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Impacts of COVID-19 lockdowns on water quality along the coast of Morocco

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ABSTRACT

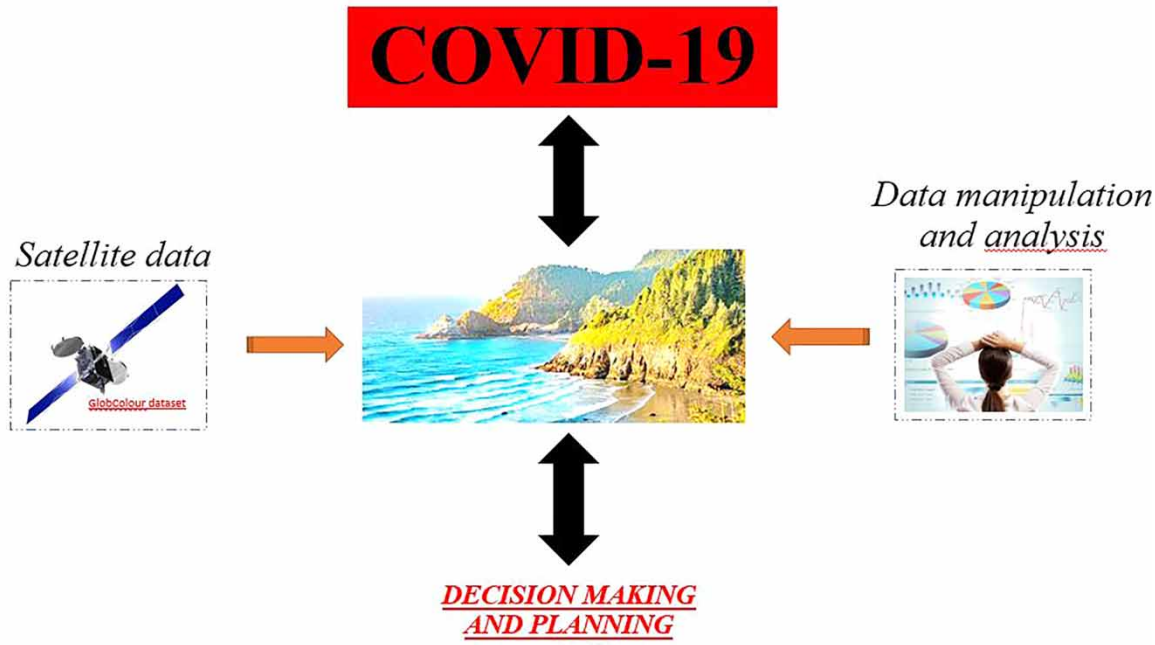
Due to the COVID-19 pandemic, most of the marine activities and all the anthropogenic activities along the coast have been shut off for several months. The total suspended matter (TSM) was analyzed before and during COVID-19 lockdown in the coast of Morocco. Therefore, the aim of this study was to assess all the changes reflected through the coast in April of 2018, 2019, 2020 and 2021. In the absence of the ground observations during this period, the remote sensing data was used in this study. The results showed a gradual reduction in TSM concentration, indicating a positive improvement during the lockdown period. The TSM concentrations during this period decreased by 40.59% on average compared with the pre-lockdown period. Further, the turbidity in the water has reduced at each stretch of the rivers. Remote sensing is a powerful tool for analyzing turbidity over the whole littoral areas, even in the absence of field observations. The ongoing pandemic shows that an ocean with cleaner water is possible. These findings provide a general reference on the state of the Moroccan coast that could contribute to improve policy and future monitoring program.

Key words: COVID-19, Morocco, lockdown period, remote sensing, total suspended matter, turbidity

HIGHLIGHTS

- Turbidity pattern associated water quality parameters were observed along the Moroccan coast for the first time.
- The coast of Morocco was investigated for water quality and COVID-19 relationship.
- During the lockdown, the Morocco coast was less polluted.
- Satellite data of the seawater is suitable to predict the water quality of the Moroccan coast.
- It is a good initiation to have a clean coastline.

GRAPHICAL ABSTRACT



INTRODUCTION

The coronavirus disease 2019 (COVID-19) was first identified in Wuhan, China in December 2019. In a short period of time, it was spreading in Africa with the first case recorded in Egypt on 14 February 2020. In Morocco, the pandemic emerged on 2 March 2020. This first case of COVID-19 prompted authorities to take preventive measures against the proliferation of the pandemic. The entire country was under lockdown from mid-March 2020 (Singhal 2020). All the markets were shut down, places of worships closed, public gathering banned, and travel restrictions imposed. Almost all vital economic activities ceased including manufacturing and transportation and energy production. The quarantine period was under the spotlight of news media worldwide, mainly because of its economic impacts, on anthropogenic as well as industrial activities. The spread of COVID-19 disrupted lives and coastal communities, including for those dependent on the ocean for their livelihoods; these include fisheries, ecotourism and coastal tourism.

The Moroccan authorities implemented stringent lockdowns starting on 23 March 2020 and then relaxing it in different phases from 1 June 2020. Thus, as in many other coastal cities across the world, environmental change in the area threatened its water quality during this period (Dantas *et al.* 2020; Garg *et al.* 2020; Yunus *et al.* 2020). In this study, we look at this event from an environmental perspective by analyzing the impact of the pandemic over the Atlantic coast and of operations like dredging on the concentration of total suspended matter (TSM). The remote mapping of TSM using satellite data is of particular importance in a wide range of aquatic science and management applications. Shallow water of the Moroccan coast is influenced by TSM, especially waters that have a strong tidal influence where the resuspension of sediments may reach much further in the offshore zone. There is also a strong influence of TSM due to High Sebou River run off (Azidane *et al.* 2021). This pandemic has provided a good opportunity to assess and analyze the anthropogenic activities on this coast. In this regard, it is hypothesized that the COVID-19 induced lockdown will improve the water quality of the region.

MATERIALS AND METHODS

Study area

Morocco is located at the north-western end of Africa, between the Atlantic and the Mediterranean Sea (Figure 1). It is bordered by Spain to the north and western Sahara to the south. The Morocco coast extends approximatively over 3,500 km. The Moroccan coastline is characterized by an important local ecological system. Along the coastline, different landform types (or geomorphology) have been recognized and described that depend on

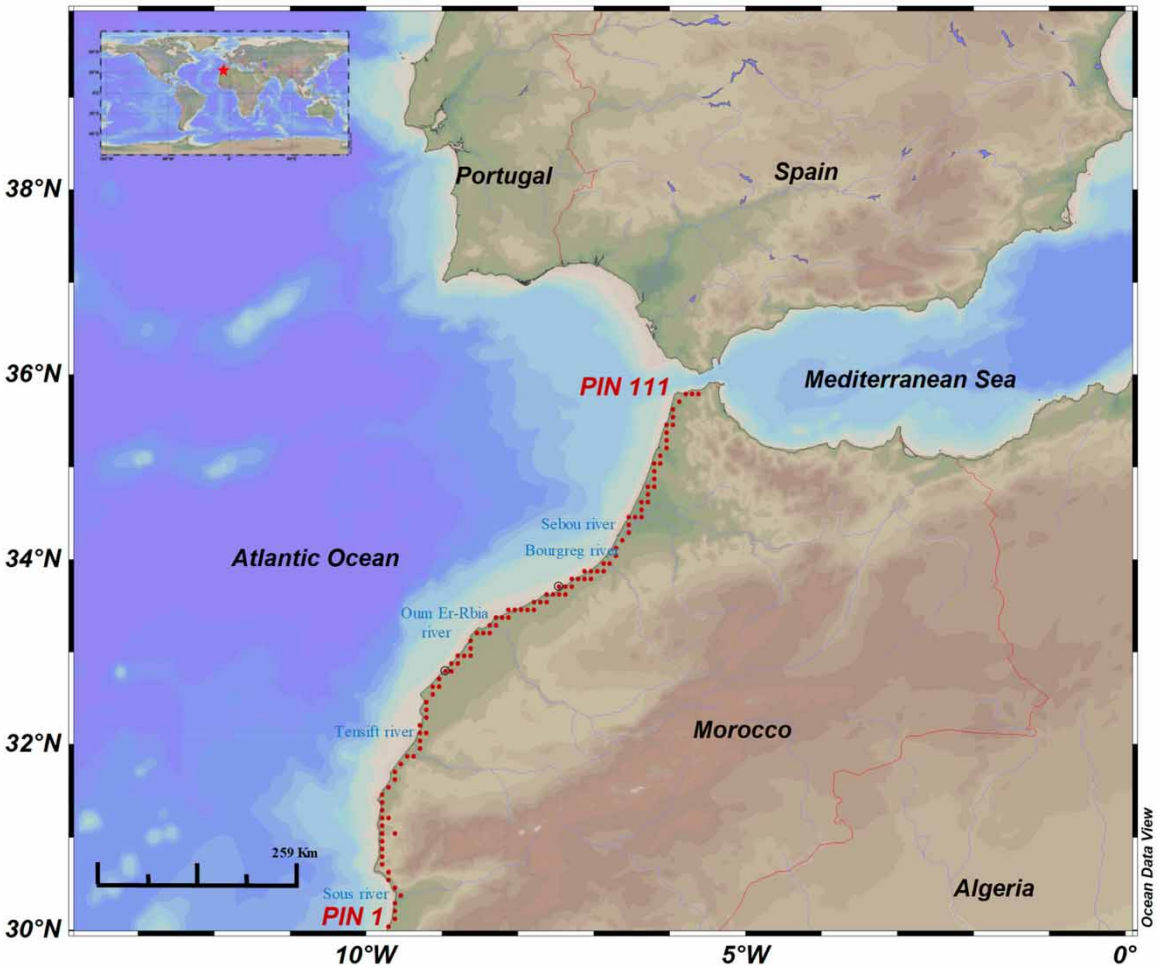


Figure 1 | Study area with the location of 111 pins.

topography, elevation, shape and composition characteristics (depends on rock types, unconsolidated materials, etc.).

This region experiences strong currents in some parts of the coast and various tidal elevations. The area harbors several major and minor ports and is subject to intensive industrial activities and urban growth (DPDPM 2008). Thus, as many other coastal regions, environmental change and inland processes including sediment, nutrient fluxes (riverine flux), and anthropogenic activities in the area threaten its water quality (Bennasser *et al.* 1998; Bouasria *et al.* 2007; Mhammedi *et al.* 2008; DPDPM 2011). An increasing level of sand mining, for example, has stirred up heavy metals in the sediment load from some lake mouths such as the Sebou river in Kenitra city (Jaaidi & Cirac 1987; DPDPM 2007; METL 2014). The longshore drifts associated with the waves are the principal agents responsible for the sedimentary transport and the sand distribution along the coast. Many researchers concluded that this area along the coast has a potential for coastal erosion (Moussaid *et al.* 2015; Azidane *et al.* 2017). A variety of the present erosion could be associated with coastal response to river sediment sources, river sediment transport, and sea level rise and dune destruction. Indeed, the higher dredging intensity that occurs along the Moroccan coast and illegal sand extraction can minimize sediment volumes. These marine activities are mostly distributed in the northern and western parts of the study area (Essilmi *et al.* 2019; Rafiq *et al.* 2022).

Datasets and image processing

We used the merged (4 km × 4 km) global monthly TSM product (2018–2019) from GlobColour. The GlobColour dataset is characterized by long time series of ocean color data that includes single-sensor and merged products. The TSM product is available from September 1997 to present. The TSM products were downloaded from the Hermes website (https://hermes.acri.fr/index.php?class=archive).

The TSM dataset has been created using the OC5 algorithm, which has been validated to work very well for case 2 waters, i.e. waters where inorganic particles dominate over phytoplankton (typically in coastal waters). We tested the dataset for the Moroccan coastline for several years, and the results show that TSM is a good indicator to assess water quality (e.g. Azidane *et al.* 2021). The datasets of the selected area were derived from satellite data and mapped during lockdown, post-lockdown and pre-lockdown. April 2018 and April 2019 represent two periods of normal livelihood for the population in the form of tourism, industry and aquaculture. However, April 2020 and April 2021 represent two periods of lockdown while all the activities closed down completely. Two hundred and forty Landsat images of Moroccan coast from April 2018 to April 2021 were downloaded from GlobColour merged with the resolution of 4 km and daily datasets (Table 1).

Table 1 | Landsat images of the Moroccan coast used in this study

Date of image acquisition	Product ID	Remarks
01/04/2018–30/04/2018	L3m_20180401__695624552_4_AV-OLA_TSM_DAY_00 – L3m_20180430__695624552_4_AV-OLA_TSM_DAY_00	Pre-lockdown
01/04/2019–30/04/2019	L3m_20190401__892672513_4_AV-OLA_TSM_DAY_00 – L3m_20190430__892672513_4_AV-OLB_TSM_DAY_00	Pre-lockdown
01/04/2020–30/04/2020	L3m_20200401__298557981_4_AV-OLA_TSM_DAY_00 – L3m_20200430__298557981_4_AV-OLB_TSM_DAY_00	Lockdown
01/04/2021–30/04/2021	L3m_20210401__660445597_4_AV-OLA_TSM_DAY_00 – L3m_20210430__660445597_4_AV-OLB_TSM_DAY_00	Post-lockdown

The TSM values corresponding to our points of interest were geo-corrected, land and cloud areas were masked out in order to obtain very precise TSM measurements. Upon extracting the dataset to a local system, the data were displayed to access image quality and then processed using ESA Sentinel Application Platform (SNAP). SNAP is a free and fully open-source software developed and maintained by ESA. The project is carried out by Brockmann Consult, Array Systems Computing and C-S. The SNAP architecture is ideal for Earth Observation processing and analysis due to the following technological innovations: extensibility, portability, modular rich client platform, generic EO data abstraction, tiled memory management, and a graph processing framework. Extraction of the mean values of TSM was done with SNAP then written to Excel format. Also, for each month (April 2018, April 2019, April 2020, April 2021), we calculate the (daily) mean of means for 30 days. Hence, we calculate the mean over the whole coast as a unit (Figure 2).

RESULTS AND DISCUSSION

General trend of TSM concentration: 2018–2021

The general trend of seasonal TSM concentration in the Moroccan coast is negative (Figure 3). The negative trend is gradual (slope = −4,137 and $R^2 = 0.988$). This indicates a moderate improvement (decline in TSM). In general, April 2018 had the highest TSM concentrations (>15 g/m^3) while the lowest value was measured in April 2021 (<5 g/m^3).

Spatial variability of satellite TSM concentration

To assess the changes of TSM distribution in the coastal area, an alternative method for analyzing the daily variability in TSM concentration is used to examine the maps of the mean in each pixel box. Thus, the pixel information values (pins) were used, the pin locations in the coastal area are indicated in Figure 1. The figure shows the pin's direction from the first one and the last one, which will facilitate the reading of our desired data.

Many studies have already been carried out in the oceans for the derivation of TSM concentration information from satellite remote sensing, such as Google Earth (e.g. Pozdnyakov *et al.* 2005; Kakati *et al.* 2021). For that, the Google Earth sensor was used in this study as well for faster processing and for rapid advancement. The variability of TSM concentration across the coast is given in Figure 4. A remarkably high TSM was observed over the shallow region for April 2018. It is noticeable that the TSM concentrations were relatively low along the shallow shoreline for April 2019 and April 2020. Furthermore, moderate values were observed for April 2021. Supporting

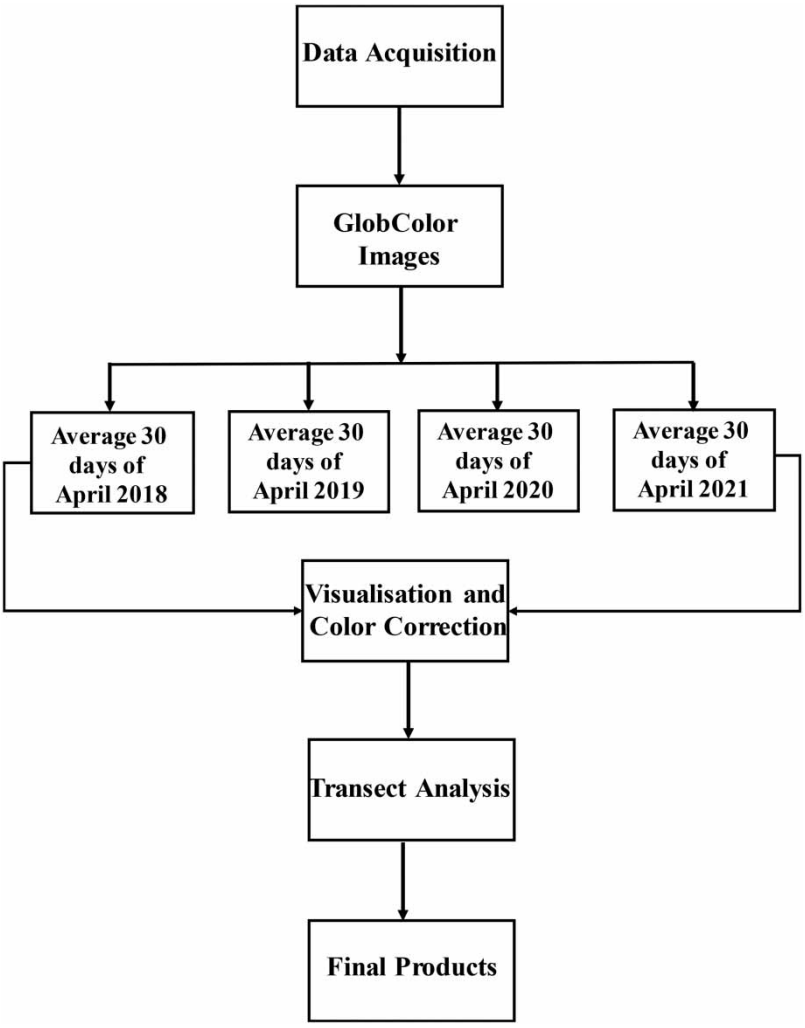


Figure 2 | Workflow of extracting total suspended matter (TSM) in SNAP (Sentinel Application Platform) software.

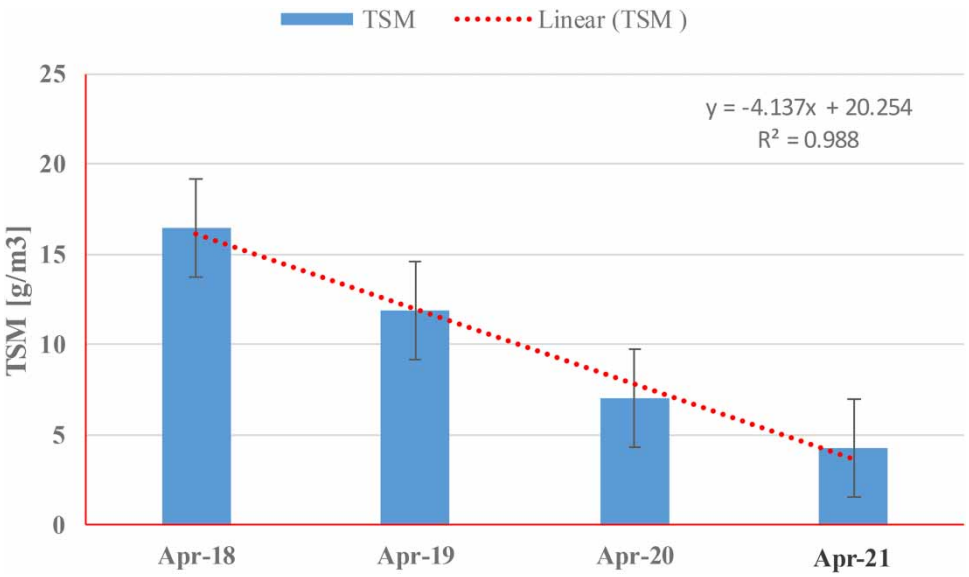


Figure 3 | Average trend of TSM concentration (g/m^3) April 2018–April 2021.

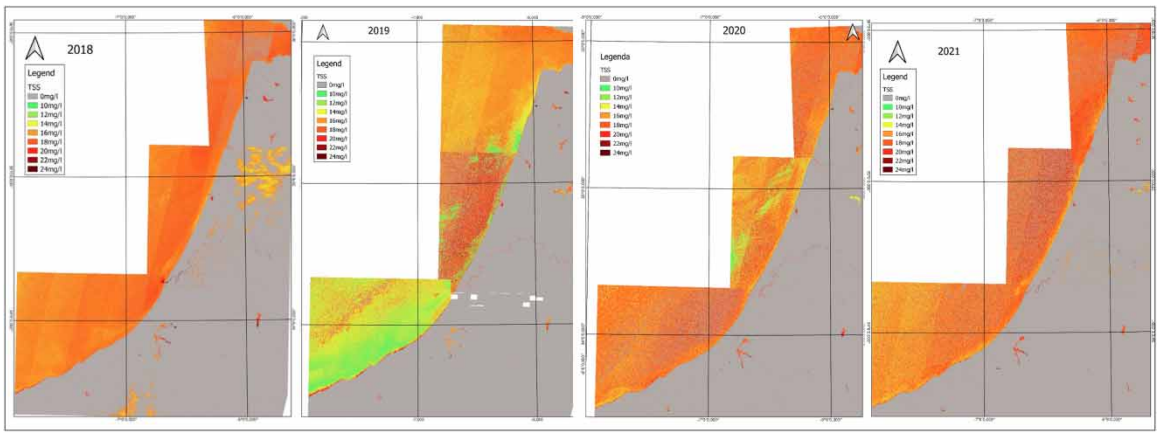


Figure 4 | Areal tracking of TSM from April 2018 to April 2021.

this, the Google Earth results also reported that a significant increase of the concentration of TSM dominated during the study period.

To investigate the TSM changes throughout the years, the satellite data provide more spatial and temporal coverage as illustrated in Figure 5. The visual interpretation of Figure 5 shows an important variation of TSM values

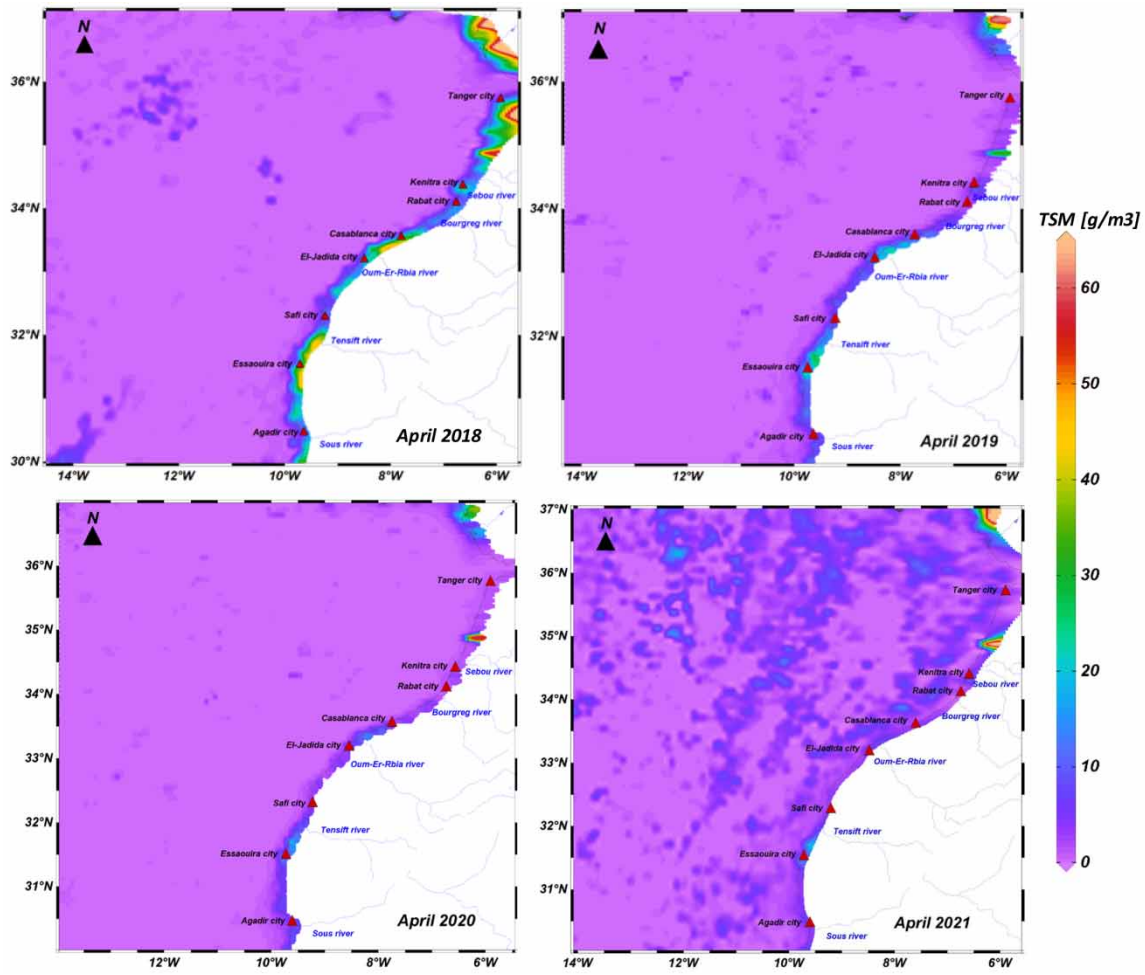


Figure 5 | Total suspended matter pattern maps from April 2018 to April 2021 in North Atlantic Ocean from satellites images in April (values in g/m^3; violet is low and red is the highest concentration). Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/wpt.2023.047.

from the north to the south. In April 2018, the highest values were registered in northern Morocco (Tanger region), in the center (Oum-Er-Rbia river mouth) and in western Morocco (Safi-Essaouira), corresponding to turbid water in coastal areas while the deeper parts of the study area remain clean. The coastal area exhibits a lower signature in TSM in the period April 2019; these results were registered in the same regions mentioned before. It can be said that water was less turbid in April 2019. However, there is a significant trend in the pattern and level of TSM from April 2020 to the end of the study period (April 2021), corresponding to clear water in the deeper part and along the Moroccan coast.

From our results and in-depth literature review, the following factors were identified to be driving the ongoing TSM changes taking place in the north (Tanger region): Effect of anthropogenic activities, especially as that zone is one of the most urbanized of the Moroccan Atlantic coastline (Omar *et al.* 2015); a large quantity of urban and industrial wastewater is released directly or indirectly into the sea, without any previous treatment; and the metal stored in the sediment contaminates the coastal areas and is released into the water column (Bartels 2001). Furthermore, the excavation trench resulting from sand dredging in the area could move toward the shore and may act like a sandpit on sediments of the coastal water by the generated turbidity and move pollutants deposited on the bottom (Patrick *et al.* 2012). Also, Azidane *et al.* (2021) revealed that the amount of sand dredging concentrated in the region is very high.

Oum Er Bia estuary is also under the influence of important anthropogenic activities (agricultural, industrial and urban). The area, sited along the west bank, discharges urban wastewater directly into the lower estuary and directly affects the coastal systems in which wastewater is often deposited. Also, this estuary has been deeply modified due to the first dredging activities in the estuary (Zourarah *et al.* 2009). Supporting this, Zourarah *et al.* (2007) and Maanan *et al.* (2004) also reported that municipal and/or industrial wastewater discharges into coastal zones are the most important sources for contamination of water and sediment with heavy metals.

Furthermore, the important aspect to consider in Safi-Essaouira region is the impact of the phosphate industry. There are chemical industry plants that produce phosphate derivates including phosphoric acid and fertilizers. The liquid effluents of the plants are discharged directly into the sea water without any previous treatment. The impacts of the phosphate industry on the coastal environment have also been investigated by Cheggour *et al.* (1999) who showed high concentrations of phosphate in the sea water of Safi-Essaouira.

Effect of COVID-19 on TSM concentration

Morocco is important socio-economically, shown by its intense industrial activity. Being on the bank of the river, the effluents from these industries reach the rivers (e.g. Sebou river (northern), Oum-Er-Rbia river (center) and Tensift river (western)) and pollute the water. However, the pattern of turbidity completely changed in April 2020 and 2021. This shows that the water quality of the coast water has been improved.

Overall, during April 2018 and April 2019 (pre-lockdown period), high TSM concentration was observed along the coastline area while the deeper part remained clean. The Moroccan coast experienced notable positive progress in its water quality owing to a reduction in the amount of the major influxes of contaminants from rivers, industrial and agriculture waste that lasted for one year approximately during the lockdown and post-lockdown periods (April 2020 and April 2021). Further, comparing the average TSM during the lockdown period with those of the pre-lockdown period, an important decrease was observed (−40.6% on average) (see Table 2). Because of the pandemic, a noticeable improvement in the shallow water characteristics was detected during the lockdown period.

Table 2 | Mean TSM concentrations along the Moroccan coast in 2020

	TSM average (g/m^3)		
Area	**Pre-lockdown**	**During lockdown**	**% Decrease (pre-lockdown and during lockdown)**
The Moroccan coast	11.88278744	7.058973045	40.59497334

Descriptive statistics and time series analysis are used to detect the trend of water quality during pre-lockdown, lockdown, and post lockdown. This is summarized in Figure 6. The TSM had spatial variability between 2018 and 2021. The results of statistical analysis showed that the turbidity of water was the lowest in April 2020 followed by 2021. On the other hand, the northern part located close to the mouth of Sebou river (between pins 95 and 97)

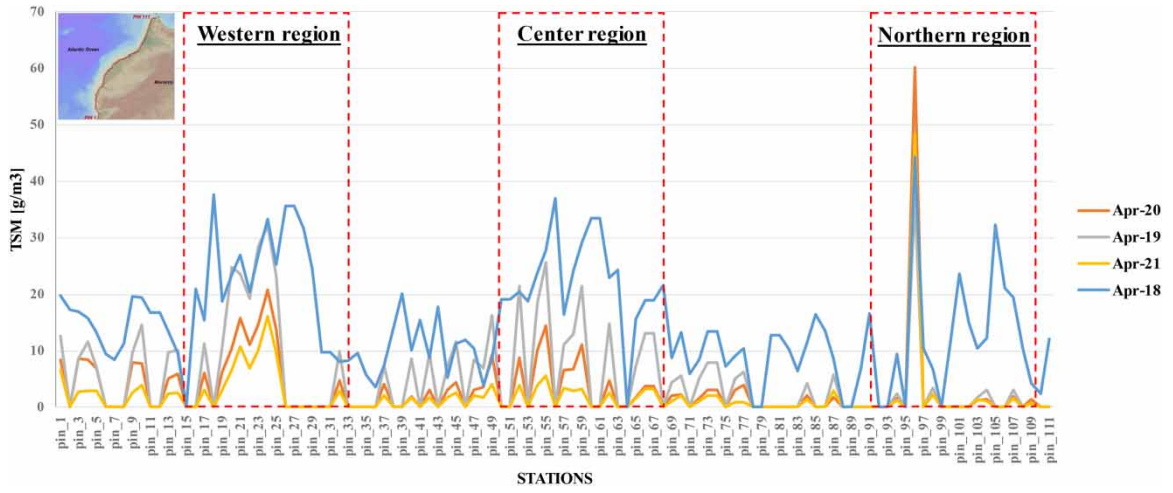


Figure 6 | Time series analysis of suspended particulate matter concentrations in Morocco during April 2018, April 2019, April 2020 and April 2021 (refer to Figure 1 for station identification).

recorded the higher TSM concentration in these periods (April 2020 and April 2021). However, *in situ* data will be a good step to show this differentiation.

A noticeable improvement in the shallow water was detected during the lockdown period at various location throughout the stations (Figure 6), especially the northern part where low TSM was observed in the Sebou River. So, it is suspected that there was less sand dredging or other coastal activities.

The decline in TSM (an indicator of improved shallow water quality) is largely due to the closing of almost all activities allowed on the Moroccan coast, thus, reducing the organic matter load in the rivers. As tourism was prohibited this brought a reduction in the amount of water discharges from restaurants and hotels close to the coast. Certainly, lockdown reduced all the sources of the heavy metal pollution such as activities related to shipping, untreated sewage, fishing, and phosphate mines activities.

It is well documented that satellite images recorded in April 2018, 2019, 2020 and 2021 were good tools to analyze the TSM concentration (e.g. Dantas *et al.* 2020; Wang *et al.* 2020). Within a few months, the water quality has improved in this area. So, for the eco-restoration of different components of the environment along the coast, the wastewater and the industrial waste or other input elements should be managed properly, to reduce further contamination and environmental pollution, which is now a matter of concern globally.

There are rules and regulation formulated to preserve the marine ecosystem. However, it seems less action is being taken on the ground level. The purpose of this study is to assess the trend of water turbidity and not in absolute values. The results obtained showed that the pollutant level decreased considerably when industries and boating were suspended. Therefore, now is the time for the Moroccan authorities to take stipulated actions based on the framework of the RAMSAR, Sea Law n°37-17 and Littoral Law 11-03 to reduce the environmental damage. We are of the opinion that to further decrease TSM concentrations in Moroccan coastal water, more aggressive and localized control strategies should be implemented to remove any contaminant or pollutants, such as nitrates and phosphates, in the future.

At the same time, communication and awareness plans for beach users, and particularly managers of sports and leisure services and activities, need to be strengthened. The rivers play an essential role in the mixing between ocean and river water and the health of aquatic ecosystems. The municipalities should be treating any sewage and litter, and adjusting agricultural practices before discharging to the rivers or lakes. These measures could potentially improve the water quality of the Moroccan rivers. Also, the future management efforts and plans in Moroccan coastal landscapes can strengthen the control of human activities and improve the values of the studied areas. The lockdown period should be a wakeup call to the Moroccan authorities to take urgent and appropriate management measures.

CONCLUSION

This study enabled us to demonstrate how satellite data and time series analysis of TSM products may contribute to the understanding of how the lockdown period may affect shallow coastal areas. Our analysis reveals a decline

of TSM, suggesting there is an improvement in the state of Morocco's coastal waters. This study observed that the shallowest part of the sea was the most problematic with high observable concentration of TSM during pre-lockdown period (April 2018). Observable differences were seen in the coastal water during the lockdown period. In this period, reduced TSM concentrations were observed due to the closing of all anthropogenic activities. To conclude, it is highly recommended to avoid or at least mitigate all these activities. Various studies have confirmed that marine litter degradation, sewage discharge from touristic units, agricultural practices and urbanization growth on beaches are major trace pollution sources in the Moroccan coasts and rivers. Future studies could assess *in situ* data during the post-lockdown period near the mouths of some major rivers in Morocco.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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