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Assessment of water quality in a tropical ramsar wetland of southern India in the wake of COVID-19

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ABSTRACT
The novel SARS-CoV-2 virus influenced the world severely in the first half of 2020 caused shut down of all kind of human activities. It is reported that a word-wide ecological improvement in terms of air quality and water quality during this lock down period. In the present study, an attempt has been made to study the progression in water quality through examining suspended particulate matter using remote sensing data in a tropical Ramsar site viz, Asthamudi Lake in Southern India. The change in spectral reflectance of water along the study area were analyzed and suspended particulate matter (SPM) is estimated from Landsat 8 OLI images. A comparison analysis of pre and co lockdown periods reveal that the concentration of SPM values during lockdown (mean SPM 8.01 mg/l) is lower than that of pre-lockdown (10.03 mg/l). The time series analysis of last five-year data from 2015 to 2020 also shows an average decrease of 43% in SPM concentration during lockdown period compared to the last five-average value of 9.1 mg/l.

1. Introduction

Despite the various efforts to protect vulnerable marine and inland ecosystems, anthropogenic activities remain as the primary source responsible for degrading the water quality (Kulk et al., 2021). In India, more than 38,000 million liters of untreated sewage water are discharged daily into the rivers due to limited sewage treatment capacity (CPCB, 2015). It has been proven that the combination of anthropogenic activities and climate change have negative impact on various aquatic environment (Hader et al., 2020). Conventional approach of water quality monitoring is relying on in-site measurements which are precise but are generally labor intensive and time-consuming which makes it difficult for continuous monitoring of water bodies (Quang et al., 2017) In addition, these estimates are limited to point-to-point information, thus extrapolation often becomes generalized in the complex ecological issues of water bodies (Gholizadeh et al., 2016). The application of earth observation-based satellite data products provided a breakthrough for fast and easy understanding of surface water quality. Remote sensing data products provides spatially explicit and temporally frequent observations about the extent and quality of water bodies at regional or even global scale (Huang et al., 2018; Sahadevan et al., 2021). Mapping of water quality and extend of inland waterbodies using remote sensing techniques have been carried out since 1970s, with the launch of Landsat series (Klemas et al., 1971; Johnson 1975; Ritchie et al., 1975).

Among the different water quality parameters, abundance of suspended particulate matter (SPM) is the most common problem in surface waterbodies (Garg et al., 2020). These suspended particles reduce the penetration of the sufficient light required for aquatic life and also considered as an indicator of eutrophication (Güttler et al., 2013; Sebastià-Frasquet et al., 2019). The turbidity of waterbody increases with an increase in the concentration of SPM in water (Yunus et al., 2020). There can be temporal variation in turbidity concentration due to fluctuation in weather, climate pattern and human activities along the banks as well (Luis et al., 2019a,b). Mapping of total suspended matter concentration from satellites imagery has become a significant tool for marine scientists to estimate and monitor suspended sediment
distribution in waterbodies (Nechad et al., 2010). The turbidity in water is analyzed by how SPM concentration alters optical properties of the water column. It is also reported that the concentration of SPM or turbidity shows good relation with the visible region of the spectrum whereas red and NIR regions are more sensitive towards turbidity (IOCCG 2000; Toming et al., 2016; Caballero et al., 2019; Sebastiá-Frasquet et al., 2019).

The novel Corona Virus (COVID-19) has emerged as 21st-century’s deadliest disease all over the world, affected around 210 countries (Aman et al., 2020). The COVID-19 affected millions of people around the globe and global economy severely. In response with the COVID-19 pandemic, government of India imposed a nationwide lockdown on March 25, 2020 that lasted until May 31, 2020 and this lockdown resulted reduced mobility, shutdown of schools, industries, businesses, markets, religious and social gatherings, and kept people at home. This lockdown period was further extended into many phases till June 8, 2020 formed a total lockdown period of 75 days with strict regulations and minimal mobilizations. Studies reported that the environmental conditions at various parts of globe increased in terms of reduced air and water pollution (Braga et al., 2020; Chauhan and Singh, 2020; Colli-vignarelli et al., 2020; Dantas et al., 2020; Lal et al., 2020; Muhammad et al., 2020a,b; Otmani et al., 2020; Chakraborty et al., 2021; Najahe t al., 2021; Tokatlı and Varol, 2021). In India also studies shows that both air quality and water quality across the country improved during lockdown period (Thomas et al., 2020; Chauhan and Singh 2020; Saadat et al., 2020; Yunus et al., 2020; Aman et al., 2020; Kulk et al., 2021; Chakraborty et al., 2021; Kour et al., 2021). To study whether the reduction in anthropogenic activities during the nationwide lockdown led to improved water quality in Asthamudi Lake, Southern India, the present study used multi-spectral remote sensing observations to analyses changes in the SPM as a water quality indicator.

2. Study area

The area selected for the current study is a portion of Ashtamudi wetland system, which is a designated Ramsar site, in the state of Kerala (Kollam District), India and located between 8°53’-9°2’N latitude and 76°31’–76°41’E longitudes (Fig. 1). Ashtamudi estuary is a palm-shaped extensive waterbody with eight prominent arms and also the second largest estuarine system in Kerala (Hussain et al., 2020). Kallada river is the major freshwater contributor to Asthamudi estuary, originates from the Kulathupuzha hills of the Western Ghats have an annual discharge of 75 × 10^3 m^3 of water into this estuary (Sujatha et al., 2009). The Kallada river system is a confluence of three small tropical rivers such as the Kulathupuzha, the Chendurni and the Kalthuruthy, originates from Western Ghats. The Asthamudi Lake is permanently connected with the Arabian Sea, and the lake water is exchanged daily by tidal fluctuations (Hussain et al., 2020). The lake is one of the leading centres of marine fish production and landings along the Malabar coast (Thresiamma and Nair, 1980) and receives significant attention due to its rich and varied fishery resources and an annual production of 23000 t of fish (Kurup and Thomas 2001). Subsequently, the lake supports livelihood of thousands of fisherfolk. The region experiences tropical humid climate with two distinct rainfall seasons viz., south-west monsoon from Jun to September and north-east monsoon from October to November. South-west monsoon alone contributes more than 85% of the rainfall and average annual rainfall of the region is 2400 mm. The average annual temperature of the region is about 25.5–31.4 °C (Chinnadurai et al., 2016). The underlying lithology of the Asthamudi Lake is mainly consisting of deposits of Quaternary and Tertiary sedimentary formations. The Quaternary sediments consists of marine, fluvial, and alluvial origins, and Tertiary formations comprise Laterite, Sandstones, and clays of Warkalai formation (Soman 1987).

The Asthamudi Lake has a total area of 61.4 km^2, among which the main lake is selected for the present study (see Fig. 1) which have a total area of 26 km^2. This Lake is one of the prominent tourist places in the state and this act as a source of livelihood to majority of local people in the form of tourism and aquaculture. The lake is severely polluted through several major and minor drainage channels loaded with waste products from municipal and industrial (mainly fish processing units) sources join the lake at the southern end (Sujatha et al., 2009). Asthamudi lake supports a large number of mangrove species as well as over 40 associated plant species, and 57 species of birds have been observed, including six that are migratory, in addition Nearly 100 species of fish have been identified (https://rsis.ramsar.org/ris/1204).

Fig. 1. Location map of the Asthamudi lake.
3. Materials and methods

3.1. Theoretical background

Suspended particulate matter (SPM) is the heterogeneous aggregates of organic matter, mineral fragments and microbiological fractions caused by run off, silt deposition, sedimentation, disposal of sewage and other pollutants from point and non-point sources, deposition of metals, and bacteria occurs in any of the aquatic environments (Vidmar et al., 2017; Yunus et al., 2020; Garg et al., 2020). Even though turbidity characteristics of water alone cannot be considered as a primary indicator of quality of water, but many of the researchers has used/using this as in overall indicator to assess quality of water (Woodruff et al., 1999; Davies-Colley and Smith, 2001; Luis et al., 2019a,b). The conventional form of estimating the turbidity is through observations checks using Secchi disk-based measurements (https://www.aquaculturealliance.org/advocate/secchi-disk-visibility-correct-measurement-interpretation/). However, these field-based methods have several limitations in assessment in larger water bodies, since spatial coverage and representation of the ecosystem is a major constraint. In addition, these methods are labor intensive and hence costly and also time consuming. Although with the introduction of advanced spatial technology using remote sensing application, extensive research has been carried out to identify the association between turbidity and waterbody in terms of quality based on the reflectance (Novo et al., 1989; Curran et al., 1987). Subsequently it has been noted that water quality parameters are sensitive to optical properties and can be studied through remote sensing techniques (Garg et al., 2020). For instance, results of the investigation of Curran et al. (1987) showed that increased reflectance was observed with higher turbidity. In addition, a study conducted by Doxaran et al. (2002) concluded that reflectance occurring between 400 and 1000 nm had a higher correlation with the levels of turbidity and it increases with the increase in the level of turbidity from 35 to 250 mg/L. Several authors developed empirical equation calibrated and validated the models using different mathematical expressions in the form of linear, logarithmic, non-linear and exponential regressions by linking the turbidity with that of reflectance based on the spectrum from the remote sensing satellite images (e.g., Wass et al., 1997; Tassan 1994; Song et al., 2011; Nechad et al., 2016; Dogliotti et al., 2015). However, with the introduction of large number of advanced sensors such as LANDSAT, SeaWiFS, MODIS Aqua and Terra, SPOT, MERIS, Sentinel-2, OceanSAT and recently Sentinel-3 OLCI images with open-source data platforms made the mapping of SPM or TSM has been widely conducted (e.g., Ritchie et al., 1990; Tassan 1994; Vanhellemont and Ruddick 2014; Wei et al., 2018). Both MODIS and MERIS had frequent revisit time (1–3 days) and sufficient radiometric resolution (12-bit) needed for dark objects like waterbodies. However, spatial resolution of these sensors (300–1000 m) was unsuitable for moderate size lakes. Although previous Landsat series (Landsat 5/7) satellites had good spatial resolution (30–79 m) but limited radiometric resolution (6–8 bits) being usable to certain extent for mapping lake water quality parameters. However, the later series of Landsat 8 satellite sensor which has a sufficient radiometric resolution (12-bit) suitable for dark object sensing and a spatial resolution of 30 m makes it a better choice for monitoring the lake water quality (Li et al., 2021). Therefore, in this study we used Landsat 8 OLI images acquired between 2015 and 2020 for analyzing the level of SPM using the methodology proposed by Nechad et al. (2010).

3.2. Data preparation and pre-processing

In the present study, seven Landsat 8 OLI images of Ashtamudi Lake area from February 14, 2015 to April 16, 2020 were downloaded from USGS earth explorer (https://earthexplorer.usgs.gov/) and detailed in Table 1. Detailed methodology adopted in the study for image pre-processing and SPM calculation is given in Fig. 2. All the satellite images downloaded were of level-1 category, indicating that they all are corrected for terrain co ordinates (geo-registration) and having high precision since the root mean square error (RMSE) are within prescribed limits. This level-1 terrain corrected scenes were undergone two pre-processing steps: (1) radiometric calibration for attaining Top of Atmosphere (ToA) Reflectance, and (2) atmospheric correction.

Pre-processing of the Landsat 8 OLI scenes were carried out using ACOLITE software. It is a software package developed at Royal Belgian Institute of Natural Science (RBINS) to carry out the process such as atmospheric correction using readily available algorithms for Landsat (5/7/8) and Sentinel-2 (A/B) satellite images and it is mainly used in environmental applications. The main advantage of ACOLITE is the simple and fast processing of high-resolution satellite images for aquatic applications (coastal/marine and inland water) and it also provides both command line and GUI based interface. Several previous studies successfully implemented this ACOLITE software for estimating chlorophyll-a, suspended sediments and for bathymetric survey in inland waterbodies and ocean/sea interfaces (e.g., Soriano-González et al., 2019; Caballero and Stumpf 2019; Yunus et al., 2020; Aman et al., 2020; Kulk et al., 2021). ACOLITE have four major phases of pre-processing, starting from transformation of raw DN (digital numbers) to radiance values by means of gain and bias values and thereafter it converts these radiance values to Top of the Atmosphere reflectance values. In the next phase, ACOLITE executes the atmospheric correction through “dark spectrum fitting” (DSF) method (Vanhellemont 2019; Vanhellemont and Ruddick 2018). In general, a mixture of the Short-Wave Infrared (1.6 μm) and NIR (0.8 μm) channels were used for this process. Few studies have proved that this combined strategy is successful in processing (Pahlevan et al., 2017).

3.3. SPM algorithm

In a previous study Prasad and Kani (2017) measured turbidity value of Ashtamudi Lake and reported that 24 NTU in post monsoon to 26 NTU in monsoon season. In addition, Santhosh and Bodusha (2017) measured turbidity values in summer months and ranges from 1.16NTU to 5.82NTU in some selected sites. These studies advocated that the level of turbidity in the Ashtamudi Lake is below 110 mg/l throughout the year. In the previous studies researchers established that using a single band for Turbidity estimation can provide a robust result if the band is chosen appropriately (e.g., Mobed Hasmadi and Norsaliza, 2010 and Papoutsia et al., 2014). On the basis of this, the present study used a SPM algorithm, which uses a empirical algorithm based on the single band to calculate the SPM concentrations for waters and it works well when the SPM concentration is less than 110 mg/l (Nechad et al., 2010). The SPM is calculated by using the red band (655 nm) by adopting the following equation (1):

\[
SPM = \frac{A_{PW}}{(1 - p_{PW}/C)}
\]

where \(p_{PW}\) is water-leaving reflectance (Rrs), A and C are empirical values.
4. Result and discussions

Spatio-temporal variations in SPM concentration in Asthamudi Lake from 2015 to 2020 including pre-lockdown and during lockdown period is demonstrated in Fig. 3a to Fig. 3g. It can be noticed that a decrease in overall SPM during co lockdown period is visible compared to previous years of pre-lockdown periods. This is evident from the time series analysis of Landsat 8 images from February 2015 to February 2020, which were depicted in Fig. 3a-f. Inter monthly variation and rainfall can also cause reductions in SPM concentrations. To confirm the same, time series images were taken for different years but at the same month and rainfall data were also analyzed and found no significant variation was observed during that period (data not shown). This confirmed that COVID-19 lockdown has strongly influenced the water quality of this RAMSAR site in a positive way and significantly brought down the pollution level. The reasons for low level of pollution is that domestic waste water discharge was continue to be there even during the period of lockdown. But our results confirmed, that pollution from tourism sectors, industrial sector and other associated anthropogenic activities are less during lockdown and hence it had a positive impact on water quality of the lake.

In addition, an average SPM concentration of last five years is compared with SPM concentration of lockdown period and given in Fig. 3h and i respectively. A quantitative analysis of the SPM concentration over the study area is given in Table 2. Result shows that highest mean SPM concentration of 12.02 mg/l found in February 2015 followed by 2019 (11.88 mg/l) and 2020 (10.03 mg/l). It is also noted that SPM concentration during lockdown period is from 3.65 mg/l to 23.61 mg/l with a mean SPM of 8.01 mg/l which is considerably lower than the pre lockdown period. In addition, a comparison between pre-lockdown period and co lockdown period shows a decrease of mean SPM values from 10.03 mg/l to 8.01 mg/l. The time series analysis showed that higher SPM concentrations are observed in northern, southern and south-western region. Especially this was high during the year of 2015–2019 and this SPM was reduced in the year 2020 and during lockdown period this spatial pattern is limited to south-western region. In general the higher SPM concentration at the south-western region, might be due to the fact that it is the entrance point to the Arabian Sea. This might be due to the fact that since it is closer to sea, during the high tide situation results in intrusion of salinity into the lake, which altered the pollution load in those regions, even though industrial activities were not there. A comparison between an averages SPM concentration of last five years (Fig. 3h) with SPM concentration during lockdown (Fig. 3g) shows a substantial decrease of 43% in SPM concentrations during lockdown period as compared with the last five years average (Fig. 3i).

Thus, the closure of anthropogenic activities including industries and tourism has resulted in the decline of SPM concentration in Asthamudi Lake. Due to the lockdown and absence of onsite data, validation and comparison with onsite data is not considered in this study. However, the result of the present study is comparable with the studies conducted elsewhere in Indian regions. For instance, Aman et al. (2020) studied the turbidity level changes during lockdown period in Ahmedabad metropolitan city in India and found that a 36.48% change in SPM compared to pre-lockdown period. Another study by Yunus et al. (2020) showed the SPM changes in Vembanad Lake in Kerala which have more or less similar environmental conditions to Asthamudi Lake and reported an average 15.9% decrease in SPM. The aforementioned results are found similar to the results of the present study. In addition, Kulk et al. (2021) studied the water quality changes in Vembanad Lake during lock down period using both remotely sensed satellite images and in site measurements and reported the water quality improvement during lockdown period. Thus COVID-19 lockdown not only resulted increase in water quality but also the improvement in air quality. An observational study conducted by Thomas et al. (2020) too indicates that due to lock down, air quality parameters such as NOx, NOy, CO and particulate matter shows substantial decease resulting an improvement in the air quality.

The lower SPM levels in these RAMSAR site tends to improve the penetration of sun light and definitely have positive impacts on marine benthic ecosystems and overall ecological status of the water body. A word of caution, is that this conclusions are derived from satellite observations only and hence it may be difficult to get the details on the chemical composition of the particulate assemblage and thus dedicated field level studies are needed to confirm the same and long term monitoring of such data will be useful in devising suitable management constants: $A = 289.29$ and $C = 0.1686$ (Nechad et al., 2010).

Fig. 2. Workflow of the methodology adopted in the study.
strategies With the COVID-19 pandemic lockdown, which has provided new avenues like this and hence an attempt was made to understand the temporal and spatial data on water quality of this RAMSAR site.

The COVID-19 pandemic lockdown at this study site is likely to initiate a revival and recovery process of the natural ecosystem, in spite of other anthropogenic challenges. However, policy makers and concerned department officials should take note of the situation and the extent and quantum of the revival, this lockdown has brought in to these water bodies. Hence, it is also suggested that these kinds of strict enforcement can enhance the self-revival ability of the ecosystems, an aspect which human beings are taking it for granted, since centuries.

![Time series SPM concentrations estimated for the Ashtamudi lake from 14th February 2015 to 16th April 2020 and change in SPM values. Red values indicate higher concentration of SPM and green values indicates low concentration.](image)

**Table 2**

| Date of Acquisition | SPM concentration | Remarks          |
|---------------------|-------------------|------------------|
|                     | Minimum          | Maximum         | Mean  | SD    |                  |
| 2/14/2015           | 8.16             | 27.19           | 12.02 | 1.50  | Previous Years  |
| 2/01/2016           | 3.75             | 24.55           | 9.79  | 2.79  |                  |
| 2/03/2017           | 3.76             | 21.42           | 9.56  | 3.43  |                  |
| 2/06/2018           | 4.88             | 21.54           | 9.23  | 2.19  |                  |
| 2/25/2019           | 4.27             | 32.76           | 11.88 | 3.32  |                  |
| 2/12/2020           | 2.97             | 28.89           | 10.03 | 2.48  | Pre-lockdown     |
|                     |                  |                 |       |       | period           |
| 4/16/2020           | 3.65             | 23.61           | 8.01  | 1.59  | During lockdown  |
|                     |                  |                 |       |       | period           |
5. Conclusion
SARS-CoV-2 is becoming a severe threat to human life and more than 163 Million people were affected and more than 3.37 Million death reported worldwide (as of May 17, 2021). With the severe outbreak of COVID-19 many countries were completely shut down with complete restrictions on economic, social, educational, religious, and all other activities and this lockdown turning into a “blessing in disguise” in the cause of water quality and atmospheric pollution (Muhammad et al., 2020a,b). In the present study, an attempt has been made to recognize the effect of COVID-19 lockdown in Ashtamudi Lake with spatial technology by using data products from remote sensing. Although we were not able to pinpoint specific sources of pollution, the result of the present study showed that water quality (SPM) can improve substantially when anthropogenic activities are reduced. The analysis of the SPM concentration in Ashtamudi Lake using Landsat 8 OLI image shows that the concentration of SPM values in lockdown (mean SPM 8.01 mg/l) is lower than that of pre-lockdown (10.03 mg/l) and last five-year average (9.1 mg/l). An average decrease of 43% is noticed in SPM concentration during lockdown compared to last-five-year average. It is also noted that during the lockdown, domestic sewage continues to drain into the Ashtamudi Lake which shows industrial waste and tourism are the major activities that deteriorating the hydropshere and severely polluting the lake water. Thus, the present study provides some important insights into the future management of Lake Ashtamudi and other coastal and aquatic ecosystems. Therefore, the policymakers should take note of these improved water quality conditions due to the reduced anthropogenic activities and should plan the future Ashtamudi Lake management policies accordingly.

Ethical statement
The authors declare that all ethical practices have been followed in relation to the development, writing, and publication of the article.

CRediT authorship contribution statement
T.S. Aswathy: Writing – original draft, Writing – review & editing, Visualization. A.L. Achu: Data curation, Writing – original draft, Writing – review & editing, Visualization. Shincy Francis: Writing – original draft, Writing – review & editing, Visualization. Girish Gopinath: Conceptualization, Data curation, Writing – review & editing. Shijo Joseph: Supervision, Writing – review & editing. U. Surendran: Supervision, Writing – review & editing. P.S. Sunil: Supervision, Writing – review & editing.

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

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