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RESEARCH ARTICLE

Pre-to-post COVID-19 lockdown and their environmental impacts on Ghoghla beach and Somnath beach, India

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Abstract

Environmental impact of COVID-19 imposed lockdown (2020) and the new normal condition (2021) on two different beaches of India (Ghoghla beach, Diu and Somnath beach, Veraval) were compared with the pre-lockdown era, 2013. The lockdown phase favored the natural restoration of the beaches and showed infinitesimal values of the parameters tested when compared with the pre-lockdown regime. However, the new normal situation in 2021 opened up the accessibility of these beaches to the tourists and pilgrims resulting in significant changes of water quality. The release of diluted sewage mixed with freshwater from the Somnath town to the sea has led to the drastic change in beach water quality. The mean cadmium concentration increased drastically in beach waters (Ghoghla: 1.35, 0.28 and 7.09 µg/L; Somnath: 0.45, 0.28 and 0.58 µg/L) during pre-to-post lockdown, respectively. However, post-lockdown resulted in the rise of toxic heavy metals in the sediments of Somnath beach but Ghoghla beach remained to be pristine which may be due to the Blue Flagship status. The total number of marine bacteria was higher during 2013 and 2021 when compared during lockdown describing greater human interventions. For instance, *Vibrio* spp. count in Ghoghla beach water during pre-lockdown phase was 7733 CFU/mL and this value reduced to 70 and 5 CFU/mL in the lockdown and post-lockdown phases. Interestingly, the diversity of planktonic and benthic components showed a different trend from pre-to-post lockdown due to significant change in the inorganic nutrients and metal bioaccumulation. To our knowledge, this will be the first comprehensive assessment to report the environmental and ecological health of Ghoghla beach and Somnath beach during the pre-to-post lockdown.

Keywords COVID-19 · Somnath · Ghoghla · Lockdown · New Normal · Assessment

Introduction

Globally, intensive human activities have resulted in significant deterioration of seawater quality and coastal habitats (Hosseini et al. 2021; Chapman 2017). Combination of chemicals and trashes result in the disruptive levels of marine pollution that becomes extremely detrimental to the health of all aquatic organisms (Behera et al. 2021). Sedimentation, eutrophication, pollution and overexploitation of marine resources are all issues that have wreaked havoc on near-shore marine ecosystems (Özden et al. 2021). Ecosystems that are in danger of deteriorated water quality will in turn create a daunting effect upon the parameters of health. Coastal regions are the most valuable and fragile habitats as they contribute significantly in socioeconomic growth and human health, thus safeguarding them is a major concern (Bharathi et al. 2018). Healthy marine environment depends upon the excellent water quality; when the water is clean and nutrient-free, the seagrasses and coral reefs flourish (Sheppard et al. 2021).

Scattered pollutants on the beaches and waste dump along the coastlines enter the ecosystem in the worst ways possible that not only generates health-related challenges

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but also serious economic losses as well (Depledge et al. 2013; Seth and Shriwastav 2018; Sunitha et al. 2021). Many variables affect water quality including the physicochemical, nutrient and biological parameters. Nutrient inputs into coastal waters have increased drastically during the last four decades, causing quick and significant changes in coastal ecosystems around the world (Edward et al. 2021). Coastal regions get nitrogenous nutrients from a variety of places, including coastal upwelling, freshwater runoff/rainfall, cyclones/depressions and sewage from the industrial/household sectors (Bharathi et al. 2018; Sarma et al. 2020). Therefore, quality maintenance program generates guidelines for activities to maintain and restore the water quality levels required to support the healthy animal and plant populations (Botero et al. 2015).

Traditionally humans are attracted toward the coastal zone aesthetics and as a result, the coastal zones are extensively developed (Luijendijk et al. 2018). Sea beach is an area of the seashore consisting sediments, sand pebbles, shingle-like elements, shells, coralline algae, and is a home to a diverse range of landforms and ecosystems (Abreu et al. 2016). This area is predominantly used for the recreational activities like bathing, water sports and other entertainment purposes. Indian coasts stretch for over 7500 km and ample of sea beaches are present through the coastal side of the Indian subcontinent, *viz.,* starts from the eastern side of the country extended through the southern part to the western side of India. As the sea beaches are used for many human activities, it is necessary to maintain the proper environment concerning the safety issues of the area (Nayak 2017). Sea beaches are vulnerable to pollution as they are overexploited and many of them are in the verge of losing their aesthetic values (Vikas and Dwarakish 2015; Anbuselvan et al. 2018). Sediments are fine-grained particles with larger surface area, facilitating accumulation of pollutants (heavy metals, microplastics, etc.) on them, thus sediments are considered as storehouse of contaminants (Goswami et al. 2021; Fu and Wang 2011; Bramha et al. 2014; Qian et al. 2015).

Ghoghla beach is a sandy beach with crystal pure Arabian seawater, which is around 15 km from the main town of Diu, Union Territory that extends to the neighboring state of Gujarat (India) and latter known by the name Ahmedpur-Mandvi beach. This beach offers many attractive water sport adventures like parasailing, surfing and water scooters. Diu is one of the well-known tourist destinations and 2.3 million people have visited Diu in the year 2014 (NIP 2020; Diu Tourism Department 2022). The beach is well maintained, but least explored place, which eventually is the main reason for the pristine nature of Ghoghla beach (https://ddd.gov.in/centers/ghogla-beach/). Ghoghla beach was declared with the blue flagship in October 2020 (https://pib.gov.in/Pressreleaseshare.aspx?PRID=1684105).

Somnath is situated along the southwest coast on the Saurashtra peninsula, beside the Arabian Sea, and is located 5 km east of Veraval, India. Somnath beach is about 750 meters from the Somnath shrine, which is a well-known tourist attraction because of its religious significance (Gaur et al. 2002). Predominantly, the tourist activity is concentrated in a small stretch of the beach. Therefore, different types of wastes are discarded and get spreads to the entire beach area creating aesthetic issues and pollution problems. Horse/camel riding results in congestion and animal excreta on the beach area (GEC 2012).

Coronavirus disease 2019 (COVID-19) is caused by the novel SARS-CoV-2 (acute respiratory syndrome coronavirus), which turned to be pandemic with high infection rates and mortality (Coccia 2021a). COVID-19 extended its severity in phase wise depending on the different attributes such as social and environmental factors (Coccia 2018 & 2021b). Several countries have forcefully imposed complete restrictions for the man movement in order to contain the spread of this dreadful infection (Coccia 2022a). The environmental monitoring during the course of lockdown as well as their comparative assessment has gained greater attention from environmentalists (Coccia, 2020, 2021c and 2022b). There are assessment reports explaining the quality of water, ambient air and other environmental attributes during the pre-to-post lockdown at Indian and global context (Saraswat and Saraswat 2020; Chanchpara et al. 2021; Sun et al. 2021; Sahoo et al. 2021). The entry to Somnath shrine and Diu Island for the tourists and pilgrims was banned until the end of 2020.

With this backdrop, we aimed to understand the environmental quality of two beaches (Ghoghla beach, Diu and Somnath beach, Veraval) of Indian coasts in pre-to-post COVID-19 lockdown. We aimed to compare the baseline data generated through three time-regimes, *viz.,* pre-lockdown (May 2013), lockdown (October 2020) and post-lockdown (October 2021), to understand the environmental behavior of the beach's health with respect to physicochemical, nutrient and biological parameters. To best of our knowledge, this report will be serve as a baseline data of Ghoghla and Somnath beaches during pre-to-post lockdown. This manuscript can be an important document to identify the point source of pollution in the beaches due to anthropogenic activities in future.

Materials and methods

Samples and data collection

The samples (seawater and sediments) were collected from Ghoghla beach–Diu and Somnath beach–Veraval during low and high tides at different transects. The sample transects were established to cover both the active and non-active areas of each beach. A handheld global positioning system (Garmin, GPS) device was used to record the locations of all sampling transects. The coordinates and observations made during field visit are enlisted in the Supplementary Materials Table S1 and the generated map is given in Fig. 1.

The water and sediment samples were collected aseptically from all sites during high and low tides and then transported to the laboratory after imparting pre-treatment. The water samples were collected as per APHA, 1998 and 2017 guidelines depending on the nature of tests to be performed. The samples for microbiological analyses were collected in sterile vials and 250 mL plankton samples were collected by filtering ~100 L surface waters using pore-sized plankton net as per requirement. Sediment-slurry was prepared with seawater and sieved through 430 m ASTM mesh for concentrating the benthic organisms. The phytoplankton samples were fixed using formalin and Lugol's iodine, while zooplankton and benthic samples were fixed with formalin and Rose Bengal solutions.

Measure of parametric variables

The water and sediment quality parameters such as pH, seawater & air temperature, total suspended solids (TSS), turbidity, salinity, dissolved oxygen (DO), biochemical oxygen demand (BOD), total organic carbon (TOC), nitrite (NO_2-N), nitrate (NO_3-N), ammonia (NH_4-N), phosphate (PO_4-P), silicate, chloride and toxic heavy metal contents were assayed as per the method described in APHA (1998 & 2017). Supplementary Materials Table S2 gives the summary of the analytical test and methods involved in the analyses of seawater and sediment samples. The handheld pH meter (EuTech) and refractometer (ATAGO master) were used to measure the pH and salinity of seawater on the site itself. Total organic carbon (TOC) content of the seawater

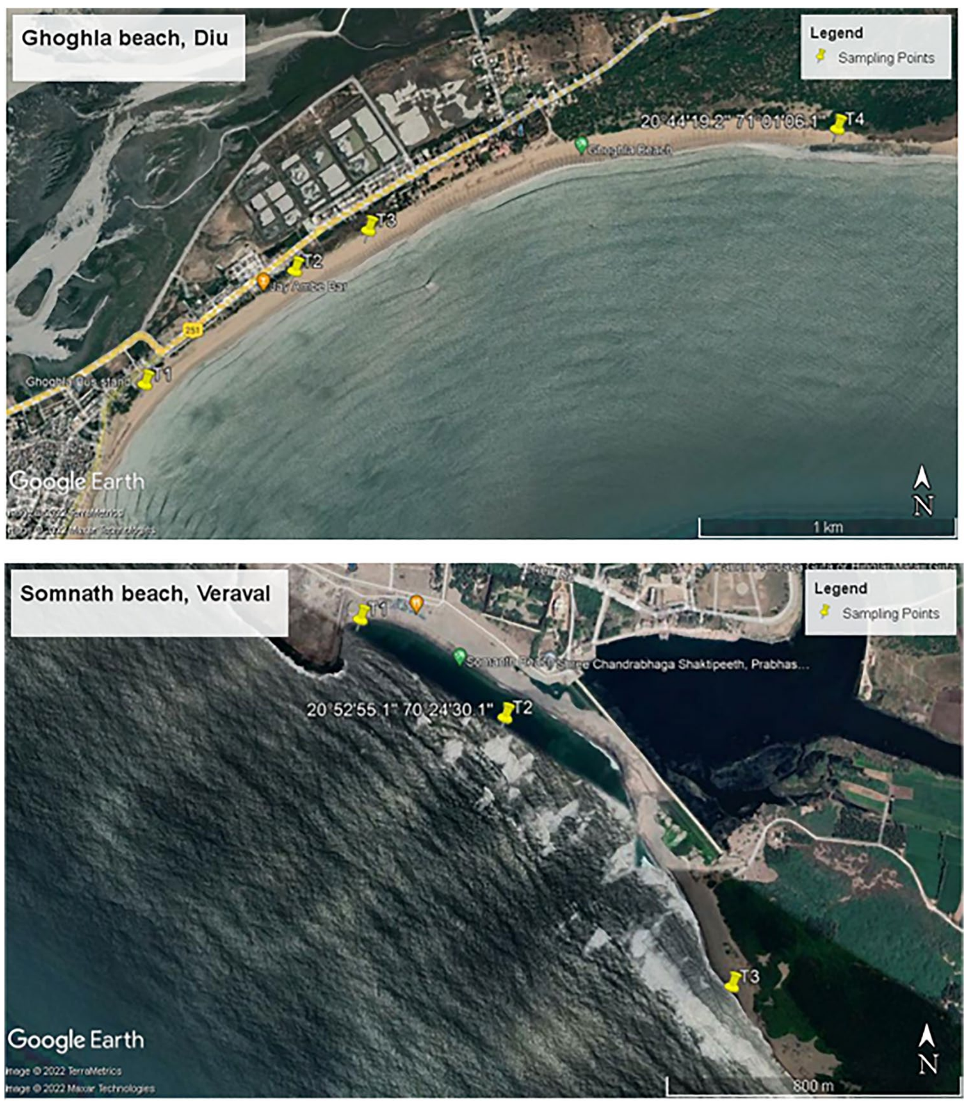


Fig. 1 Map showing the sample collection sites at Ghoghla beach, Diu and Somnath beach, Veraval

and sediments was analyzed using Elementar Vario TOC select analyzer. The absorbance values were recorded on Systonic Microprocessor UV–Visible spectrophotometer. The heavy metal contents of seawater and sediment samples were quantified on an inductively coupled plasma mass spectrometry iCAP RQ (ICP-MS).

Data analysis procedure

Qualitative and quantitative analysis of planktons and benthic organisms was performed microscopically. The phytoplankton and zooplanktons were imaged for the qualitative and quantitative determination on Olympus BX53 fluorescent microscope, while the benthic organisms were enumerated on a Leica S8APO microscope. The cells were counted using Sedgewick-Rafter to understand the genera and the generic diversity. Phytoplanktons and zooplanktons were expressed as number of cells per mL of the sample, while benthic count is expressed as number or weight of benthos per m^2 area of the sea floor. The number of cells was used to calculate the Shannon–Wiener diversity index.

$$SWDI = -\sum \left(\frac{n_i}{n}\right)\log_2\left(\frac{n_i}{n}\right) \quad (1)$$

where n_i is the number of individuals of each species in the sample and n is the total number of individuals of all species in the sample (Simpson 1949; Winder and Sommer 2012). The bacterial load in the seawater (CFU/mL) and sediments (CFU/g) were assayed for the presence of total number of bacteria and coliform, *Salmonella* spp., *Vibrio* spp., *Streptococci*, *Pseudomonas, Escherichia coli*, *Aeromonas* and *Enterococcus*.

Results

The results of the physicochemical parameters analyzed during the years' 2013, 2020 and 2021 tabulated in Table 1. The minimum and maximum air temperature at Ghoghla beach were 31–41°C (2013), 28–32°C (2020) and 25–29°C (2021), while Somnath beach ambience was 30–32°C (2013), 29–30°C (2020) and 30–33°C (2021). The high temperature during 2013 is due to the month of sampling (March 2013) and similar trend was witnessed in case of water temperature at all transects of both the beaches. pH variation in water depends upon the amount of free carbon dioxide, carbonate and bicarbonates. The mean pH levels of both the beaches ranged between pH 7.3±0.1 and 7.8±0.3 for the years 2013 and 2021, respectively, and the waters with pH range 6.5–9.0 are optimal for fish production (Tucker and Robinson 1990). pH levels measured during the years 2013 and 2020 at Ghoghla beach showed similar trend, but in the year 2021 (post-lockdown) showed in incremental rise in pH level from 7.3 to 8.2. In case of Somnath beach, the mean pH level at all transects was pH 7.3±0.1 during 2013 and this has increased to pH 7.8±0.3 in the years 2020 & 2021.

The beach waters of Ghoghla beach did not show much difference in the salinity levels during HT and LT when compared between (36.1±0.4 ppt) 2013 and (33.9±1.1 ppt) 2020, whereas salinity level decreased to 28.5±2.51 ppt during 2021. The average salinity level at Somnath beach waters was 35.17±0.41 and 34.33±1.03 ppt during pre-lockdown and lockdown regimes; however, post-lockdown sampling inferred that the salinity values were 0 and 17 ppt in the transects studied. Turbidity is a measurement of the water clarity and turbid water is due to the contamination of water by the suspended particles. In this assessment, there is a drastic decrease in average turbidity from the year 2013 (42.83 NTU), 2020 (21.2 NTU) and 2021 (4.88 NTU) at Ghoghla beach.

The presence of solids (total suspended solids; TSS and total dissolved solids; TDS) in the beach water has direct implications on the water quality. HT water of transect-2 at Ghoghla beach had the following parametric values; TDS, 255.6 mg/L; TSS, 51.17 mg/L and turbidity, 1.028 NTU particularly in 2013. The above values did not correlate with the values of the HT/LT waters of other transects. Subsequent sampling during 2020 and 2021 did not express the same trend among the samples tested while drastic reduction in the TDS level of Ghoghla beach water was observed in the post-lockdown. From Table 1, it is also inferred that the TSS levels were high in all transacts of Ghoghla beach. TDS concentrations in Somnath beach were in the range of 25.66±0.54, 55.42±82.60 and 8.69±5.69 mg/L during pre-lockdown, lockdown and post-lockdown. The higher level of TDS during lockdown is mainly due to the restricted flow of sewage. Increasing trend of TSS levels was observed in both Ghoghla and Somnath beach waters during pre-lockdown, 154.20±43.25 mg/L; lockdown, 150.18±3.50 mg/L and post-lockdown, 665.13±170.35 mg/L.

The presence of solids decreases the DO content of water and this is witnessed in waters of Ghoghla and Somnath beaches as enlisted in Table 1. Other parameters influencing DO level in water are temperature and salinity (Song et al. 2019). The optimal range of DO is 4–9 mg/L, which largely supports the diverse fish population and it is known that DO values receding below 2 mg/L would result in hampering the sustainment of juvenile fishes and crustaceans (Low et al. 2021). DO level of Ghoghla beach water at all transects had an average of 5.61±0.28, 4.76±0.18 and 4.40±0.11 mg/L during pre-lockdown, lockdown and post-lockdown phases, whereas the trend observed in Somnath beach water was different (3.56±0.77, 4.55±0.19 and 2.97±0.72 mg/L). DO levels >4 mg/L were observed during lockdown phase and the quality has deteriorated during post-lockdown in 2021 (DO, 2.97±0.72 mg/L) and few transects had DO level of 2.2

Table 1 Physicochemical parameters of Ghoghla and Somnath beach water analyzed during pre-to-post lockdown regimes

Parameters	Regimes	Parametric mean values	
		Ghoghla beach water	Somnath beach water
Air temperature (°C)	Pre-lockdown	34.9±4.5	31±1.10
	Lockdown	26.8±1.3	29.35±0.31
	Post-lockdown	30.4±1.3	31.02±1.02
Water temperature (°C)	Pre-lockdown	31.3±1.4	29.33±0.41
	Lockdown	23.8±0.9	24.13±0.40
	Post-lockdown	23.1±0.8	25.05±1.32
pH	Pre-lockdown	7.44±0.09	7.3±0.1
	Lockdown	7.46±0.18	7.8±0.3
	Post-lockdown	7.79±0.28	7.82±0.32
Salinity (ppt)	Pre-lockdown	36.1±0.4	35.17±0.41
	Lockdown	33.9±1.1	34.33±1.03
	Post-lockdown	28.5±2.51	10.83±8.40
Turbidity (NTU)	Pre-lockdown	42.83±20.29	36.7±13.4
	Lockdown	21.20±1.74	7.7±0.7
	Post-lockdown	4.88±0.60	3.5±1.2
TSS (mg/L)	Pre-lockdown	154.20±43.25	95.37±16.86
	Lockdown	150.18±3.50	117.82±3.50
	Post-lockdown	665.13±170.35	378±235.34
TDS (mg/L)	Pre-lockdown	52.59±82.03	25.66±0.54
	Lockdown	26.99±1.25	55.42±82.60
	Post-lockdown	16.23±0.07	8.69±5.69
DO (mg/L)	Pre-lockdown	5.61±0.28	3.56±0.77
	Lockdown	4.76±0.18	4.55±0.19
	Post-lockdown	4.40±0.11	2.97±0.72
BOD (mg/L)	Pre-lockdown	1.35±1.87	1.33±1.27
	Lockdown	2.60±0.31	2.88±0.29
	Post-lockdown	2.91±0.27	3.10±0.79
TOC (mg/L)	Pre-lockdown	18.35±2.66	0.001±0.001
	Lockdown	14.85±1.80	12.87±0.42
	Post-lockdown	21.29±1.05	20.53±1.00
Oil & grease (mg/L)	Pre-lockdown	4.12±3.09	8.2±3.46
	Lockdown	1.56±0.39	1.27±0.12
	Post-lockdown	0.60±0.54	0.5±0.20

mg/L which may be due to the anthropogenic inputs. BOD level increased in Ghoghla beach (1.35±1.87, 2.60±0.31 and 2.91±0.27 mg/L) and Somnath beach (1.33±1.27, 2.88±029 and 3.10±0.79) from pre-to-post lockdown period and this is in concurrence of the normal life resumption.

The organic constituents assessed in this study were total organic carbon (TOC), oil & grease contents of beach waters. Oil & grease are organic, not easily biodegradable toxic waste and possess destructive ability to the aquatic lives. They are known to form a layer on the water's surface, arrest the sunlight penetration to the water bodies and disturb photosynthesis ultimately declining the DO level (El-Gawad 2014). The acceptable limit of oil & grease in coastal water is <0.1 mg/L as prescribed by Central Pollution Control Board (CPCB 1998). Oil & grease content in Ghoghla waters was 4.119±3.091, 1.563±0.385 and 0.603±0.537 mg/L for the pre-to-post lockdown while Somnath beach water had 8.2±3.462, 1.27±0.121 and 0.5±0.204 mg/L during the regimes assessed as shown in Table 1. TOC levels of Ghoghla seawaters were 18.35±2.66, 14.85±1.8 and 21.28±1.05 mg/L while Somnath beach water had 0.0012±0.0004, 12.87±0.42 and 20.53±1.0 mg/L during pre-to-post lockdown regimes. The seawater nutrients of Ghoghla and Somnath beach waters were assessed with respect to the inorganic ions such as nitrite (NO_2^-), nitrate (NO_3^-), ammonia (NH_4), silicate (SiO_4^-) and phosphate (PO_4^-) as shown in Fig. 2.

Eleven heavy metals were monitored in the pre-to-post lockdown including the four critically categorized four heavy metals such as arsenic (As), cadmium (Cd),

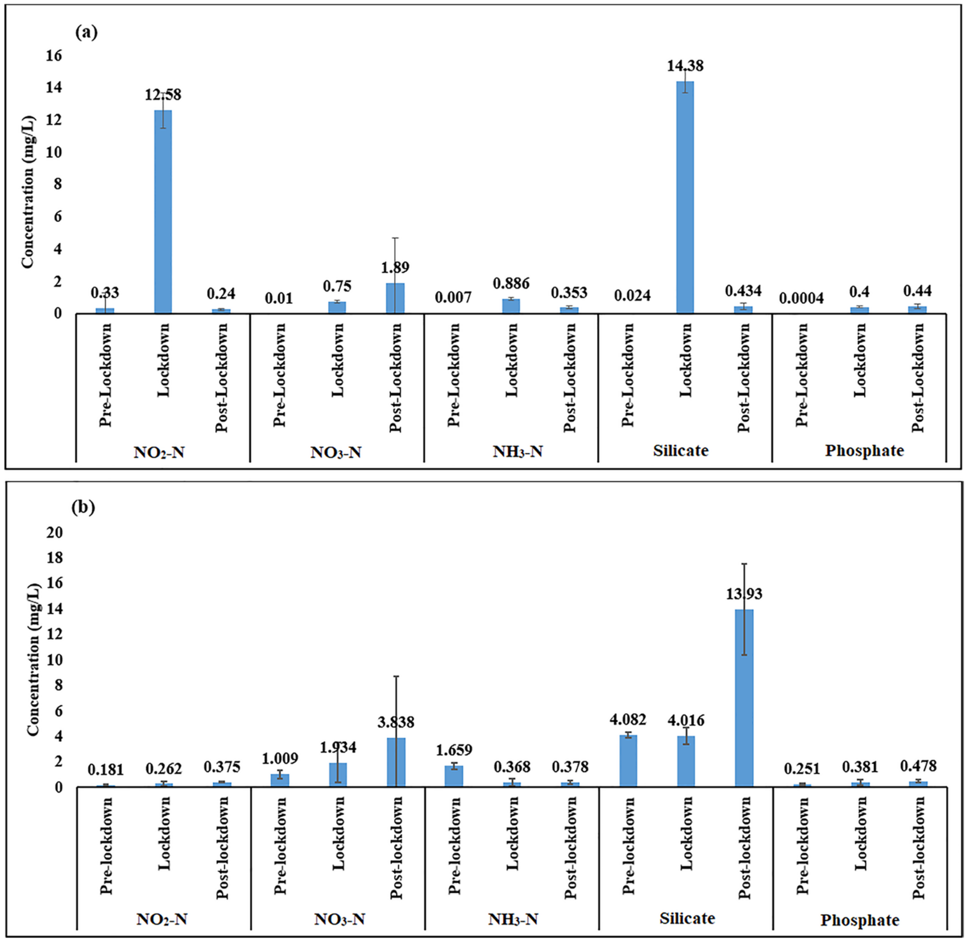


Fig. 2 Comparison of seawater inorganic nutrients in beach waters of (**a**) Ghoghla beach and (**b**) Somnath beach assessed during pre-to-post lockdown

chromium (Cr), and lead (Pb) (Kaur et al. 2011; Han et al. 2019; Rahman and Singh 2019). The lead concentration decreased significantly in the recent assessments when compared with pre-lockdown. Particularly, arsenic concentration remained to be in declining trend (Fig. 3) and within allowable limit in Somnath beach waters when assessed after pre-lockdown (Neff 1997). The mean Cd concentration increased drastically in Ghoghla beach waters; 1.35, 0.28 and 7.09 µg/L, but in case of Somnath the Cd levels were 0.45, 0.28 and 0.58 µg/L during pre-to-post lockdown, respectively.

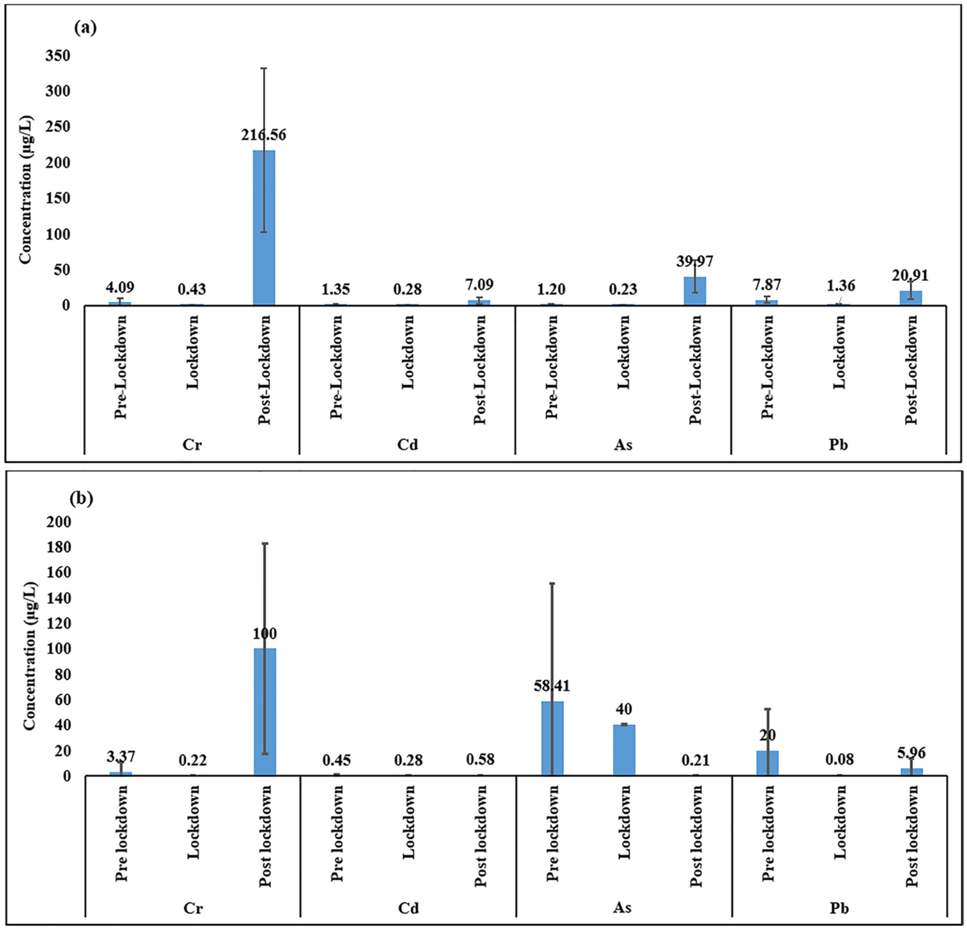
The quality of beach sediments was assessed with respect to physicochemical, organic load and toxic heavy metal constituents. Figure 4a&b illustrates the amount of clay, sand, silt and TOC of Ghoghla and Somnath beach sediments. The toxic heavy metal (Cr, Cd, As and Pb) contents in the beach sediments were analyzed in both the beaches and the values are shown in Fig. 5a&b. The outcome of this assessment reveals that Ghoghla beach environment required ample time to reduce 55.43, 4.27, 127.69 and 41.99 µg/g of Cr, Cd, As and Pb metal ions, respectively, from the pre-lockdown to lockdown (Cr, 29.23 µg/g; Cd, 2.27 µg/g; As, 12.46 µg/g and Pb, 10.25 µg/g.

The bacterial load in the beach water and sediments were assessed and compared for three different regimes; pre-to-post lockdown. For the present study, a total of nine types of selective and differential media were used to determine the overall microbial diversity present at the selected sites. The average bacterial load in water (CFU/mL) and sediment (CFU/mL) such as (1) total number of marine bacteria, (2) *Salmonella* spp., (3) *Vibrio* spp., (4) *Streptococci* sp., (5) *Pseudomonas* sp., (6) total number of coliform, (7) *E. coli,* (8) *Aeromonas* sp. and (9) *Enterococcus* sp. are tabulated in Table 2. The marine ecological health of Ghoghla and Somnath beaches was assessed with respect to the species diversity and the results are tabulated in Table 3. SWD indices of phytoplanktons and zooplanktons in the surface waters while benthic organisms were assessed in the beach sediments.

Discussion

Due to COVID-19 pandemic, complete lockdown was imposed from March 2020 and continued until May 2020 when all the anthropogenic activities including human movement was completely halted. COVID-19 imposed

Fig. 3 Comparison of toxic heavy metal contents in beach waters of (**a**) Ghoghla beach and (**b**) Somnath beach assessed during pre-to-post lockdown



lockdown has opened up many avenues for the environmentalists to understand the effects of lockdown on the improvement of environmental quality with respect to ambient air, water, human health and many other attributes (Lotliker et al. 2021; Coccia 2022b). Table 4 gives a snapshot of assessment reports conducted in specific sites during the COVID-19 pandemic period at different nations. Our present study reports a juxtaposition of environmental quality assessed during normal functioning of the world (pre-lockdown period, 2013), lockdown period (2020) and resumption of new normal, *i.e.,* post-lockdown period (2021) in the selected beaches of India (Ghoghla beach, Diu and Somnath beach, Veraval).

pH variation in water depends upon the amount of free carbon dioxide, carbonate and bicarbonates. The principal anion in saltwater, Cl^-, alone has little effect on the pH of the water; nevertheless, seawater naturally contains additional elements, such as bicarbonate ions, which make the water somewhat more alkaline, with a pH to which marine species are acclimated. Increased dissolved CO_2 and human impacts such as ocean acidification lower pH of seawater (Barford 2013). The significant increase in the pH level of the beach waters may be due to the new normal resumption of tourism and pilgrimage. Salinity influences the marine biota and most of the aquatic lives are adapted to a narrow range of salinity (Velasco et al. 2018; Cañedo-Argüelles et al. 2019). As a result, any change in ambient salinity has the potential to influence organism's capacity to carry out critical biological processes, and consequently their ability to live and thrive. Changes in salinity will have a significant impact on the marine species especially on their reproduction, distribution, larval dispersion and behavior (Ern et al. 2014). The reason for the dip in the salinity levels is the release of diluted sewage with freshwater from the Somnath town to the sea as shown in the Supplementary Materials Fig. S1.

Increased suspended silt, or turbidity, in aquatic ecosystems lowers the response distance to visual cues and may thus change movement behavior. Given that movement underpins essential behaviors including as feeding, mating and predator avoidance, a decrease in movement efficiency is anticipated to have a considerable influence on the health and population dynamics of visually guided fish species (Susannah et al. 2011). The effects of increased sediment suspension on photosynthetic species have been

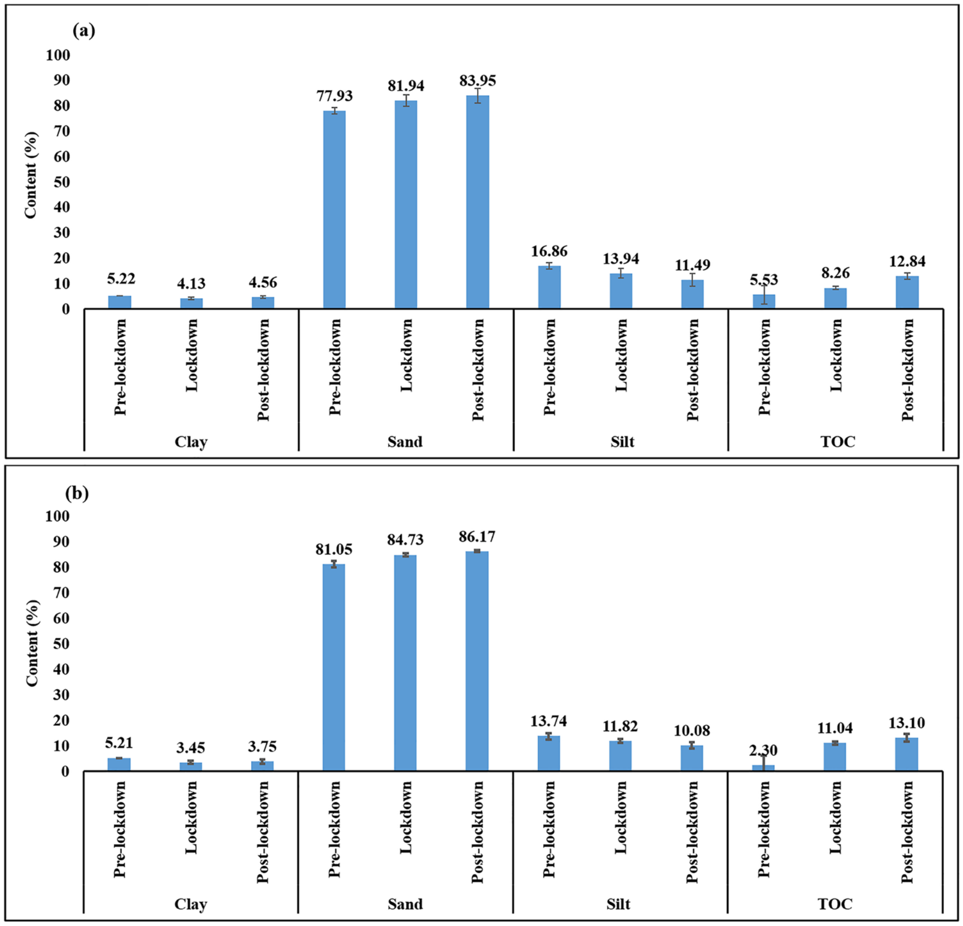


Fig. 4 Comparison of sediment quality of (**a**) Ghoghla beach and (**b**) Somnath beach assessed during pre-to-post lockdown

studied; however, there is growing evidence that fish are also significantly impacted (Newport et al. 2021).

The reason for the declined level of water haziness is that Diu Administration has taken all possible efforts to maintain Ghoghla beach water quality. Similarly, the beach waters of Somnath had turbidity levels of 36.7, 7.7 and 3.5 NTU for the pre-lockdown, lockdown and post-lockdown regimes. Reduced turbidity levels in Somnath beach water may be due to the continuous mixing of diluted sewage with freshwater. TSS has an inevitable role in imparting turbidity and they are known to absorb heat from sun; thus, they tend to increase the seawater temperature, and in turn, they decrease the dissolved oxygen (DO) content (USEPA 2000; Sembel et al. 2021). Microbial community dwelling in the aquatic ecosystem degrades the organic matter present at the bottom through DO consumption (Moresco et al. 2012; Fuhrman et al. 2015). First, turbidity affects dissolved oxygen (DO) sources by limiting light penetration and hence photosynthetic activity, as well as gas exchange with the atmosphere (Schmidt et al. 2019; Newport et al. 2021).

Lockdown has favored the decrease in the oil & grease content significantly. However, the new normal situation in 2021 has opened up the accessibility of the beaches to the common public and thus marginally increased the oil & grease content of the seawaters. TOC content of Ghoghla beaches showed inclination in their values from lockdown to post-lockdown period while opposite trend was found in case of Somnath water and this may be due to the freshwater mixing to the open sea. Generally, there is a relationship between TOC, DO and BOD value (Al-Said et al. 2018). With the increase in value of TOC, generally DO value decreases and BOD value increases. Near similar trend was observed in both of the beaches.

Interestingly, during lockdown sampling from Ghoghla beach, nitrite value was recorded very high in comparison with pre- and post-lockdown sampling. Although the absolute value was low, similar trend was also observed in the case of ammonia. This might be due to the activity of de-nitrifying and small amount ammonifying bacteria in the water which generally convert nitrate to nitrite and then to ammonia (Zakem et al. 2018). However, no such trend was observed in the case of Somnath beach-water sample, sharp spike of nitrate and nitrite was observed in the post-lockdown sampling in comparison with the previous sampling. A sudden increase in silicate value was observed in the pristine Ghoghla beach water during lockdown sampling

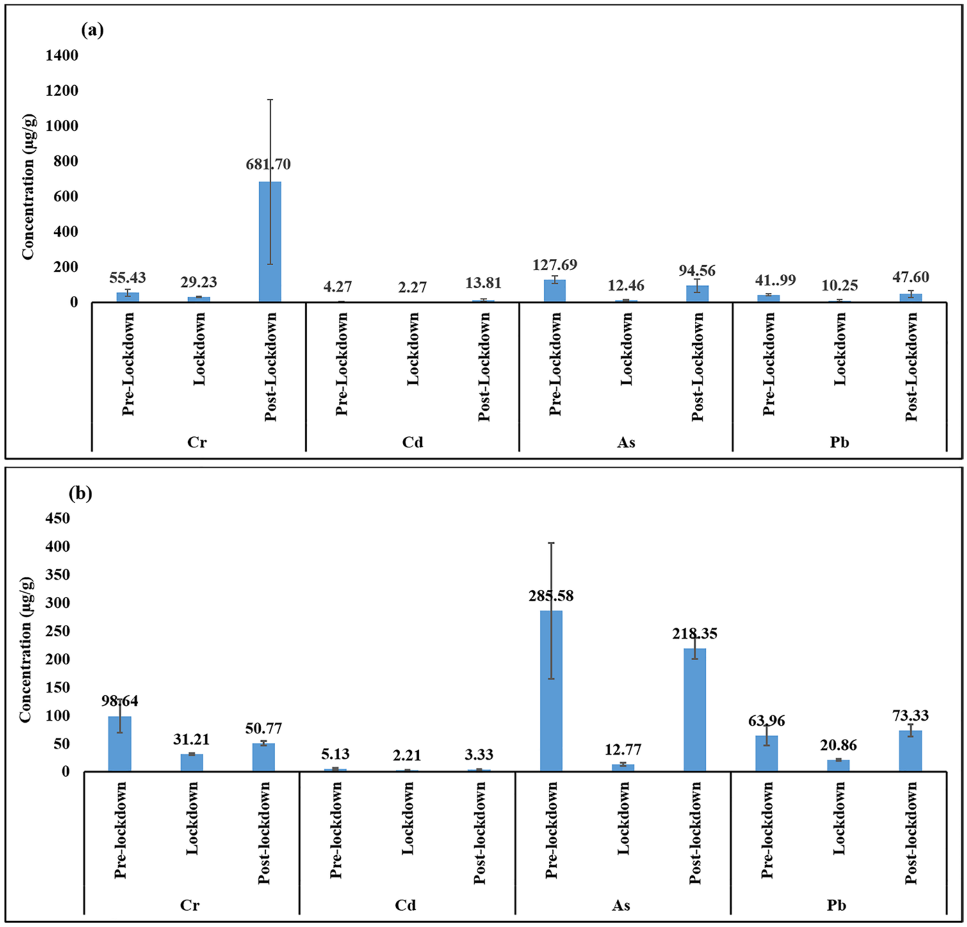


Fig. 5 Comparison of toxic heavy metal contents in beach sediments of (**a**) Ghoghla beach and (**b**) Somnath beach assessed during pre-to-post lockdown

when there were no anthropogenic activities. This proves that silicate value of water is not dependent on any of the anthropogenic source as it is mostly based on river run off and coastal upwelling (Sospedra et al. 2018; Panja et al. 2022). Phosphate value was recorded to be low in all the sampling and overall value was high in case of Somnath water in comparison with the Ghoghla.

The impact of heavy metals is drawing worldwide attention and their presence in the coastal water above the permissible limit has harmful impact on aquatic environment due to their carcinogenic, toxic, non-biodegradability and persistence nature (Wu et al. 2020). In addition to it, bio-accumulation and bio-magnification of heavy metals in aquatic organism would create more risks to the coastal populations (Ali et al. 2015; Zhang et al. 2017). Lead (Pb) is one of the heavy metals found in coastal water in different forms based on the physicochemical features of the seawater and the most regular forms of lead in seawaters are $PbCO_3$, $Pb(CO_3)_2^{2-}$ and $PbCl^+$ (Rostern 2017). The hexavalent chromium is soluble in water and has the potential to cause acute or chronic poisoning, mutagenesis, carcinogenesis and teratogenesis while undergoing bioaccumulation (Bonnand et al. 2013; He et al. 2020). The lockdown regime has favored the decrease of all heavy metals when compared with the baseline data generated on pre-lockdown phase; however, the new normal has opened up all possible ways to contaminate the environment. The risks posed by Cd metal ions would be dreadful and can be easily bio-accumulated by the aquatic organism through transport mechanism (Manzo et al. 2010; Inglot et al. 2012). The anticipated impacts of the measured toxic heavy metals are the bioaccumulation in the marine ecological components (Ali et al. 2015; Chiarelli et al. 2019).

There were no significant differences observed in the amount of clay, sand and silt at Ghoghla while drastic changes were observed in the above parameters in Somnath beaches, which is due to the siltation, and mixing of wastewater discharges to the open sea during post-lockdown regimes. Aeolian sedimentation, sewage discharges, deep-sea mining, etc., have resulted in the augmentation of metals into the water bodies (Naser 2013; Suresh et al. 2015; Perumal et al. 2021). All the heavy metals during the pre-lockdown period were high in all transects; however, the lockdown has favored the significant restoration of the natural environment of Ghoghla and Somnath beaches. The post-lockdown resulted in the increase of all

Table 2 Average bacterial load in beach waters and sediments assessed during pre-to-post lockdown

Bacteriological parameters	Regimes	Bacterial load in water (CFU/mL)		Bacterial load in sediment (CFU/g)	
		Ghoghla beach	Somnath beach	Ghoghla beach	Somnath beach
Total number of marine bacteria	Pre-lockdown	105500	165666.7	53675	165667
	Lockdown	1142.5	566.67	2555	566.667
	Post-lockdown	875	2200	2550	2200
Salmonella spp.	Pre-lockdown	233.75	10543.33	15	10543.3
	Lockdown	12.5	#	93	#
	Post-lockdown	#	106.67	#	106.67
Vibrio spp.	Pre-lockdown	7733.75	1913.33	510	1913.33
	Lockdown	70	30	20	30
	Post-lockdown	5	43.33	23	43.33
Streptococci sp.	Pre-lockdown	426.75	943.33	183	943.33
	Lockdown	#	#	10	#
	Post-lockdown	15	#	5	#
Pseudomonas sp.	Pre-lockdown	#	#	#	#
	Lockdown	10	#	20	#
	Post-lockdown	22.5	26.67	3	26.67
Total number of coliform	Pre-lockdown	187.5	1776.67	73	1776.67
	Lockdown	#	3.33	225	3.33
	Post-lockdown	#	123.33	#	123.33
Escherichia coli	Pre-lockdown	313.25	2390	230	2390
	Lockdown	7.5	#	133	#
	Post-lockdown	#	210	#	210
Aeromonas sp.	Pre-lockdown	#	816.67	#	816.67
	Lockdown	7.5	#	#	#
	Post-lockdown	35	106.67	#	106.67
Enterococcus sp.	Pre-lockdown	#	100	#	100
	Lockdown	1967.5	113.33	2101	113.33
	Post-lockdown	72.5	83.33	10	83.33

#: Not detected

Table 3 Species diversity and Shannon–Wiener diversity index of phytoplanktons, zooplanktons and benthic organisms during pre-to-post lockdown

Site of study	Species diversity			Shannon–Wiener Diversity Index		
	Pre-lockdown	Lockdown	Post-lockdown	Pre-lockdown	Lockdown	Post-lockdown
Phytoplanktons						
Ghoghla beach	9.25±2.75	5.5±1.29	7.5±1.91	3.42±2.19	1.48±0.25	1.19±0.27
Somnath beach	7.0±1.0	2.67±0.58	8.67±3.51	5.75±1.4	0.75±0.007	1.77±0.38
Zooplanktons						
Ghoghla beach	1.5±1.29	2.5±0.58	5.25±0.5	1.46±1.24	0.87±0.11	1.57±0.10
Somnath beach	0.67±0.58	1.33±0.58	4.67±0.58	0.67±0.58	0.35±0.13	1.42±0.10
Benthic organisms						
Ghoghla beach	1.5±0.58	0.5±0.58	5.5±0.58	1.15±1.0	#	2.27±0.18
Somnath beach	1.33±0.58	#	1	1.23±0.4	#	#

#: Not Detected

heavy metals in the beach sediments of Somnath beach but Ghoghla beach sediments remained to be pristine. The efforts of Diu Administration to maintain the Blue Flagship status has reduced the pollution load and this has resulted in significant reduction in toxic heavy metals even after resuming to new normal.

Pre-lockdown period (year 2013) had high bacterial load in Ghoghla beach water which drastically decreased to a

Table 4 List of environmental monitoring and assessment reports pertaining to COVID-19 pandemic

Environment matrices assessed	Country	References
Water	Tangier, Northern Morocco	Cherif et al. 2020
Lake	Kerala, India	Yunus et al. 2020
Air	India	Sharma et al. 2020
Air	Sao Paulo, Brazil	Nakada and Urban 2020
Air, Water	Uttar Pradesh, India	Lokhandwala and Gautam 2020
Air	China	Wang and Su 2020
Air	Indonesia	Caraka et al. 2020
Air	Europe	Nižetić 2020
Water	Lebanon	Kassem and Jaafar 2020
Air, Water	Philippines	Pacaol 2021
Air, Water, Plastic waste	Chennai, India	Robin et al. 2021
River	River Gomti, India	Khan et al. 2021
River	Northwest Turkey	Tokatlı and Varol 2021
River	River Damodar, India	Chakraborty et al. 2021
Air, Water, Sediment	Alang, India	Chanchpara et al. 2021
Air	India	Sahoo et al. 2021
Air	Delhi, India	Bhat et al. 2021
Air	Delhi, Kolkata, Bangalore, and Hyderabad, India	Ambika et al. 2021
Air	Avellino, South Italy	Cucciniello et al. 2022
Seawater	Diu, India	Panja et al. 2022
Air	USA	Straka et al. 2021
Beach quality	Ecuador	Ormaza-Gonzailez et al. 2021
Coastal water quality	Chennai, India	Prakash et al. 2021
Beach quality	Diu and Somnath, India	Present study

certain extent few bacterial loads were absent when assessed during lockdown and the new normal has resulted in the increase of microorganisms. Total coliform count and *Streptococci* sp. were not detected in Ghoghla beach water tested during lockdown. Individuals of family Enterobacteriaceae, *viz*., *E. coli* and *Enterobacter* sp., were found in higher concentrations in pre-lockdown period indicating the greater human activities in the coastal environment. Pathogenic bacterial load were found be lesser in Ghoghla waters and sediments describing the efforts taken by the local administration in maintaining the beach quality. In case of Somnath marine environment, *Salmonella* spp., *Streptococci* sp., *Pseudomonas* sp. and *E. coli* were not detected in the beach waters during lockdown implying that water was least contaminated. However, the data presented in Table 2 of post-lockdown period have shown the presence of the pathogenic bacteria in the marine environment which is in concurrence of human interventions in deteriorating environmental quality (Arias-Andres et al. 2018). An interesting trend for overall bacterial load both in the seawater and sea sediment was observed in both the beaches. It was clearly observed during pre-lockdown sampling in 2013 that the microbial pollution was high in both the beaches but reduced drastically during lockdown and post-lockdown sampling. This is mostly due to improve beach management by the statutory authority which result drastic improvement in the microbial load in the water and sediments samples.

The diversity of planktons depends upon the physico-chemical characteristics of the water and the diversity is usually low in eutrophic (increased pollution load) waters. The maximum value of Shannon–Wiener diversity index (SWDI) of plankton for clean waters is 6 and index ≥ 3 reveals the healthy condition of water bodies. However, values between 1 and 3 represent semi-productivity and SWDI<1 describes the poor productivity (Matta et al. 2018). *Coscinodiscus* sp. and *Tabellaria* sp. were the commonly found phytoplankton species in regimes of assessment while *Nauplius* larvae existed in case of zooplanktons at Ghoghla beach. Whereas in Somnath beach, the phytoplanktons were higher in number when compared to zooplankton and benthic organisms as they acquire the base of the oceanic food chain (Peña et al. 1990). Among all the phytoplankton species obtained, *Coscinodiscus* sp. was observed during sampling of all the three years of assessment, as it is cosmopolitan in distribution (Cefarelli et al. 2010). *Biddulphia* sp. was also found during pre-lockdown and lockdown; however, it was not observed during the post-lockdown period. None of the zooplankton species were found in common for all the sampling regimes.

Benthic diversity was higher in the pre-lockdown period and Gastropods were found to dominate among all the benthic species. The decreased diversity of planktonic species may be attributed to cadmium and microplastics bioaccumulation in these ecological indicators (Shi et al. 2016; Cho et al. 2019; Daniel et al. 2020). SWDI values of phytoplanktons in Diu coastal water ranged between 3.42, 1.48 and 1.19 for the pre-to-post lockdown periods, which indicates that healthy and semi-productivity nature of the water. The zooplankton's SWDI was 1.46 in pre-lockdown and this value decreased during lockdown to 0.87 (poor productivity) and eventually increased to 1.57 in post-lockdown, indicating that the new normal has resulted in significant rise of inorganic nutrients to support the plankton's growth and productivity (Llebot et al. 2010). SWDI values in Somnath surface water had good productivity (5.75) of phytoplanktons assessed in pre-lockdown and this value reduced to 0.75 indicating the loss of diversity during lockdown. However, the zooplankton's SWDI describes the poor productivity during 2013 and 2020.

Benthos are the organisms found almost everywhere in the marine environment, starting from the littoral zone to deep sea. The most important factors that influence benthic diversity and abundance are habitat type and availability of food. The intertidal areas are very dynamic environment impacted by the waves and currents, which influences the sediment habitat of benthos (Vezzulli et al. 2009). Somnath beach is very dynamic and physically disturbed station by natural and anthropogenic activities thereby making the condition unsuitable for the benthos to dwell. Hence, macro-benthos were not found at Somnath beach, except *Dotilla* sp. (sand crabs), which was found during high tide as the beaches are less influenced by the waves and currents. However, Ghoghla beach excelled good species diversity and SWDI as they had favorable environment to harbor crustaceans like amphipods, isopods and sand crabs.

Conclusions

Environmental and ecological health of two beaches, Ghoghla and Somnath, was investigated during the pre-to-post lockdown phases. Considerable reduction in the physicochemical parameters and pathogenic bacterial load were observed during the COVID-19 imposed lockdown. The uplift of lockdown distinguishably deteriorated the beach water and sediment qualities as well as the planktonic and benthic communities. Lockdown and post-lockdown data were compared with the primary data generated in the year 2013, which describe the deterioration of water quality predominantly due to social factors. Conclusively, the results presented in this report would facilitate future prospects to undertake regular monitoring and assessments of the pristine Ghoghla beach and largely exploited Somnath beach.

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