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Linking climate variability and water associated diseases through Earth Observation in coastal areas of India

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Abstract

Climate-related extreme weather events impinge on human life and assets in various ways wherein their contributions to the transmission of water-associated diseases introduce additional hurdles on our efforts to control them. This article examines the impacts of extreme weather events on water-associated diseases using examples from the Kerala flood of 2018, and its impact on the microbial pollution in Vembanad lake and coastal regions of Kerala, using in-situ and remote sensing-based monitoring of water quality, models, and digital platforms. The article also discusses capacity building initiatives such as citizen science, awareness building, and training programmes for supporting efforts to control the outbreaks of epidemics during extreme weather conditions.

1. Introduction

Human populations across the globe are exposed to risks associated with climate variability, more than 80% of which are water related. Climate and water-related issues are more prominent in Asian countries, with 81 events in 2022 alone, with more than 83% of them being related to flood and storm events. These events have affected nearly 50 million people in Asian countries in 2022, causing an economic loss of US$36 billion and a death toll of five thousand. Apart from damages to the agriculture, infrastructure and associated economic loss, extreme weather events also impact human health through outbreaks of water-associated diseases. Variations in temperature, rainfall and precipitation influence the distributions of pathogenic bacteria in aquatic ecosystems. Such changes, often accompanied by breakdown in the availability of clean water, can lead to increases in the burden of diseases in humans and outbreaks of water-associated diseases such as cholerae, diarrhoea, leptospirosis and mosquito-borne diseases.

Lack of access to safe drinking water and close interactions with microbially-polluted aquatic systems increase the vulnerability of humans to water-associated diseases. Across the world, more than 2 billion people use drinking water contaminated with faeces; and approximately 4 million people suffer from cholera, a water-associated disease every year, of which nearly 143000 lead to death . UN Sustainable Development Goal 6 (SDG 6) aims to reduce these numbers through providing access to clean water and safe sanitation facilities for the entire global population. Awareness programmes and involvement of citizen scientists could encourage people to follow WaSH (water sanitation and hygiene) protocols and thereby reduce the incidence of disease outbreaks. The chances of contracting bacterial infections from contaminated waters are higher in Asian countries, especially during extreme weather events such as flash floods when people are forced to interact with polluted water (Fig. 1). Therefore, it is important to understand the influence of environmental conditions and processes on water-associated diseases, to develop appropriate management strategies.

Figure 1. Photograph showing exposure of people to contaminated water during a flash flood in 2022 in Ernakulam district, Kerala, India

The major factors which augment the spread of water-associated diseases in coastal regions include: increasing occurrences of floods along with mixing of coastal and inland waters with microbial pathogens from land (through terrestrial runoff); changing environmental conditions that could alter the survival and growth of pathogenic bacteria in natural water bodies; high population pressure; development activities that modify water flow and water quality; and breakdown in, or lack of access to, a supply of safe drinking water and sanitation facilities. This article examines the influence of climate variability on the proliferation of microbial pathogens in coastal and inland aquatic systems; its relevance to human health; and capacity building towards mitigation of the risks, for the specific case of Vembanad Lake and surrounding regions in Kerala, India. The article uses the data generated in our previous and ongoing research programmes: REVIVAL supported by DST (India) and UKRI (UK) under India-UK water quality research; PODCAST supported by DBT (India), UKRI (UK) and JAMSTEC (Japan) under the TaSE scheme; WADIM supported by the Wellcome Trust, and the network project ONWARD supported by GCRF (UK).

2. Climate variability, microbial pollution, and water-associated diseases

Various studies of outbreaks of water-associated infectious diseases have some links between climate change and incidence of cholera disease caused by Vibrio cholerae . Apart from V. cholerae, there are at least 12 other Vibrio spp. that cause diseases in humans and aquatic animals, which are prevalent in the coastal waters. The incidence of infections caused by Vibrios have been reported from a number of areas, including Israel and Northern Europe where the Vibrio-related diseases were not prevalent earlier showed that the number of Vibrio cases increased with annual maximum sea surface temperature and labelled non-cholera Vibrios as the microbial barometer of climate change. Considering relationships between Vibrios and environmental conditions, geographic areas suitable for Vibrios have been characterised using an ecological niche model (Escobar et al. 2015). Their model output, extracted from the global map showed in Fig. 4 of their paper, shows that the northern Indian Ocean conditions are generally suitable for Vibrio cholerae bacteria under current climate. In another study, an index labelled as "satellite water-marker", estimated from two-wavelength remote-sensing reflectance observed from satellite ocean-colour data has been shown to be related to reported cases of cholera in the Bengal Delta and Mozambiue. Cholera outbreaks have also been associated with rainfall and storm events. In the northern Indian Ocean, year-to-year variations in oceanic and atmospheric conditions are influenced by large-scale patterns in inter-annual climate perturbations such as the El Niño and the Indian Ocean Dipole (i.e., accounting El Niño for 30 and IOD for 12% of the total variation of anomalous Indian Ocean sea surface temperature). These variations in climate conditions have been shown to modulate phytoplankton dynamics and affect the dynamics of cholera outbreaks in the Indian Ocean region. Faecal contamination from anthropogenic sources is considered to be a major source of V. cholerae in coastal waters, and Escherichia coli is considered an indicator bacteria for faecal contamination. Furthermore, E. coli itself is a pathogenic bacterium responsible for diarrheal infection.

3. Study area

We studied E. coli and Vibrio cholerae data from Vembanad lake in 2018-2019. Vembanad lake (09°00' - 10°40' N latitude and 76°00' - 77°30' E longitude) which straddles Alappuzha, Ernakulam, and Kottayam districts of Kerala, was severely affected during the flood in 2018, as it has a large drainage area of 15,770 km^2. During the flood, more than 400 km^2 of land near the lake was submerged, and the areas near the lake in Kuttanad region of Alappuzha district were submerged to heights of 2.4–4.6 m. Vembanad Lake is an ideal location to examine the influence of climate variability on water associated diseases, for various reasons: 1) This is a low-lying area, vulnerable to high impact from sea-level rise associated with climate change, 2) Nearly 1.6 million people interact with Vembanad lake and use for washing, fishing, recreation, and transportation (Fig. 2), 3) Vembanad Lake receives freshwater discharges from 10 rivers covering ~40 % of the drainage area of the state, 4) It also receives a significant fraction of ~235 million litres of sewage produced every day in the residential areas of Cochin city through non-point sources, 5) Faecal contamination of ground water and surface water and associated disease burden are common in Kerala, 6) Finally, the literacy rate, public awareness, human development index and medical facilities in the area are much higher and comparable to those of European countries, which could facilitate translation of scientific findings to policy action.

Figure 2. Images from Vembanad lake, which shows interactions of people with Vembanad lake – tourism (a), transportation of people (b), different types of fishing (c), waste disposal (d), washing and bathing (e) and fish farming (f).

4. Methodology

Water samples were collected from multiple depths at 13 stations along the length of the Vembanad Lake once in ~20 days over a period of more than one year. Analyses of the water samples showed no instances when the abundance of E. coli decreased below detection limit. Rain and associated floods have been shown to contribute directly to elevated levels of faecal contaminants in coastal waters elsewhere. In Vembanad lake, the abundance of E. coli increased rapidly in the early two months of the south-west monsoon (June-July), indicating the role of heavy rain in washing down the faecal contaminants from terrestrial to aquatic ecosystems (Fig. 3). A plausible inference is that enhanced faecal contamination does not occur only during the floods: the problem is present well before the floods occurs and is probably associated with land drainage and a rise in ground-water levels, and consequent contamination of rivers and ground water with faecal material. In Vembanad Lake, rising water table associated with heavy rains could have caused mixing of material from septic tanks and sewage treatment systems with terrestrial runoff and ground water, which in turn could have led to the observed increase in the abundance of E. coli in the water in the first phase of the south-west monsoon . In fact, during the floods in August, the faecal contamination decreased, perhaps as a result of the contaminants being washed out to the sea as the flow rate towards the sea increased.

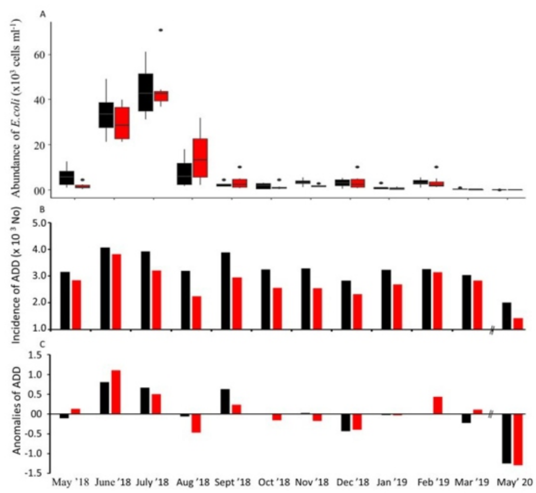

Figure 3. Temporal variation in the abundance of E. coli in the water column of Vembanad lake (A); incidence of Acute Diarrhoeal disease (ADD) (B); and the anomalies in the incidence of ADD, computed as the difference from the mean value for all available observations (C) in the brackish water (black) and fresh water (red) regions of Vembanad lake. Diseases data for Ernakulam district are assigned to the brackish-water side of the lake and sum of data from Alappuzha and Kottayam districts are assigned to the southern, fresh-water side of the lake.

The number of cases of acute diarrheal disease (ADD) in the three districts around the lake never dropped below 1000 per month in 2018. The anomalies in the occurrence of ADD showed a significant Spearman correlation ($r = 0.58$, $p<0.05$) with E. coli abundance in the lake , which provides some indirect indication that the occurrences of ADD are related to the faecal contamination in the lake. Upsurges in faecal contamination and subsequent incidence of water-associated diseases subsequent to natural disasters such as storm surges and floods have been reported from coastal regions across the globe. However, in Vembanad Lake, the level of contamination peaked prior to the floods of 2018, suggesting that land drainage, rising water tables and mixing of sewage with ground-water supply in the wake of heavy monsoon rains all play important roles in dictating contamination levels in the lake, even in the absence of floods. The chances of acquiring water-associated diseases are high among women and children who interact frequently with contaminated water bodies for washing and recreation, respectively.

5. Capacity building and prevention of microbial pollution

Extreme weather events extend the geographical distribution of pathogens in coastal areas and increase the chances of epidemics. The links between climate change and water-associated diseases are yet to be understood completely. Addressing this problem needs a multidisciplinary approach, which is encapsulated within different Sustainable Development Goals for 2030. SDG 3 (Health) aims to "Strengthen the capacity of all countries, especially developing countries, for early warning, risk reduction and management of national and global health risk". SDG 6 (water) also covers this issue and aims to "Ensure availability and sustainable management of water and sanitation for all". The SDG13 relevant to climate change aims "improved education, awareness raising and human institutional capacity in climate change mitigation, adaptation, impact reduction and early warning". Capacity building is also relevant to SDG 8 (Decent work and economic growth), SDG 10 (Reduced inequality) and SDG 14 (Life below water). Redesigning sewage treatment systems in flood-prone areas to avoid mixing of septic-sewage with coastal waters is proposed in a recent study as a necessary step to reduce the risk of water-borne diseases.

Overall, the capacity for managing outbreaks of water-associated disease related to climate change should aim at an ecosystem-based approach in which public awareness and participation in monitoring and management of ecosystems are critical. Microbial pollution of aquatic ecosystems and the spread of diseases through contact with such water bodies are low among communities aware of the importance of personal and environmental hygiene. These communities can be trained to become citizen scientists to join scientists in monitoring aquatic systems using simple tools and prompt dissemination of results, which will be invaluable in helping to identify possible development of conditions conducive to disease outbreaks (Sathyendranath et al. 2020). Citizen scientists equipped with a mini-Secchi disc for monitoring water clarity, and a Forel-Ule scale for recording water colour, and a mobile app "TubAqua" were employed successfully to monitor the colour and clarity of the Vembanad Lake and validate remote sensing data. Development of curriculum-based training programmes in water quality monitoring would also contribute to awareness building and prevention of water-borne diseases. Kerala, with its high literacy rate, has the potential to start courses on environmental health and implications for human health into its school curriculum as a measure to build an informed body of citizens who would be part of the solutions for reducing and even eradicating water-borne diseases.

The efforts to address water associated diseases remain fragmented globally, and are often focussed on a particular region, to address specific outbreaks. The lack of a common platform for different scientific disciplines (microbiology, molecular biology, modelling, remote sensing, epidemiology, clinical research, social scientist) to exchange their experiences, models and tools is a limitation to achieve global targets. ONWARD, an open network for water associated diseases (https://onwardnetwork.net), provides an online platform for scientists and stakeholders to share their common interests in better "understanding of environmental controls on outbreaks of water related diseases; the role of societal engagement in countering it; and in forecasting, early warning and risk mapping of water-associated diseases through the use of remote sensing, field observations and mathematical modelling".

Forecasting, early warning and risk mapping of water associated diseases using remote sensing, supported by in-situ observations and modelling, can help build resilience against climate-related epidemics. One could envision a future where new scientific information would enable cost-effective, regularly updated, geo-referenced and timely warnings for areas vulnerable to water associated diseases, which in turn would enable optimisation of preventive measures to be deployed to minimize the probability of epidemics. The environmental data provided by remote sensing have large spatial extents (regional) and high resolution on the ground(Sathyendranath et al. 2020). By combining information acquired from intensive in situ sampling with remote-sensing data, it should be possible to develop geo-referenced maps of risks of exposure to water-associated diseases in a complete and in-depth manner. Because the environmental component of disease risk is subject to fluctuations in climate, the question of resilience to climate change must also be addressed when dealing with risks from water-associated diseases, by modelling expected changes in intensity and frequency of extreme weather events as well as long-term trends in environmental conditions (such as increasing temperature and rising sea level).

The combination of in situ, remote sensing and citizen science data are important for developing epidemiological models, which can be used to forecast the probability of microbial pollution and disease outbreaks in coastal areas. The research projects REVIVAL, PODCAST- WADIM and the network project ONWARD are aimed at developing cell-phone-based tools to collect information leading to dynamic, regional sanitation maps that could facilitate targeted remedial action at in periods of high risk of disease outbreaks and could also serve as a communication tool to inform populations of changes in risk levels. Continuous monitoring of water quality of inland and coastal waters using in situ measurements and remote sensing, and preparation of risk maps indicating contaminated areas would motivate the public to practice environmental hygiene; and citizen science can be an effective mode of collecting data and also of societal engagement (Sathyendranath et al. 2020, Anas et al. 2021, George et al. 2021).We also recognize the importance of combining observations with hydrological and hydrodynamic models that deal with transport mechanisms and flushing rates of the lake, to understand the dynamics of pathogenic bacteria in the water. Ideally, such models would account for the growth and decay of the different types of bacteria under the local environmental conditions.

6. Concluding remarks

Here, we discuss water-associated diseases and their links to climate-related extreme weather events. As our understanding of aquatic ecosystems improve, we can improve the risk maps that can be produced to alert the local population of the threats from water-borne diseases and to help plan remedial actions. As we work towards such a holistic solution, the importance of personal hygiene cannot be overstated, as a necessary measure to minimise health risks from contaminated water. Our studies have revealed a complex and integrated path that has to be followed to achieve the global target of eliminating the transmission of water-associated disease by 2030.

In this paper, we have highlighted some of the work being done in the Vembanad Lake region, which has helped improve our understanding of environmental factors related to water-associated diseases. The problem cannot be said to be solved when the prevalence of risk from water-borne diseases has been identified: there are also many scientific challenges to be tackled, to improve our understanding of the epidemiology of many water-associated diseases. It is a problem that straddles fresh and saline waters and calls for collective action from scientists of many disciplines. New information must then lead to appropriate action to improve environmental conditions and reduce risks to human health. Natural water bodies that bear the burden of pathogenic microbial pollution are often the life blood of people who live in the area, who rely on them for drinking, cooking, recreation, fishing, aquaculture, transport, and tourism. Finding solutions and implementing remedial actions are therefore of paramount importance.

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Tuna fish market in the Androth Island, UT of Lakshadweep, India – A field study


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Abstract

The Laccadivian islands are rich in Thunnus fish species that have high market values across different continents. Hence, Tuna fish industry is one of the major industries in all islands of the Union Territory of Lakshadweep (UTL). Therefore, to examine the current scenario of tuna fish industry, a field study on different attributes of tuna fishing and trading in the Androth island of UTL was performed. A morning fish market located in the eastern side of Androth island, UTL was selected as the field of study.

The fishermen of Androth jetty fish market participated in the field study. Details regarding Tuna landings were collected from the fishermen. The field study identified that fishing and trading is done for raw tuna fish as well as dry tuna fish forms. House hold tuna consumption and local tuna-based food markets resonates well as there is high abundance of tuna species during the seasons. It can be said that Tuna based traditional food markets are sustainable in Androth due to converting raw tuna fish into dried form called “mass meen”. A market thus exists for developing Tuna based sea food industry on a larger scale at Androth.

Key Words: Coastal Island, Androth, Fish market, Tuna fish industry

1. Introduction

Androth is one of the coastal islands of Lakshadweep lying on the Arabian sea, 220 – 440Kms off the Kerala coast. It lies in the east west orientation, between 10° 48' and 10° 50'N latitude and 73° 38' and 73° 42 E' longitude (http://lakshadweep/gov.in). Androth is the largest island of UTL with an area of 4.90 sq, length of 4.66 km and a maximum width of 1.23 km. It stands apart from other islands of Lakshadweep in having a very small lagoon area and in the orientation. It is the most populated island among the eleven inhabited islands of Lakshadweep (Chandramohan et al., 1993; Koya et al., 2021).

Fishing is the major industry in Androth (Pillai et al., 2006; Vinay et al., 2017; Koya et al., 2021). Fish markets thrive in Androth due to landings of different Tuna species and lagoon fishes. Due to low lagoon area, the number of landing sites are less when compared to other islands of Lakshadweep. There are two major landing sites in Androth island, one at Androth jetty area and other at the Tharavakar junction. The present study is a field analysis on Tuna landings and Tuna fish market existing at the jetty area of Androth, UTL.

2. Method

A questionnaire was prepared and visits were made to the Androth fish market. Attributes of Androth tuna fish market were collected from the fishermen (Table 1). The questionnaire had different sections A, B and C. Section A dealt with general attributes of fishermen like age, gender, education, source of income. The section B gave information on all fish landings (including Tuna) and section C on attributes of the Tuna fish market in the jetty area of Androth, UTL.

Table 1. Major Attributes of the field analysis

Sr. No	Section A
1	Age
2	Education level
3	Trained
4	Boat owner
5	Boat – Gear
6	Major source of income
	Section B
7	Time of landings
8	Duration of landings
9	Landing size – infinite (>50,000) or finite
10	Catch of all species
11	Catch by Tuna species
12	Consumption patterns
13	Commercial landing categories – large species (A, B, etc), small species (A, B, etc)
14	First sale prices
	Section C
15	Main opportunities available in Andrott fish market
16	Significant trends observed in Androth fish market
17	Factors that are predicted to propel the growth of Androth fish market
18	Factors that are expected to limit the growth of Androth fish market
19	Opportunities for Androth fish market expansion and global reach
20	High season months in Androth fish market
21	Low season months in Androth fish market
22	Common varieties of Tuna species found in Andrott fish market
23	Unusual varieties of Tuna species found in Andrott fish market
24	Tuna fish market size in Androth
25	Growth rate of overall market in Androth

3. Results and Discussion

3.1.Study population

The study population consist of male fishermen from Androth, a coral island of the UT of Lakshadweep. All respondents are in the age category of 30 to 50 years and fishing forms their major form of livelihood and income generation. Majority respondents are venturing into the sea for long years (>30 years) and a few are less than five years.

Seasoned fishermen who participated in the study are trained on safety and security measures by the dept of fisheries, Androth unit. The new fishermen are yet to receive any training. Majority are boat owners and have boat with gear. The revenue generated from landings depended upon the catch for the day.

3.2. Landings at Androth Fish market

Landings are mostly done after fishing for an average duration of 6 hours. Some landings are done after 12 hours in the sea with different time gaps. It was reported that the catch (Fig. 1) is most yielding during the early time of the day. Tuna and Lagoon fishes are prominent among the catch (Fig. 2). Landings include large Tuna fishes (Yellow fin and Bluefin tunas) and small Tuna fishes (Skipjack), Lagoon fishes (Reef fish, Rainbow runner, seer fish, sail fish) and octopus. Skipjack is the most occurring among the Tuna species caught. Normally target landings are achieved during the monsoon when the fish numbers are increased due to a favorable productive time.

Figure 1. A glimpse of landings at Androth fish market

Figure 2. Catch by Species

3.3. Trading at Androth fish market

Majority of the fisherman are also traders. The fish is traded in raw form and given to customers after cleaning and cutting (Customer friendly). Domestic consumption of Tuna is as cooked Tuna curry and fried. Dry fish market is mainly Tuna based and depends on the availability of Tuna fish and Mass production. For preparing "Mass", fresh Tuna fish is taken and the abdomen region is processed by removing head, tail and gut content. The fish is cut into pieces, washed and cooked in brine for 2 hours. Smoking is performed over the brined tuna for 2 to 3 hours using smoke from burning coconut husks (thondu). This is an important process to help preserve the fish as the smoke delivers an acidic coating onto its skin surface. This coating prevent oxidation and slows the growth of bacteria, which in turn slows the decomposition of fish. The smoked fish is sun dried and stored in containers as mass meen (Fig. 3).

Figure 3. Mass meen

3.4. Tuna Mass based food market

Mass produced is mostly consumed during the off season when fresh tuna availability is limited in the island and also in preparing traditional mass-based dishes of Androth (Table 2). In Androth island, the mass production is low on an industrial scale, though it is made in individual families where the mass and traditional dishes are prepared using open kitchen spaces (Fig. 4).

Figure 4. Open kitchen space for preparing traditional Tuna food items

Table 2. Traditional food items prepared in Androth from Tuna fish & Mass

Mass podichath
Mass appam
Tuna fish bowl
Madakkappam
Mass Idiyadda
Idichathum kanjiyum
Tuna fish pickle
Mass undakadi
Tuna fish kadi
Tuna nadan biriyani
Tuna kozhukatta
Tuna cutlet
Tuna samosa
Mass puttu
Massanum & orotti

Mass podichath" is made by cutting dried Tuna into small pieces and mixed with coconut, turmeric powder, onions and garlic, grinded into a powder form. This is consumed along with rice. For mass appam (Fig. 5), mass and coconut gratings are mixed and are covered with flour spread, then and cooked in oil.

Figure 5. Mass Appam

3.5. Tuna fish market in Androth

A stable Tuna fish market exists in Androth due to overall landings and trading. Several opportunities contribute such as supply meets demand, availability of monsoon and availability of a fish market space (MPLAD Building). However, the first sale prices often fluctuate according to the demand and supply. Certain attributes like fish transportation and storage facilities exist and if enhanced is beneficial for the overall improvement in the livelihood of fishermen who are into fish trading. Fluctuations in climate, selling price, and less tuna processing facilities are found to lower the overall revenue generated from the Androth tuna fish market. Further, Androth being a coastal island, subsequent covid lockdowns and changes in policies have slowdown the market expansion, though an availability of more cargo from Androth fish market is expected to accelerate the limited tuna export specially to gulf countries. Overall, the Androth fish market is now approaching into a monsoon when the study was carried out. The yield is expected to be high compared to the off season. A favorable expansion of Androth Tuna fish market due to the onset of monsoon is possible with more storage and processing facilities.

3.6. Welfare measures for Androth fishermen community

Fish markets operating in the islands of Lakshadweep are supported by government welfare measures. In Androth, fisherman registered with the fisheries department are provided subsidies through Pradhan Mantri Matsya Sampada Yojana (PMMSY) to purchase ice boxes, installation of cold storage/ ice plant and boat upgradation to export competency. There are also awareness classes on territorial water borders and security measures. Insurance coverage are given to fishermen. However, some welfare schemes are covered under "island" population throughout Androth (overall Lakshadweep). This limits the coverage of fishermen community from Androth under similar government welfare schemes that are given to mainland fishermen community.

4. Conclusion

Androth is a coastal island belonging to the Lakshadweep archipelago of 36 islands in the Arabian sea (Tripathy, 2002; Rajan et al., 2021). Tuna landings are more prominent and Tuna based fish industry is one of the main revenue generations in Androth. Therefore, the purpose of this field study was to compile information on tuna fishing and trading activities at the jetty fish market, in the eastern side of Androth.

The field study included visits to the fish market, interacting with fishermen registered at the dept of fisheries, Androth unit, UTL through a questionnaire mode. The respondents of this study were traditional fishermen, with fishing activities stretched over long years and experienced with tuna and lagoon fish landings. They are familiar with the fluctuations of the Tuna fish market in Androth. They have overcome natural calamities and covid lockdowns over the years and strive to maintain the fishing industry in Androth.

The major attributes of opportunities and significant trends identified in the present field study indicates a favorable tuna fish market in Androth Island. At the same time, the limitations for further expansion of the Androth tuna fish market and its global reach can be overcome by the key components identified from the field study. This field study carried out at Androth fish market is first of its kind. The field study observed that the Tuna fish market size and growth rate of overall market in Androth is limiting at times. Therefore, the study concludes that this field study couldassist Androth fishermen in informing appropriate technological assistances and govt policies to sustain their livelihood through Tuna based fishing industry.

Acknowledgements: This study would not have been possible without the assistance and cooperation of a number of individuals. The authors would like to thank all of those individuals who took part in the field study. Our sincere thanks are in order for the Androth Fisheries department staffs Shri. Noorul Ameen PP, In-Charge, Fisheries unit and Shri Abdul Muasid, Technical Assistant for their assistance with the design of the questionnaire and data collection. Without their able assistance, the study would not have been possible. The authors also wish to thank Shri Harshit Saini, DC Cum CEO, Androth and Kalpeni Islands, UT of Lakshadweep, for his constant support and willingness to help us overcome all problems faced. We thank Dr. Shahul Hameed, HOD, Dept. of Aquaculture, Govt. College of Arts and Science, Androth, UTL for his assistance in carrying out the study.

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Research Highlights

High waves measured during tropical cyclones in the coastal waters of India


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In the coastal waters of India, the highest waves are observed during the tropical cyclones. The high wave heights significantly affect the offshore industry and shipping. The marine structures have to withstand extreme waves (Goda, 1985). Numerical wave models provide information on significant wave height (Hs) but fail to provide data on the maximum height of the individual waves (Hmax). For applications like designing the air gap for offshore structures, the maximum height of an individual wave in a sea state of 20-30 minutes at a given place is required. The crest height of the design wave is another critical input while fixing the air gap of the fixed ocean facilities. For the design of breakwaters, coastal engineers require the average of the highest 10% of the wave heights in 30 minutes sea-state ($H_{1/10}$) (CEM, 2008).

Considering the above, this article examines the characteristics of high waves measured using the directional wave rider buoy (Datawell, 2020) during tropical cyclones at 14-50 m water depth in the coastal waters of India. Five tropical cyclones formed in the north Indian Ocean from 2011 to 2021, during which measured wave data is available close to the cyclone track, are used in this study. Of these five cases, two are over the Arabian Sea, viz. Kyarr (22-27 October 2019) and Tauktae (14-18 May 2021), while the remaining three formed over the Bay of Bengal, viz. Thane (26-29 December 2011), Phailin (10-14 October 2013) and Hudhud (10-15 October 2014). The shortest distance of buoy from the cyclone track was 10, 70, 77, 96 and 269 km for Hudhud, Phailin, Thane, Tauktae and Kyarr respectively.

The profile of the sea surface between two consecutive up-crossings of the still-water level (SWL) is considered a wave. For each individual wave, the wave crest height (Hc), which is the height of the crest level above SWL and the wave trough height (Ht), which is the depth of the trough below the SWL, are calculated from the 30-minute duration heave time series data. The height of the individual wave (H) is the total of the crest height and trough height. Hmax is the height of the largest wave in a time series of 30-minutes duration. The Hs is the mean of the one-third highest waves in each record.

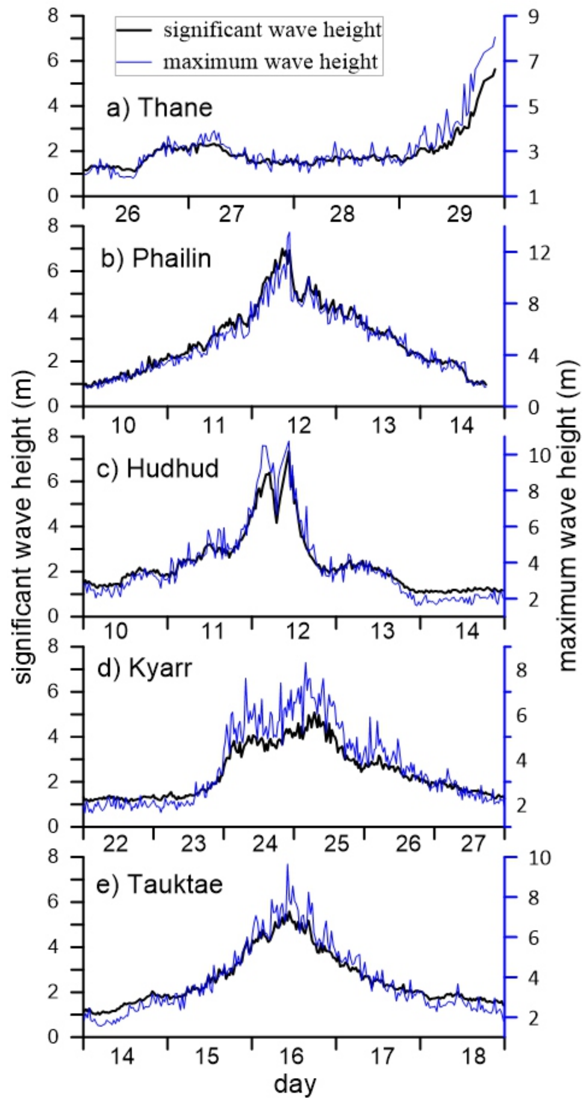

Figure 1. Variation of significant wave height and maximum wave height during different tropical cyclones

The maximum wave height during the Thane, Phailin, Hudhud, Kyarr, and Tauktae cyclones are 8.1, 13.5, 10.8, 8.3 and 9.7 m and the significant wave height is 6.1, 7.3, 7.6, 5.1 and 5.6 m (Fig. 1). In the Bay of Bengal, the largest Hs measured in the deep water was 8.4 m on 28 October 1999 during the passage of the Orissa super cyclone (Rajesh et al., 2005). The wave heights in the coastal waters during the tropical cyclones considered in the present study are much smaller than those reported in the deep waters of the global ocean. The largest measured wave height is 32.3 m recorded by a buoy, the M6 buoy, off the coast of Ireland at 3000 m water depth in October 2020 (Nic Guidhir et al., 2022). In the southern hemisphere, a wave height of 23.8 m is recorded by MetOcean Solutions on 8 May 2018 by a moored buoy in the Southern Ocean (McComb et al., 2021).

The study indicates that the interval of data collection also is very important. If the data is collected at 1-hour intervals, there is a possibility that one can miss the highest wave height values since the next highest wave heights measured during tropical cyclones are 3 to 28% lower than the highest value.

The ratio between $H_{1/10}$ and Hmean varied from 1.78 to 2.03 and is slightly lower than the value (2.03) following the Rayleigh distribution in all cyclones except that during Tauktae. The ratio between Hs and Hmean varied from 1.53 to 1.62 and is close to the value (1.6) following the Rayleigh distribution. $H_{1/10}$ is 1.15 to 1.29 times Hs with a mean value of 1.22 Hs, which is slightly lower than the value of 1.27 following the Rayleigh distribution.

The maximum height of the extreme wave is 1.75 times the significant wave height. The crest height of the highest wave is 0.51 to 0.67 times the height of the wave, with a mean value of 0.58. The crest height of the extreme waves is 0.6 to 1.2 times the significant wave height, with a mean value of 0.9 Hs.

The wave length of the highest waves varied from 110 to 158 m. Because the wavelength increased with wave height, the steepness ranged in a narrow range of 0.068-0.086 for the highest wave during different cyclones and the steepness of the waves was always less than the limiting steepness value of 0.142.

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Challenges of fisheries sector in a climate change scenario

An Awareness Seminar on the occasion of the World Ocean Day 2023 organized by OSI Cochin Chapter jointly with Department of Chemical Oceanography, CUSAT at School of Marine Sciences CUSAT dealt with an important topic 'How ocean biology of the northern Indian Ocean changed in the recent past?' by Dr. Grinson George, Principal Scientist, ICAR- Central Marine Fisheries Research Institute, Cochin. Recent study on impact of climate change on marine fisheries sector by ICAR-CMFRI, the carbon footprint in India's marine fisheries has been estimated at 1.32t of CO_2 to produce one tonne of fish which is much lower than the global average of around 2t CO_2. CMFRI has taken imperative steps to minimize the carbon footprint and work for sustainable production systems. Coral reef environments support a great diversity of benthic organisms. The Islands have a true maritime climate with least variation in maximum and minimum temperatures throughout the year. Dr.George suggested Zoanthids could be used as an adaptive species which may support reef resurgence in degraded reefs under stress from climate change effects.

Overfishing and illegal fishing practices have put pressure on fish populations in the northern Indian Ocean, but studies conducted by CMFRI showed 91.1% of the fish stock are assessed as sustainable or healthy stock. Regionally, the southeast coast had the highest percentage of healthy stocks (97.4%) in 2022, followed by the southwest (92.7%), the northeast (87.5%), and the northwest was at the lowest at 83.8%. The west coast of India contributes 70% of total fishery production over the Arabian Sea, supporting considerable fishery resources by virtue of well-known upwelling processes during the summer monsoon season. The landing of Indian oil sardines, Sardinella longiceps Valenciennes, along the southwest coast of India is extremely variable. A few physical parameters and processes correlated with sardine landing could not establish a connection to explain these high of interannual unpredictability. The study at CMFRI showed the average chlorophyll a for the bloom initiation month (1998–2006) matches with oil sardine landings, which means concentration of chlorophyll during the bloom initiation month can be used better to assess the quantity of fish that recruit into the population.

The climate model projections showed that the SST during 2080 is likely to rise by 0.69°C for the lowest emissions scenario and 2.6°C for the highest emissions scenario. Elevated temperature disturbs the homeostasis of fish and subjects to physiological stress in the habitat resulting in mortality. Changes in sea level rise and sea surface salinity reduce water quality, spawning and seed availability, increased disease incidence and damage to freshwater aquaculture system by salinization of groundwater. The synergic effects of climatic variations are found to have negative implications on capture fisheries as well as aquaculture system.

The Seminar inaugurated by Prof.P.G. Sankaran, Vice Chancellor of CUSAT was attended by more than 100 scientists, researchers and students from School of Marine Sciences (CUSAT), KUFOS, CMFRI, DRDO-NPOL, CMLRE and others.

(**Article prepared by Dr.M.Baba, Chairman, OSI Cochin Chapter and Dr. S.S. Shaju, Head, COD, CUSAT and Secretary OSI Cochin Chapter**)

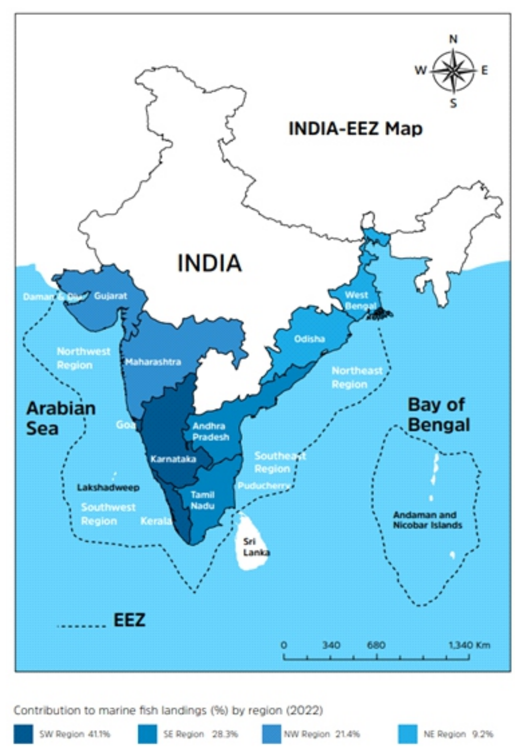

Figure 1. Contribution to marine fish landings percentage by region in 2022 (CMFRI Booklet Series no 32/2023)

OSI Webinar Series (April-June 2023)

Topic: Oxygen deficiency and biogeochemical response in the Eastern Arabian Sea

Speaker: Dr. V. Sudheesh, University of Kerala, Kasaragod

Date & Time: 21 April 2023; 04:00 PM – 05:00 PM IST

About the Talk:
Oxygen is fundamental for life and biogeochemical processes in the ocean. On another words, a deficiency in oxygen significantly impact biological productivity, biodiversity, and biogeochemical cycles. The talk details the characteristics of oxygen minimum zone of eastern Arabian and their intra-and inter seasonal dynamics. It also provides the biogeochemical response of EAS shelf during the seasonal anoxic/hypoxic event during summer monsoon.

World Oceans Day 2023 - 8 June 2023

Ocean Society of India (OSI) in collaboration with National Centre for Coastal Research (NCCR), Ministry of Earth Sciences (MoES), Government of India celebrated World Oceans Day 2023 with several outreach programmes on 8 June 2023. One of the programmes on that day was beach cleaning at 17 locations of the Indian coastline. Prof. (Dr.) K. V. Jayachandran, Member of the GC, OSI and Honorary Professor, University of Kerala was the National co-ordinator of the programme. The locations covered, number of participants and the quantity of waste collected are given below.

State/UT	Name of Beach	No. of participants	Quantity of waste collected (kg)	No. of items	Length of beach (km)
GUJARAT	Chopati, Veraval	92	855.25	65	2.0
	Dumas	102	136.97	40	1.0
MAHARASHTRA	Mumbai, Versova	80	430.00	40	1.5
	Bhatye	100	150.43	30	1.6
GOA	Caranzalem	120	256.95	65	1.0
KARNATAKA	Rabindranath Tagore Beach	80	566.10	65	2.0
	NITK Beach	40	585.00	65	3.0
KERALA	Papanasam,Varkala	150	147.48	65	1.25
	Edvanakkad, Kochi	120	460.50	65	1.0
	Ponnani	60	572.12	37	1.0
TAMIL NADU	Pudumadam	90	168.00	19	1.25
PUDUCHERRY	Veerapattinam	230	601.20	10	0.6
ANDHRA PRADESH	R.K. Beach	97	43.65	60	1.7
	NTR Beach	80	200.17	60	1.7
ODISHA	Puri	101	49.08	38	2.0
	Chandipur	65	104.00	31	1.25
WEST BENGAL	Digha	70	148.36	58	1.0
	TOTAL	1677	5475.26	10-65	22.0

Articles/research highlights of general interest to the oceanographic community are invited for the next issue of the Ocean Digest. Contributions may be emailed to osioceandigest@gmail.com

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Cover Photo: *The image shows the floating vegetation, dominated by water hyacinth (Eichhornia sp.) in Vembanad lake during monsoon season. This dense vegetation disrupts local transportation and fishing activities, blocks sunlight penetration, and provides a breeding ground for mosquitos, insects and faecal indicator bacteria . Image courtesy: Dr. Anas Abdulaziz , Principal Scientist, CSIR -National Institute of Oceanography, Regional Centre Kochi, Kerala*

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