, in one hand, all these industries use a major portion of the Mahanadi River water, and on the other hand, they flush the impurities and other effluents into its basin. Effluents from these industries contain many toxic elements including heavy metals and toxic elements although such industries usually possess environmental audits clearance (Mohanty & Samanta, 2016). During January to May every year, this river is always filled with the stagnant water and hence acts as a source of pollution accumulation in the area. Finally, the polluted water is discharged to the Bay of Bengal during rainy season. Noteworthy to mention that water in the above basin of the river is polluted and found to generate several bio-molecular stresses on the inhabitants including a wide range of fishes (Mohanty & Samanta, 2016; Paital, 2016a; Paital et al., 2015, 2016). Keeping in mind the above fact and possibility of reduction in pollution under the imposed lockdowns, the industrial belt of Mahanadi River near Jagatpur industrial belt, Cuttack, was chosen for the sampling site. The locations such as the mouth of canals and study sites before and after the lockdowns were photographed using a camera (Redmi note 5 pro 18 megapixel camera).

Water sampling

Clean opaque polyethylene bottles (500 mL) rinsed with distilled water were used to collect the water samples from three different sites along the Cuttack Industrial belt of Mahanadi River near Jagatpur (approximately from 20°30′14.5″ N 85°54′29.2″ E to 20°28′34.4″ N 85°57′19.3″ E). Jagatpur is considered as the main hub for the industry and the basin water therefore remains polluted throughout the year due to industrial discharges. Anthropogenic discharges also contribute to the pollution in the basin. Therefore, three stations were chosen for the study, i.e. near the Jagatpur industry (Mid-Basin, MB), down the Jagatpur site (Downstream, DS) and before the Jagatpur basin (Up-Stream, US). So the study sites were around the Jagatpur–Madhupatna–Choudwar (approximately from 20°30′14.5″ N 85°54′29.2″ E to 20°28′34.4″ N 85°57′19.3″ E) basin.

Physico-chemical quality analyses of water

Water samples were collected in the last week of March-2020 (pre-COVID-19-induced lockdown time periods) and in the last week of May 2020 (after 2 months of a stringent lockdown period) from MB, DS and US of Mahanadi River. About 500 mL of water samples (below 30 cm deeper from the surface) was collected in opaque plastic bottles and were immediately transported to the field laboratory in dark under ambient temperature (Rath et al., 2021). About 50 mL water was taken at the site in opaque glass bottles in dark and pH, Dissolved Oxygen (DO), Total Dissolved Solids (TDS) and conductivity in water samples were measured with the help of specific electrodes (mp Based Soil and Water Analysis kit, Model 1160, Esico International, New Delhi, India). The temperature of the river water was
measured directly during sampling by using a mini Hg thermometer in °C scale, and pH was measured immediately after collection of water. The electrodes were calibrated using appropriate standards just before measurements.

Heavy metal analyses of water

Elemental (Fe, Cu, Ni, Cd, Pb and Zn) analysis was done by using an inductively coupled plasma atomic emission spectrophotometer (Perkin Elmer, Waltham, Massachusetts, USA, Model no. AVIO 200) modified after Mohanty & Samanta (2016) and Samanta & Paithal (2016). In brief, water samples (~50 mL) were preserved in opaque plastic bottle at −20 °C until analysis. Water samples were mixed with 1% (v/v) HNO₃ prior to elemental analysis. Above samples were filtered using membranes (0.45 mm filter) and were directly used to take atomic absorption spectra. The multi-element standard solutions were prepared at five points and the limits of detection of different samples were set at 0.850, 0.004, 0.035, and 0.001 and 0.0001 μg L⁻¹, respectively. Results were expressed as μg of heavy metal present L⁻¹ water sample.

Landsat-8 OLI data collection and processing

For the comparison of the environmental changes in the study site, data from both in situ results and form Landsat-8 OLI satellite (USGS earth explorer website, USGS, 2015). The Trophic State Index (TSI) of the Mahanadi River near Jagatpur, Cuttack from in situ and satellite data were compared. The in situ data such as Secchi Disk Transparency (SDT) collected from three different sampling stations, i.e. up, mid and downstream of the river at Jagatpur industrial region were used to correlate with the satellite data. ENVI software was used for image processing and analysis of Landsat-8 OLI satellite data. The satellite data were converted to radiance image using the parameter provided in meta data file through Eq. (1) (USGS, 2021a, b).

\[
L = M \ast Q_{cal} + A \tag{1}
\]

“\(L\)” is the cell value as radiance. “\(M\)” is the multiplicative factor in (W/m²sr*m). “\(Q_{cal}\)” is the quantized and calibrated standard pixel values (DN).

The TSI (scale of 0 to 100) of the river generated from SDT data although it can also be derived from other parameters such as total phosphorus and chlorophyll (Carlson, 1977). Based on TSI, the river water was categorized into four groups based on Carlson TSI values such as (1) oligotrophic: clear water (TSI<38), (2) mesotrophic (TSI=38 to 48), (3) eutrophic: turbid water (TSI=49 to 61) and (4) hypereutrophic: highly eutrophic (TSI>61). The relationship between SDT and TSI has been widely used by many researchers for lake and river water studies (Bio et al., 2008; Carlson, 1977). The TSI and SDT relationship is presented in Eq. (2).

\[
\text{TSI(SDT)} = 10(6 - \ln \text{SDT}/\ln2) \tag{2}
\]

The in situ observations were carried out during March and May 2020 and were correlated with satellite data (Fuller & Minnerick, 2007). An algorithm was drawn to estimate STD for the Mahanadi River using Landsat-8 OLI radiance data. The in situ measurements were carried out synchronous to Landsat-8 OLI pass. The relationship between ratio of the Landsat-8 OLI band (band 3: band 4) and SDT was drawn. The analyses to draw the relationship were carried out in linear, exponential, logarithmic, polynomial, power and moving average mode with a coefficient value of \(R²=0.79\) as mentioned in Eq. (3) and supplementary Fig. S1.

\[
\text{SDT} = 0.1739 \exp^{0.0239\text{OLI}3/\text{OLI}4} \tag{3}
\]

Air quality analyses and locating the fish A. panchax

Air quality data such as the levels of NO₂, SO₂, NH₃, PM₂.₅, PM₁₀, CO and O₃ were correlated from the website updated by the Central Pollution Control Board, Government of India (https://app.cpcbcr.com/AQL_India/) by choosing nearby area air station. The data for the entire last week (each day at 12 pm of every day) of March 2020 and May 2020 were compared. Similarly, the average data documented for the above air quality parameters on 29th May 2019 at 12 pm were compared with the data observed on 29th May 2020 at 12 pm. The water sampling dates were correspondingly considered for the air quality data correlation. During sampling, presence of the fish A.
panchax was noticed and subsequently was recorded (random sampling) by using a video camera and still photos were captured using a camera (Redmi note 5 pro 18 megapixel camera). Preliminary analyses of the results were correlated with the appearance of the fish in the river. The fish count was done in 100×3 m² length along the shore line in the study area by employing random sampling method. About 3 m distance from the shore line was chosen to locate them as this fish prefers this area.

Statistics

Results were expressed as mean ± standard deviation (n = 3). Means of different parameters were compared and analysed for differences using Two-way ANOVA (StatPages.org.) followed by Duncan’s new multiple range test. T-test was employed to determine the changes in parameter between before and after lockdown. All numerical data were subjected to Discriminant Function Analyses using the methods described in Samanta & Paital (2016). Difference among the means was considered significant at p < 0.05 level.

Results and discussion

Water and air quality

Many cities have been experiencing heavy pollution during pre-COVID-19 timings and water bodies near industries and cities were found to be the main hub for pollution. The reason could be due to the drainage or discharge of industrial and anthropogenic pollutants into water bodies without/less proper treatment. Instances of loose environmental audit and environmental clearances to industries also have been reported to contribute unprecedented damage to such water ecosystems (Castiglione et al., 2009; Mirabile et al., 2008). As a result, pollution accumulates in rivers and riverine systems (Paital et al., 2018). Keeping in mind about the intensity of pollution, sampling was done in the study site to analyse the effects of industrial effluents in the study site (Fig. 1a).

The observed higher water pollution in the study site (Fig. 1b–d) could be a sensible factor, perhaps for which, the fish A. panchax was not found in the river when it was searched for experiments during 2018–2019 (Panda et al., 2020; Panda et al., 2020). Although some of the studied parameters, especially the levels of heavy metals, were under control during the pre-COVID lockdown times, it was probably enough toxic to the above fish to grow in the study site. The pollution could also be the reason why large scale die-off events have been noticed along the rivers and riverine systems in India including Bay of Bengal and Mahanadi River during pre-COVID-19 timings (Paital et al., 2018, Fig. 1d). Two months of full and stringent lockdown in the study area was resulted in the clear water and associated ecological improvements in industrial canals discharging water into the river (Fig. 1b–k). Clear base of the canal (Fig. 1e), schooling of fish (Fig. f and g), shrinking of the canals discharging polluted water with growth wild plants (indicating increase in biodiversity, Fig. 1h, i and j), and clear water (Fig. 1k) in the mouth of the discharging canals observed in the last week of May 2020 are few of the outcomes of the lockdowns. Probably, this is the first report done with planned experiment that analyses environmental parameters at pre and post-COVID-19 time points indicating the appearance of a species in a niche.

We found that the dissolved oxygen level was increased during lockdowns by 15, 40 and 26% in US, DS and MB, respectively, than pre-lockdown times (Fig. 2a). Similarly, water temperature was also reduced by 4 (in US), 9 (in DS) and 8% in MB regions (Fig. 2b). pH of US and DS area was increased by 12 and 7%, respectively (p < 0.003, Fig. 2c). Water conductivity was drastically reduced by 47 (in both US and DS) and 44% in MB area (Fig. 2d). It could be due to loss of total dissolved solutes by 18 (in US), 15 (in AS) and 11% (in MB) regions during lockdown than pre-lockdown time (Fig. 2e). The changes are drastic and could be exemplary enough to accept the fact that lockdowns had paramount effects on increasing the water quality of Mahanadi River and in other rivers of India and abroad such as Yamuna River of New Delhi and Venice canal of Italy (Paital, 2020; Paital et al., 2020; Patel, et al., 2020). Similar results with or without experimental analyses of the environmental quality were reported (Das et al., 2021; Gholi-zadeh et al., 2016; Paital et al., 2018, 2020; Yunus et al., 2020). For example, the suspended particulate matter in surface water was reduced by 15.9% in the Vembanad Lake, the longest one in India (Yunus et al., 2020). This is possibly due to zero
Fig. 1 Visible ecological changes and spotting the fish *Aplocheilus panchax* in the Jagatpur industrial basin area of Mahanadi at Cuttack, India during COVID-19-induced lockdown. **a** The study area at its basin near Jagatpur which is approximately from 20°30′14.5″ N 85°54′29.2″ E to 20°28′34.4″ N 85°57′19.3″ E, **b** Pre-COVID-19 time period indicates industrial effluent discharge via canals to Mahanadi River especially to the study site, polluted water enters in the near industrial catchment area from industries (white arrows, (c, b, photographed during March 2nd week 2020) and also from city discharging canals making its water sometimes black (red arrow in Fig. c) colour. **d** As a result large scale fish die-off events (red arrow) due to pollution from industrial and anthropogenic activities in Mahanadi and its tributaries have been noticed at its lower basins due to heavy/toxic pollution load (Paital et al., 2018). **e** However, during-COVID-19-induced lockdown periods, it was observed that the base of most of the discharging canals (red arrow) were cleanly visible with clear water as a result decrease in pollution load. **f** Re-appearance of the fish *Aplocheilus panchax* (red arrow) in the studies area was clearly observed. **g** A close view of schooling of fish *A. panchax* is observed in the study area. **h** Also due to less polluted water load in lockdown periods, shrinking and drying (i) of the canals (red arrows) due to lack of discharging industrial effluents were observed followed by clear and visible water in the studied catchment area. **j** At some places where the canal mouths open to the river were also found to be grown with various wild plants and clean water indicating increase in biodiversity in the area. (Fig. 1e–k photographed in last week of May 2020)

effluent discharge into the river as cleanness of its water was observed (Fig. 1 b–j). Perhaps this is the reason why the fish *A. panchax* count during lockdowns was noticed being an average of 12, 8 and 16 numbers per 100×2 m² area at UB, MB and DS, respectively, (Fig. 2f) after the lockdowns are implemented.

Similar data also have been noticed for many other species. Few of such examples are appearance of elephant strolling through roads, deer on street of Japan, whales in Indonesia sea water, peacocks in human habitats at Delhi India, spotting coyotes (that normally timid of traffic) on the Golden Gate Bridge in San Francisco, USA, grazing deer few miles from the White House near Washington homes, wild boars in Barcelona and Bergamo, Italy, wild puma in Santiago, the capital of Chile, peacocks have strutted through Bangor and goats through Llandudno and sheep in Wales, and the most convincingly, crabs and fish in Venice canal of Italy (Loring, 2020; Palait, 2020). They are spotted during lockdowns. The invasion or (re)appearance of such species to human dominant area during lockdowns could be due to the reduction of environmental pollution or due to fewer movements of human beings in the area and the former one is evident from the present study.

It was observed that air quality of the study area was also improved drastically (Fig. 2g). Data indicate that overall air quality parameters such as levels of NO₂, SO₂, NH₃, PM₂.₅ and CO were drastically reduced (*p* ≤ 0.001). The levels of NO₂, SO₂, NH₃, PM₂.₅, PM₁₀ and CO were reduced (*p* < 0.001) by 58.75, 80.33, 72.22, 76.28, 77.33 and 80.15%, respectively in post 2 months lockdowns than pre-COVID-19 study time whereas, O₃ level was increased (*p* < 0.01) in the air (Fig. 2g). Fall of temperature, greenhouse gases, and industrial exhaust especially less release of chlorofluorocarbons could be the reasons behind the rise in Ozone layer in air. Similar results have been noticed in many cities in the studied state Odisha and across the world (Arora et al., 2020; Mack, 2020; Nath et al., 2021; Panda, Mallik, et al., 2020; Panda, Paital, et al., 2020; Saadat et al., 2020; Sahu et al., 2021; Sarin et al., 2021). More particularly, reduction in 60% PM₁₀, 39% PM₂.₅, 52.68% NO₂, 30.35% CO and improvement ≥31% air quality index in New Delhi, India, in March 2020 than April 2020 under COVID-19-induced lockdowns is documented (Mahato et al., 2020). In China, overall environmental pollution level was reduced by 30% in 2020 than 2019 due to 90% reduction in human mobility (Muhammad et al., 2020). Air temperature was also found to be low (*r* = 0.392; *p* < 0.01) during the above timings at Jakarta, Indonesia that had induced positive effects on climate (Panda et al., 2020; Panda, Paital, et al., 2020). In some places in India, the temperature was also found to be reduced from 3 to 5 °C and noise pollution was reduced from 85 to <65dBA (Mandal & Pal, 2020). The most advanced countries such as the USA, Italy and Germany were also found to experience the historical reduction in NO₂ level at least by 25.5% under the lockdowns (Berman & Ebisu, 2020). It is noteworthy to mention that PM₁₅ and NO₂ emissions have an intricate relation with COVID-19 in humans to increase the rate of infection and aggravation (Paital & Agrawal, 2020).

The observed data indicate that air quality on 29th May 2020 was significantly improved as results of lockdowns, as compared to the air quality data noticed on 29th May 2019 at the same study area. Air quality parameters such as emissions of NO₂,
SO₂, NH₃, PM2.5, PM10 and CO were 74.93, 50.30, 40, 94.33, 96.49 and 26.72% lower on last week of May 2020 as compared to the same time period during 2020. In constant, the ozone concentration was 151.50% higher in last week of May 2020 than last week of May 2019 (Fig. 3). Similar data have been observed in different cities throughout the world (Scungio et al., 2021). This provides a clue that the revived nature observed due to COVID-19-induced shutdowns must be considered as spotlight for the protection of nature and natural environments (Paital, 2020).

To compare the water quality data especially SDT with pollution, we have drawn the satellite data of Landsat-8 OLI from 2020 to 2021 matching the time zone of in situ observations. One of the objectives of the present study was to measure the TSI of the Mahanadi River from in situ observation as well as
satellite data. The SDT in the study site during March 2020 was 67.02 ± 2.09, 61.92 ± 3.12, 65.94 ± 3.82 cm, at up, down and mid-basin respectively. Similarly, the data for SDT during May 2020 were 41.91 ± 2.12, 43.72 ± 2.25 and 43.21 ± 3.01 cm at up, down and mid-basin respectively. In the present study both ground truth observed and satellite estimated water quality parameters are analysed. The spatial and seasonal variation in SDT of 2020 was analysed during the summer months (March–May) of 2020–21 to correlate with satellite data. Figure 4a, 1(b) and 1(c) SDT value shows northern, few pockets of central and southern part of the river water is low transparency (0.39 m). This may be due to urban garbage and industrial waste near Jagatpur. The SDT was very low during the summer season due to low volume of water, which increases the pollution level. Figure 4a–c indicates the central part of the river is clean and clear water (0.8 m), whereas the SDT values of 0.45 m in north-western, 0.42 m central and 0.39 m in south-eastern part exhibits low transparency with contaminated water. This may be attributed to mainly, the influx of urban drainage and industrial wastewater into river. The analysis of river water transparency indicates eutrophic to hypereutrophic condition in nature.

Trophic State Index of the Mahanadi River near Jagatpur has been estimated using field observation and satellite data. Figure 5a–c shows the graphical representations of in situ observed TSI. Figure 5a shows the high to low concentration of TSI values (64.02—57.12) followed by Fig. 5b (64.33—56.71) and Fig. 5c (63.8.37—55.17). From the overall observation it is found that TSI value shows the river water is highly polluted and it is eutrophic in nature. The increasing pollution level and algal bloom leads to river water contaminated. Many investigators have been used different optical remote sensing satellite data for the comprehensive study of river water quality, lake water quality and eutrophication, i.e., Landsat-TM (Brezonik et al., 2005; Olmanson et al., 2002; Zhang et al., 2003), Landsat-ETM (Mishra & Garg, 2011), Sentinel-2 (Toming et al., 2016), Landsat-8 OLI (Pahlevan et al., 2014; Trisakti et al., 2017), MODIS (Wu et al., 2009; Knight et al., 2012).

The Landsat-8 OLI satellite data have been used to measure the spatial and seasonal variability of trophic status of the Mahanadi River water during the period of 2020–21. The satellite estimated TSI is presented in Fig. 6a–c. Figure 6a shows that north and north-western part of the river water is in highly polluted (eutrophic to hypereutrophic) condition, whereas the southern and central part of the river is oligotrophic to mesotrophic condition. Similarly, Fig. 6b indicates most of the parts of the river water were eutrophic to hypereutrophic condition except some pockets.
Fig. 4 Interpolated images of the spatial and seasonal distribution of Secchi disk transparency pattern during pre-monsoon season 2020–21 of Mahanadi River near Jagatpur industrial belt at Cuttack, Odisha, India during 2020–2021. SDT during in situ observation in a March 2020, May 2020 and May 2021. The scales are given in X and Y coordinate to describe the location and colour scale is given to indicate the level of SDT values.
Fig. 5 Interpolated images of the spatial and seasonal distribution of trophic state index pattern during pre-monsoon season 2020–21 as observed at Mahanadi River near Jagatpur industrial belt at Cuttack, Odisha, India during 2020–2021. TSI observed during in situ observation in a March 2020, May 2020 and May 2021. The scales are given in X and Y coordinate to describe the location and colour scale is given to indicate the level of SDT values.
of southern part of the river i.e. oligotrophic condition (clear water). Figure 6c exhibits some pockets of north-western part of the river water is polluted (eutrophic condition), whereas rest of the part is clean and clear water (Oligotrophic condition).

Heavy metal distribution

The physico-chemical characteristics and concentrations of various heavy metals in the water samples collected from the three study sites are shown in Table 1. It was noticed that heavy metal (except Fe) concentration was reduced by ≥ 50% in the water at all the stations (Table 1). Particularly, Cu content was reduced by 58, 59 and 65% at US, DS and MB areas, respectively. Similarly, Ni content was reduced by 91, 92 and 59% (US, DS and MB, respectively) in the studied area. The level of Cd was undetectable in lockdown time and similar data was found for Pd in US and DS area, but it was reduced to 93% in the MB area. Notably, Zn content in the water was also reduced by 98% (in US), 90% (in DS) and 86% (in MB) in the studied area (Table 1) in lockdown period than pre-lockdowns timings. Data on effects of lockdowns on heavy metal content in water bodies are scanty. Although the change in heavy metal contents in water bodies as a function of lockdowns is scanty, similar results of the reduction of Cr, Fe, Cu, Zn, Cd, Pb, As, and Se were noticed in coastal industrial city of Tuticorin, South India (Selvam et al., 2020).

Overall results and appearance of A. panchax in the study site

The DFA analyses have confirmed that all parameters taken together or in groups such as the studied environmental parameters or heavy metals have yielded all studied groups into six (before and after lockdown at three sites, Fig. 7). Therefore, all parameters were subjected to change as a function of COVID-19-induced lockdowns. Almost all parameters had a very high standardized coefficient for canonical variables via root 1 to root 4 (Table 2, supplementary (Table S1 and S2)). Therefore, since an overall improvement of the environmental parameters was noticed as a result the fish A. panchax appeared in the river (Fig. 1g, 2f, Fig. 8). It is because this fish prefers clear water in areas with dense growth of rooted or floating macrophytes are available (Beck et al., 2017; ETB, 2020).

Air quality of any area is intricately related to the water and soil quality as far as pollution of the above three habitats are concerned (Manisalidis, 2020). Environmental and geochemical studies have confirmed it. Usually, a positive correlation is observed at the degree of pollution when pollution to any or two of the above inhabitants. In the present study, higher degrees of pollution observed in both air and water during the pre-COVID-19 timing than post or after significant days of lockdowns could contribute to the appearance of many species in the river. It is because; pollution level is intricately related to the health status of the inhabiting organisms. Higher the pollution level leads to more disturbed physiology of organisms (Kjellstrom et al., 2006; Orru et al., 2017). This could be the reasons why the reappearance of the fish A. panchax was noticed after the lockdowns.

The fish A. panchax can survive till the last few mL of water left in ditches for which it is employed to identify palaeo drainage basins for climatic and geological oscillations, biodiversity and evolutionary distribution of biota (Katwate et al., 2018; Manna et al., 2011). The small size (about 2 cm) of the fish is considered as an advantage for such studies. This is a fresh water inhabitants usually survives in water bodes under standard DO, temperature, and other fresh water conditions. This fish is susceptible to water pollution, as they were not available in the above basin on Mahanadi during pre-COVID-19 timings (Panda et al., 2020; Panda et al., 2020). It clearly indicates that the Mahanadi River at the studied basins remains polluted although some of the toxic heavy metals are found to be under standard level (Mohanty & Samanta, 2016) (Table 1). The growth period of this fish to reach adulthood is around 2 months (Katwate et al., 2018; Manna et al., 2011). Hence, healthy fish could be migrated to this area from the non-polluted sites and/or the fish could reproduce and fingerlings would have been grown to reach adulthood.

Environmentalists have been advocating that the self-regenerated nature will be degenerated quickly
in post-COVID-19 phases because of the massive re-opening of the industries and vehicular exhaustion. The industries will try to cover up the loss they had bear during the shutdowns in post-COVID-19 phases (Aceti et al., 2020; Drefahl et al., 2020; Nissen et al., 2020; Sahlol et al., 2020). Mahanadi River system is the 3rd largest in the peninsula of India that serves as the source of domestic water supply to

Table 1 Heavy metal distribution before and after COVID-19 lockdowns in Mahanadi industrial river basin at Cuttack, India

| Metal | Time | Up-stream | Down stream | Mid-basin | WHO* | ICMR** | BSI# |
|-------|------|-----------|-------------|-----------|------|--------|------|
| Fe    | BL   | 0.13 ± 0.001c | 0.15 ± 0.002c | 0.56 ± 0.005a | 1 | 1 | 1 |
|       | AL   | 0.073 ± 0.000c | 0.083 ± 0.000d | 0.30 ± 0.002b | 1 | 1 | 1 |
| Cu    | BL   | 0.76 ± 0.02b  | 0.78 ± 0.061b  | 0.89 ± 0.043a  | 2 | 1.5 | 1.5 |
|       | AL   | 0.32 ± 0.01c  | 0.31 ± 0.01c   | 0.31 ± 0.01c   | 2 | 1.5 | 1.5 |
| Ni    | BL   | 0.011 ± 0.000b | 0.013 ± 0.002a  | 0.015 ± 0.001a  | 0.02 | BDL | BDL |
|       | AL   | 0.001 ± 0.000d | 0.001 ± 0.002d  | 0.008 ± 0.001c  | 0.02 | BDL | BDL |
| Cd    | BL   | 0.0007 ± 0.000b | 0.0009 ± 0.000a | 0.0010 ± 0.000a | 0.003 | 0.001 | 0.01 |
|       | AL   | BDL         | BDL          | BDL          | 0.003 | 0.001 | 0.01 |
| Pb    | BL   | 0.004 ± 0.000c | 0.009 ± 0.000a | 0.009 ± 0.001a | 0.01 | 0.1 | 0.05 |
|       | AL   | BDL         | BDL          | BDL          | 0.009 ± 0.000b | 0.01 | 0.1 | 0.05 |
| Zn    | BL   | 0.07 ± 0.001b  | 0.07 ± 0.002b  | 0.14 ± 0.020a  | 5 | 15 | 15 |
|       | AL   | 0.001 ± 0.000d | 0.001 ± 0.000d | 0.02 ± 0.000d | 5 | 15 | 15 |

Data on heavy metal distribution (µL⁻¹) are represented for three consecutive day readings in up, down and mid-stream of the Mahanadi industrial belt at Cuttack. Before lockdown (BL, pre-COVID-19 time) and after lockdown (AL, during COVID-19 timing) sampling time difference was about 60 days. MANOVA was employed to know the significant difference among the mean values within a set (as on 23.05.2020) and before COVID-19 period. Mean values are considered as significantly different (assigned with different superscript) from each other at \( p \leq 0.04 \) level

* limit of heavy metals set by the World Health Organisation, ** limit of heavy metals set by the Indian Council of Medical Research, New Delhi, India, # limit of heavy metals set by the British Standards Institution

Fig. 7 Discriminant function analysis of environmental parameters and heavy metals as a function of COVID-19 timings and site of water stream in relation to the industrial belt in Mahanadi River. Environmental parameters (taken alone in figure a and heavy metal levels (taken alone in figure b) in Mahanadi River during pre-COVID-19 and during COVID-19 period (after about 2 months of lockdown) periods in the industrial belt in Mahanadi River, near Jagatpur industrial belt, Cuttack, India. Figure a clearly indicates that environmental factors noticeably and strongly contribute to separate the studied groups into six (before and after lockdowns in COVID-19 in three sampling sites i.e. in up, down and mid-basin of industrial belt of Mahanadi River), whereas, when heavy metals are taken alone (b) or together with environmental factors (c), up and down stream shows an unclear separation as compared to the distinct separation of the other groups as described above. Overall, all parameters have a strong contribution to separate the studies variance into clear six groups indicating their changes in relation to COVID-19-induced lockdowns. BL-before lockdown, AL-after lockdown, UP-upstream, DS-downstream, MS-mid basin
many cities including Sambalpur (0.2 million population), Cuttack (0.5 million population) and Paradeep (a major port of the country and 0.15 million population) besides many officially undocumented number of rural and minor urban settlements. However, its basin near Choudwar-Jagatpur industrial belt is used to supply water to mainly steel, ferroalloys, charge chrome, textile, polythene, plastic and paper and pharmaceutical industries. Use of water from the river and flushing their effluents containing many pollutants in turn are the main source of pollution in Mahanadi River (Mohanty and Samanta, 2016, Panda et al., 2020; Panda et al., 2020). Therefore, stringent environmental audits need to be employed to maintain the revived biodiversity in post-lockdown periods (Arora et al., 2020; Mirabile et al., 2008; Samanta & Paital, 2016). In India, the environmental clearance from the governing body i.e. the Central Pollution Control Board states that the applications received and approval given for industrial activities are highly stringent and none of the industries violates them (Supplementary Fig. S2). If it is true in India, and in other countries, then the environment would not be polluted, but the increasing trend in environmental pollution raises finger on the transparency in environmental audit.

Stringent environmental audit to implement “pollution clearance regulations” and implementation of “strict environmental safety and precautions” is needed during the post-COVID-19 periods. It would result in improving natural sparkling in water bodies to supply unpolluted water to drink and clean air to breathe. The reduction in the prevailing pollution from pre-lockdown to post-lockdown phases strongly suggests that local, institutional, national

Table 2 Standardized coefficient for canonical variables of environmental parameters and heavy metals as a function of COVID-19 timings and site of water stream in relation to the industrial belt in Mahanadi River

| Parameters | Root 1 | Root 2 | Root 3 | Root 4 | Root 5 |
|------------|--------|--------|--------|--------|--------|
| DO         | −0.2   | 0.442  | 0.889  | −1.2205 | 1.89164 |
| Temp       | −0.4   | 0.318  | −1.385 | −0.3416 | 1.16639 |
| pH         | −4.0   | 0.717  | −0.995 | −0.2967 | −0.63521 |
| Conductivity | −0.9  | 2.049  | 0.915  | −0.5242 | −0.80021 |
| TDS        | −1.3   | 0.260  | 0.375  | −0.2428 | −0.51262 |
| Fe         | 7.0    | −0.592 | −0.713 | −0.6565 | −0.46642 |
| Cu         | 1.1    | −0.851 | −1.731 | 0.3770  | 2.78746 |
| Ni         | 5.5    | −0.288 | 0.309  | 0.6369  | −2.22165 |
| Cd         | −3.7   | 0.479  | 0.071  | 0.4343  | 0.39227 |
| Pb         | 1.4    | −0.119 | −0.893 | −0.4383 | 0.68407 |
| Zn         | −0.8   | −0.156 | 0.984  | 0.1687  | −2.00592 |
| EV         | 150,933.3 | 8475.336 | 3034.573 | 172.6590 | 81.64398 |
| CP         | 0.9    | 0.980  | 0.998  | 0.9995  | 1.00000 |

Environmental parameters and heavy metals as a function of COVID-19 timings (pre and during COVID-19 timings) and site (up, mid and downstream of Mahanadi River industrial belts near Jagatpur, Cuttack are included in the DFA analyses. The bold data indicate their significant contribution in segregating the groups distinctly as a function of the variable. DO—dissolved oxygen, Temp—temperature, TDS—total dissolved solid, EV—Eigenvalue, CP—cumulative proportion.

Fig. 8 Reappearance of the fish Aplocheilus panchax, in Mahanadi River polluted patch near Jagatpur industrial belt. Arrow indicates the fish schooling after 2 months of lockdown due to the reduction in pollution.
and international bodies must join hands to implement strict audit system for industries, anthropogenic and vehicular operation that act as the measure sources of pollution. Probably in few counties such as India, implementation of such stringent rules has been started after the mishap occurred with a massive leak of styrene gas at an LG Polymer plant in Visakhapatnam early on Thursday i.e. 7th May 2020 which had killed 11 people and affected around 1100 people along with many environmental crises. The Central Pollution Control Board of India has directed all industries and state pollution control boards for a “good operable conditions” that include monitoring the deployment of pollution control equipment and effluent treatment plants, including safety equipment and machineries, and connectivity of sewers should be kept in before resuming operations at post-lockdown time. The board also issued a set of instructions to all pollution control boards and centres to ensure all units to undertake a “proper safety and hazard audit” before they start operations after the lockdowns that had to be ended on 31st May 2020 after the first wave of COVID-19 hit the country. Similar steps by all nations need to be taken on urgent basis. Interference of international bodies in such environmental intervention programme must be highly solicited (Arora et al., 2020; Child, 2020; Das et al., 2021; Gholizadeh et al., 2016; Mack, 2020; Saadat et al., 2020; Yunus et al., 2020). Therefore, the world must put forth steps for the long terms maintenance of the self-regenerated environment in post COVID-19 periods before nature bounce back to experience the pre-COVID-19 time pollution (Arora et al., 2020).

Conclusion

For the first time the reappearance of the fish A. panchax in Mahanadi River industrial basins near Cuttack city was documented and it was solely due to the COVID-19 lockdown induced reduction in water pollution including heavy metals. This was clear from the field and images obtained from Landsat-8 OLI satellite bands from 2020 to 2021. Drastic diminish in effluent discharge from industries has contributed to the observed reduction in water pollution in many water bodies across the globe. It clearly indicates that environmental audit has been not transparent, so very stringent implementation of environmental audit with follow up action is suggested during post-COVID-19 periods in order to sustain the long lasting regenerated nature (Fig. 9). Intervention of international agreements and involvement of international, national, institutional and local bodies are highly encouraged.
Otherwise, the planet will miss the chance to recover and take control over such self-regenerated environment and it would still wait for another COVID-19 outbreak for the revival of nature.

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Declarations

Conflict of interests  The authors have not disclosed any competing interests.

References

Aceti, A., Margarucci, L. M., Scaramucci, E., et al. (2020). Serum S100B protein as a marker of severity in Covid-19 patients. *Science and Reports*, 10, 18665. https://doi.org/10.1038/s41598-020-75618-0

Arora, S., Bhaumikhandi, K. D., & Mishra, P. K. (2020). Coronavirus lockdown helped the environment to bounce back. *Science of the Total Environment*, 742, 140573. https://doi.org/10.1016/j.scitotenv.2020.140573

Bala, A., Panda, F., Pati, S. G., Das, K., Agrawal, P. K., & Paital, B. (2021). Modulation of physiological oxidative stress and antioxidant status by abiotic factors especially salinity in aquatic organisms. *Comparative Biochemistry and Physiology C*. https://doi.org/10.1016/j.cbpc.2020.108971

Beck, S. V., Carvalho, G. R., Barlow, A., et al. (2017). Plio-Pleistocene phylogeography of the southeast asian blue panxhax killifish, *Aplocheilus panxch*, *Plos One*, 12(7), e0179557. https://doi.org/10.1371/journal.pone.0179557

Berman, J. D., & Ebisu, K. (2020). Changes in US air pollution during the COVID-19 pandemic. *Science of Total Environment*, 739, 139864. https://doi.org/10.1016/j.scitotenv.2020.139864

Bhumireddy, J., & Nuvvula, M. S. K. S. (2021). Challenges and possible solutions in dental practice during and post COVID-19. *Environmental Science and Pollution Research*, 28, 1275–1277. https://doi.org/10.1007/s11356-020-10983-x

Bio, A., Couto, A., Costa, R., Prestes, A., Vieira, N., & Valente, A. (2008). Effects of fish removal in the Furnas Lake, Azores. *Arquipelago: Life and Marine Sciences*, 25, 77–87.

Brezonik, P., Menken, K. D., & Marvin, B. (2005). Landsat based remote sensing of lake water quality characteristics, including chlorophyll and colored dissolved organic matter (CDOM). *Lake and Reservoir Management*, 21(4), 373–382.

Carlson, R. E. (1977). A trophic state index for lakes. *Limnology Oceanography*, 22(2), 361–369.

Castiglione, S., Todeschini, V., Franchin, C., Torrigiani, P., Gastaldi, D., Cicatelli, A., Rinaudo, C., Berta, G., Biondi, S., & Lingua, G. (2009). Clonal differences in survival capacity, copper and zinc accumulation, and correlation with leaf polyamine levels in poplar: A large-scale field trial on heavily polluted soil. *Environmental Pollution*, 157(7), 2108–2117. https://doi.org/10.1016/j.envpol.2009.02.011

Chainy, G. B. N., Paital, B., & Dandapat, J. (2016). An overview of seasonal changes in oxidative stress and antioxidant defence parameters in some invertebrate and vertebrate species. *Scientifica*, 6126570, 1–8. https://doi.org/10.1155/2016/6126570

Chakraborty, I., & Maity, P. (2020). COVID-19 outbreak: Migration, effects on society, global environment and prevention. *Science of the Total Environment*, 729, 138882. https://doi.org/10.1016/j.scitotenv.2020.138882

Chauhan, A., & Singh, R. P. (2020). Decline in PM2.5 concentrations over major cities around the world associated with COVID-19. *Environ Res*, 187, 109634. https://doi.org/10.1016/j.envres.2020.109634

Child D (2020) The positive impacts on the environment since the coronavirus lockdown began. (2020). Retrieved 21, Mar 2021 from https://www.standard.co.uk/news/world/positive-impact-environment-coronavirus-lockdown-a4404751.html

Coccia, M. (2021). Effects of the spread of COVID-19 on public health of polluted cities: Results of the first wave for explaining the déjà vu in the second wave of COVID-19 pandemic and epidemics of future vital agents. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-020-11662-7

Das, S., Kaur, S., & Jutla, A. (2021). Earth observations based assessment of impact of COVID-19 lockdown on surface water quality of buddha nala, Punjab India. *Water*, 13, 1363. https://doi.org/10.3390/w13101363

Drefahl, S., Wallace, M., Mussino, E., et al. (2020). A population-based cohort study of socio-demographic risk factors for COVID-19 deaths in Sweden. *Nature Communications*, 11, 5097. https://doi.org/10.1038/s41467-020-18926-3

Dutheil, F., Baker, J. S., & Navel, V. (2020). COVID-19 and air pollution: The worst is yet to come. *Environmental Science and Pollution Research*, 27, 44647–44649. https://doi.org/10.1007/s11356-020-11075-6

ETB (2020) Audit must for reopening of plants: Pollution Board. (2020). Retrieved 18, Mar 2021 from https://economictimes.indiatimes.com/news/politics-and-nation/
audit-must-for-reopening-of-plants-pollution-board/articleleshow/75635878.cms

Fuller LM, Minnerick RJ (2007) Predicting water quality by relating secchi disk transparency and chlorophyll-a measurement to Landsat satellite imagery for Michigan Inland Lakes 2001–2006. Fact sheet 2007–3022, U.S. Geological Survey, Science for Changing World.

Gholizadeh, M. H., Melesse, A. M., & Reddi, L. (2016). A comprehensive review on water quality parameters estimation using remote sensing techniques. *Sensors, 16*, 1298. https://doi.org/10.3390/s16081298

Jayaweera, M., Perera, H., Gunawardana, B., & Manatunge, J. (2020). Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy. *Environmental Research, 188*, 109819. https://doi.org/10.1016/j.envres.2020.109819

Katwate, U., Kumkar, P., Britz, R., et al. (2018). The identity of *Aplocheilus andamanicus* (Köhler, 1906) (Teleostei: Cyprinodontiformes), an endemic Killifish from the Andaman Islands, with notes on Odontopsis armata van Hasselt. *Zootaxa, 4382*(1), 159–174. https://doi.org/10.11646/zootaxa.4382.1.6

Knight, J. F., & Voth, M. L. (2012). Application of MODIS imagery for intra-annual water clarity assessment of minnesota lakes. *Remote Sensing, 4*(7), 2181–2198.

Loring K (2020) In San Francisco, coyotes are your wildest neighbors (2020). Retrieved 18, Mar 2020 from https://www.kalw.org/post/san-francisco-coyotes-are-your-wildest-neighbors

Mack E (2020) Global coronavirus shutdowns let the environment breathe a bit easier. Retrieved 18, Mar 2020 from https://www.cnet.com/news/global-coronavirus-shutdowns-let-the-environment-breathe-a-bit-easier/

Mahato, S., Pal, S., & Ghosh, K. G. (2020). Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi India. *Science of the Total Environment, 730*, 139086. https://doi.org/10.1016/j.scitotenv.2020.139086

Mandal, I., & Pal, S. (2020). COVID-19 pandemic persuaded lockdown effects on environment over stone quarrying and crushing areas. *Science of the Total Environment, 732*, 139281. https://doi.org/10.1016/j.scitotenv.2020.139281

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: A review. *Frontiers in Public Health, 20*(8), 14. https://doi.org/10.3389/fpubh.2020.00014

Manna, B., Aditya, G., & Banerjee, S. (2011). Habitat heterogeneity and prey selection of *Aplocheilus Panchax*: An indigenous larvivorous fish. *Journal of Vector Borne Diseases, 48*(3), 144–149.

Mirabile D, Hodge J, Pearson S, Wilding J, Essing A, Rutarova P, Kozarzsczuk M, Charissou AM, Jourdain MJ (2008) Most appropriate treatment to control environmental impact of effluents in iron and steel industry. European Commission, Brussels. ISSN 1018–5593, ISBN 978–92–79–07650–3

Mishra, A. K., & Garg, N. (2011). analysis of trophic state index of Nainital Lake from landsat-7 ETM data. *Journal of Indian Society Remote Sensing, 39*(4), 463–471.

Mishra, A. K., & Garg, N. (2011). Critical review on the unresolved dichotomy. *Sensors, 16*, 1298. https://doi.org/10.3390/s16081298

Mousazadeh, M., Paiyal, B., Naghdali, Z., et al. (2021). Positive environmental effects of the coronavirus 2020 episode: a review. *Environment Development and Sustainability, 2*(9), 12738–12760.

Muhammad, S., Long, X., & Salman, M. (2020). COVID-19 pandemic and environmental pollution: A blessing in disguise? *Science of the Total Environment, 728*, 138820. https://doi.org/10.1016/j.scitotenv.2020.138820

Nath, J., Panda, S., Patra, S. S., Ramasamy, B., & Trupiti, D. (2021). Variation of black carbon and particulate matter in Bhubaneswar during the pre-monsoon: Possible impact of meteorology and COVID-19 lockdown. *Current Science, 120*(2), 313.

Nissen, K., Krambrich, J., Akaberi, D., et al. (2020). Long-distance airborne dispersal of SARS-CoV-2 in COVID-19 wards. *Science and Reports, 10*, 19589. https://doi.org/10.1038/s41598-020-76442-2

Olmanson LG, Bauer ME, Brezonik PL (2002) Use of Landsat imagery to develop a water quality atlas of Minnesota's 10,000 lakes. Proceedings of FIEOS, Conferences/Land Satellite Information IV/ISPRS Commission I. Washington, D.C.

Orru, H., Ebi, K. L., & Forsberg, B. (2017). The interplay of climate change and air pollution on health. *Current Environment Health Reports, 4*(4), 504–513. https://doi.org/10.1007/s40572-017-0168-6

Pahlevan, N., Lee, Z., Wei, J., Schaaf, C. B., Schott, J. R., & Berk, A. (2014). On-orbit radio-metric characterization of OLI (Landsat-8) for applications in aquatic remote sensing. *Remote Sensing of Environment, 154*, 272–284.

Paial, B. (2016). Full speed ahead to the city on the hill. *Science, 352*(6288), 886–889. https://doi.org/10.1126/science.aag1520

Paial, B. (2016). News at a glance. *Science, 352*(6290), 1148–1150. https://doi.org/10.1126/science.352.6290.1148

Paial, B., Bal, A., Rivera-Ingraham, G. A., & Lignot, J. H. (2018). Increasing frequency of large-scale die-off events in the Bay of Bengal: Reasoning, perceptive and future approaches. *Indian Journal of Geo-Marine Sciences, 47*(11), 2135–2146.

Paial, B., & Agrawal, P. K. (2020). Air pollution by NO2 and PM2.5 explains COVID-19 infection severity by overexpression of angiotensin-converting enzyme 2 in respiratory cells: a review. *Environmental Chemistry Letters, 19*(1), 25–42. https://doi.org/10.1007/s10311-020-01091-w

Paial, B. (2020). Nurture to nature via COVID-19, a self-regenerating environmental strategy of environment in global context. *Science of the Total Environment, 729*, 139088. https://doi.org/10.1016/j.scitotenv.2020.139088

Paial, B., & Das, K. (2021). Spike in pollution to ignite the bursting of COVID-19 second wave is more

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dangerous than spike of SAR-CoV-2 under environmental ignorance in long term: A review. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-15915-x

Paital, B., Das, K., & Parida, S. K. (2020). Inter nation social lockdown versus medical care against COVID-19, a mild environmental insight with special reference to India. *Science of the Total Environment*, 728, 138914. https://doi.org/10.1016/j.scitotenv.2020.138914

Paital, B., Das, S., & Dutta, S. K. (2015). Biochemical and environmental insights of declining vulture population in some Asian countries. *Current Trends in Biotechnology and Pharmacy*, 9(4), 389–410.

Paital, B., Panda, S. K., Hati, A. K., et al. (2016). Longevity of animals under reactive oxygen species stress and disease susceptibility due to global warming. *World Journal of Biological Chemistry*, 7(1), 110–127. https://doi.org/10.4331/wjbc.v7.i1.110

Panda, S., Mallik, C., Nath, J., et al. (2020a). A study on variation of atmospheric pollutants over Bhubaneshwar during imposition of nationwide lockdown in India for the COVID-19 pandemic. *Air Quality, Atmosphere and Health*, 14(1), 97–108.

Panda, S., Paital, B., & Mohapatra, S. (2020b). CQD@γ-Fe2O3 multifunctional nanoprobe for selective fluorescence sensing, detoxification and removal of Hg(II). *Colloid and Surfaces A: Physicochemical and Engineering Aspects*, 589, 124445. https://doi.org/10.1016/j.colsurfa.2020.124445

Patel, P. P., Mondal, S., & Ghosh, K. G. (2020). Some respite for India’s dirtiest river? Examining the Yamuna’s water quality at Delhi during the COVID-19 lockdown period. *Science of the Total Environment*, 744, 140851. https://doi.org/10.1016/j.scitotenv.2020.140851

Pei, L., Wang, X., Guo, B., et al. (2021). Do air pollutants as well as meteorological factors impact corona virus disease 2019 (COVID-19)? Evidence from China based on the geographical perspective: *Environ Sci Pollut Res*. https://doi.org/10.1007/s11356-021-12934-6

Rath, S., Bal, A., & Paital, B. (2021). Heavy metal and organic load in Haripur creek of Gopalpur along the Bay of Bengal, east coast of India. *Environmental Science and Pollution Research International*, 28(22), 28275–28288. https://doi.org/10.1007/s11356-021-12601-w

Saadat, S., Rawtani, D., & Hussain, C. M. (2020). Environmental perspective of COVID-19. *Science of the Total Environment*, 728, 138870. https://doi.org/10.1016/j.scitotenv.2020.138870

Sahol, A. T., Yousri, D., Ewees, A. A., et al. (2020). COVID-19 image classification using deep features and fractional-order marine predators algorithm. *Journal of Advances in Science and Reports*, 10, 15364. https://doi.org/10.1038/s41598-020-71294-2

Sahu, S. K., Mangaraj, P., Beig, G., Tyagi, B., Ticle, S., & Vinoj, V. (2021). Establishing a link between fine particulate matter (PM2.5) zones and COVID-19 over India based on anthropogenic emission sources and air quality data. *Urban Climate*, 38, 100883. https://doi.org/10.1016/j.uclim.2021.100883

Samanta, L., & Paital, B. (2016). Effects of seasonal variation on oxidative stress physiology in natural population of toad Bufo melanostictus; Clues for analysis of environmental pollution. *Environmental Science and Pollution Research*, 23(22), 22819–22831. https://doi.org/10.1007/s11356-016-7481-8

Sarin, T. S., Vinoj, V., Swain, D., Landu, K., & Suhas, E. (2021). Aerosol induced changes in sea surface temperature over the Bay of Bengal due to COVID-19 lockdown. *Frontiers in Marine Science*, 8, 648566. https://doi.org/10.3389/fmars.2021.648566

Scungio, M., Crognaile, S., Lelli, D., et al. (2021). Characterization of the bioaerosol in a natural thermal cave and assessment of the risk of transmission of SARS-CoV-2 virus. *Environmental Geochemistry and Health*. https://doi.org/10.1007/s10653-021-00870-w

Selvam, S., Jesuraja, K., Venkatramanan, S., Chung, S. Y., Roy, P. D., Muthukumar, P., & Kumar, M. (2020). Imprints of pandemic lockdown on subsurface water quality in the coastal industrial city of Tuticorin, South India: A revival perspective. *Science of the Total Environment*, 738, 139848. https://doi.org/10.1016/j.scitotenv.2020.139848

Sharma, G. D., Bansal, S., Yadav, A., et al. (2021). Meteorological factors, COVID-19 cases, and deaths in top 10 most affected countries: An econometric investigation. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-12668-5

Toming, K., Kutser, T., Laas, A., Sepp, M., Paavel, B., & Noges, T. (2016). First experiences in mapping lake water quality parameters with Sentinel-2 MSI Imagery. *Remote Sensing*, 8(8), 640. https://doi.org/10.3390/rs8080640

Tosepu, R., Gunawan, J., Effendy, D. S., Ahmad, O. A. I., Lestari, H., Bahar, H., & Asfian, P. (2020). Correlation between weather and Covid-19 pandemic in Jakarta Indonesia. *Science of the Total Environment*, 725, 138436. https://doi.org/10.1016/j.scitotenv.2020.138436

Trisakti, B., Suwargana, N., & Parsa, I. M. (2017). Water clarity mapping in Kerinci and Tondano lake waters using Landsat 8 data. *Int J Rem Sens Earth Sci*, 12(2), 117–124.

USGS earth explorer (2015) Landsat-8. Retrieved, 25 Oct 2021 from http://earthexplorer.usgs.gov.

USGS, 2021b. USGS EROS Archive-Sentinel-2. Retrieved, 19 Oct 2021b from https://www.usgs.gov/cyvors/eros/science/usgs-eros-archive-sentinel-2?qt-science_center_objects=0#qt-science_center_objects.

USGS (2021a). Retrieved, 25 Oct 2021a from https://www.usgs.gov/core-science-systems/nl/landsat/using-usgs-landsat-level-1-data-product.

Wu, M., Zhang, W., Wang, X., & Luo, D. (2009). Application of MODIS satellite data in monitoring water quality parameters of Chaohu Lake in China. *Environmental Monitoring and Assessment*, 148(1–4), 255–264.

Yunus, A. P., Masago, Y., & Hijikata, Y. (2020). COVID-19 and surface water quality: Improved lake water quality during the lockdown. *Science of the Total Environment*, 731, 139012. https://doi.org/10.1016/j.scitotenv.2020.139012

Zambrano-Monserrat, M. A., Ruan, M. A., & Sanchez-Alcalde, L. (2020). Indirect effects of COVID-19 on the
environment. *Science of the Total Environment, 728*, 138813. https://doi.org/10.1016/j.scitotenv.2020.138813

Zhang, Y., Pulliainen, J., Koponen, S., & Hallikainen, M. (2003). Empirical algorithms for secchi disk depth using optical and microwave remote sensing data from the Gulf of Finland and the Archipelago Sea. *Boreal Environment Research, 8*, 251–261.

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