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Research Note

Impact of Degradation in Marine Ecosystem on the Health of Divers

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Background

The oceans are at the core of life on Earth – they cover about three fourths of the Earth, absorb carbon emissions and excess heat, provide countless resources and house exquisite flora and fauna. Mankind has been in awe of these massive, complex pools full of existential treasure since the olden days. However, oceans still remain a
mystery at large.

It is a multimillion industry in which corporates, governments and the public hold stake. The indispensable aspect crucial to the smooth functioning of this industry are divers. Diving is the immersion of the body into water and can be partial immersion, complete immersion (submersion) and submersion with auxiliary breathing apparatus [5]. Diving is a versatile activity that plays an important role in athletics, naval security and medical research. In general, there are two broad categories of diving – recreational and occupational. Both these types of diving techniques have gained momentum in the recent years. According to Professional Association of Diving Instructors, in 2015 there were over 25 million certified divers across more than 200 countries with an average of 90000 additional diver certifications annually [7]. There are also unregistered recreational divers and people residing in coastal areas that rely on diving which
should be accounted for.

Despite of diving being a common exercise, there is significant evidence that divers face long term physiological effects from diving. Apart from this, every year numerous diving fatalities occur due to unforeseen circumstances. A study in Canada concluded a fatality rate of 1.8 per million recreational dives in a year [36]. Although we have access to a variety of protective equipment and physical health check-ups are mandatory for divers, there continues to be a constant threat of accidents and sustained after-effects. While a lot of focus is on improving available technology and creating monitoring systems to combat these hazards, not much work is done on a seemingly harmless aspect of diving – the underwater habitat itself.

The undersea ecosystem is a world in itself with its own unique physical characteristics such as temperature, pressure, sound. gases, etc. Along with these naturally occurring phenomenon and the marine biota, there is also huge amounts of pollution present. All of these amalgamate to create a territory that is often unsuitable for long term exposure. Evidence suggests that underwater acoustic degradation causes accelerated hearing loss in divers [30]. The concoction of different harmful oxides, chemicals and trace metals within water bodies from industry run-off is also known to cause toxicity [28]. Several other parameters of a water body can also impact the functioning of protective equipment under the water. Apart from this, the marine creatures and plant life can also cause minor injuries and poisoning, for example coral reefs have sharp edges that lead to small wounds in divers [6].

At the same time, diving is necessary for data collection and knowledge acquisition of the underwater domain as well as obtain the required resources and neither can we control the existing characteristics of a water body. Nevertheless, mankind can and does in fact influence the conditions of a marine ecosystem. Naval equipment accounts for large amounts of underwater noise [30], excessive mining and exploitation of water bodies from corporates is causing changes in the physical characteristics of the underwater climate, chemical and metallic waste from industries is causing a rise in toxin levels and rampant consumerism is leading to a lot of pollution and littering [17], especially from plastics. About 8-12 million tons of solid waste is dumped into oceans, every year [37]. As per UNSECO data, 80% of pollution in water bodies globally is due to land sources such as pesticides run off from agricultural land and untreated sewage. There are also approximately 500 marine zones that have been labelled as dead zones because oxygen gas presence in them has been exhausted due to excess nitrification. All of these have a substantial adverse impact
on the quality of the underwater climate [38].

The intensity of this problem can also be highlighted by the fact that the United Nations declared “Life Below Water” as one of the sustainable development goals established in the United Nations General Assembly in 2015. They intend to enable better conservation and optimal use of the marine and coastal ecosystems while ensuring that there is minimal exploitation and contamination of these aquatic terrains [15]. If achieved successfully, this will contribute positively to reduction of diving hazards due to unfavorable underwater conditions. Without suitable marine climates, it will not only be complex but also expensive to continue diving operations required to accumulate adequate resources and ensure coastal security. The coastal tourism industry will also cease to exist and in turn, affect large populations and economies.
Previous studies in the field of marine ecosystem degradation heavily focus on impact of anthropogenic activities on marine creatures and overall health of the underwater domain. Similarly, studies on diving and impact of underwater characteristics on divers cover various aspects of hyperbaric medicine as well as correlation between physics of diving and physiology of humans. To the best of our knowledge, limited work has been done to link degradation of marine ecosystem and its adverse influence on health of divers, especially in the Indian Ocean Region.

Marine Ecosystem

The marine ecosystem can be characterized by the interdependence of different biotic and abiotic factors. The marine biome is the largest type of biome in the world and includes an array of creatures and plant life. Some of the most commonly found animals include sharks, crocodiles and alligators, rays, octopuses, sea snakes, sea urchins and other several types of fish, many of whom are known to bite or contain venomous secretions. Complementing these are the wide variety of corals, sponges, algae and more. The functioning of a marine ecosystem is heavily influenced by the physical attributes of a particular water body. These attributes include the water body's pressure, temperature, density, optical properties and gaseous composition. Each of these attributes are capable of causing significant effect on a marine ecosystem independently as well as in combination of two or more.

On the other hand, the increase in human activities around coastal areas and inside oceans is introducing different forms of disturbances in the marine environment including underwater noise, artificial light, thermal pollution, electromagnetism, chemicals, trace metals, etc. [17]. For example, the ambient temperatures of the water bodies are being disrupted due to coolants from power plants & industries which causes a burst of thermal energy to the underwater environment and reduces the concentration of dissolved oxygen in the water, has detrimental impact on flora & fauna as well as causes a lot of unique enzymes and proteins present in the ecosystem to denature as they cannot survive higher temperatures. Similarly, deforestation and rising atmospheric temperatures are increasing the exposure of oceans to sun and heat. Temperature of a water body can also affect its density which in turn has a correlation with pressure [6].

Chemicals and trace metals are also occurring at an alarming rate. These find their way into water bodies via litter, biomedical waste, agricultural and industry run-off etc. and integrate into the marine ecosystem causing poisoning to marine creatures which later become a part of the food chain, increased levels of gaseous toxicity and also alter the pH of the water.

Another factor that remains a priority for researchers is underwater noise. This noise can be generated due to different machinery and vessels present under and on the water [30]. Studies have shown this noise, also referred to as anthropogenic noise, interferes with function marine creatures causing them distress and changes in behavior.

The largest contributing factor to the degradation of marine environments, however, is pollution. Plastic and other solid waste from sewages, dumping from vessels and industries and littering by the general population has caused unwanted materials to pile up in oceans. With the rise in diseases, the global Covid-19 pandemic for example, is also leading to large amounts of biomedical waste in forms of masks and gloves being discarded in water bodies. Most of these materials and waste do not degrade easily giving rise to residual chemicals -released from these objects- in the waters, ingestion of plastics and other harmful substances by marine creatures and reduced underwater visibility. A lot of these objects and plastics also float on the water or settle on the seabed – both of which are harmful. Most of these objects are also good at absorbing atmospheric heat and sun rays which generates increased thermal energy in the water bodies. [13],[14].

It is imperative that these disturbances are accounted for when analyzing a marine ecosystem because of their prevalence and substantial repercussions.

Health Hazards to the Divers

Diving has gained massive popularity globally however, not much attention has been given to the medical complications that are encountered due to lack of knowledge regarding the physiology of diving. The interlinked nature of different physical parameters of the marine ecosystem and their impact on the health of divers makes analyzing and pinpointing specific conditions complex. Nevertheless, a basic cause and effect relationship can be mapped out.
For the purpose of simplicity, we can choose a starting point such as density. Water density is a determining factor for whether an object will float or sink. Studies have shown that higher density of water has a correlation with the energy expenditure during locomotion which reduces a diver's efficiency under water [3]. Density also has a relationship with dynamic viscosity which affects the ability of a body to move through water. [3]. This density of water changes as per variations in temperature, pressure and salinity of water.

An increase in pressure, causes an increase in density which further enhances the effect of higher densities on divers. Along with this, undesired pressure changes can cause injuries to different physiological systems which are collectively known as barotrauma. This mainly happens due to the compression of gases at higher pressures which leads to changes in volume of gas spaces. The compression of gases leads to increase in their density which generates an increase in resistance of the airways as well as reduces maximum breathing capacity since work of breathing is also increased [2]. Apart from an effect on the lung mechanics, pressure changes can cause ear barotraumas which are classified according to the part of the ear that they damage. Middle ear barotrauma is one of the most common ailments in divers [6]. Other kinds of barotrauma include dental, skin, face, ocular, gastrointestinal and more. All these occur quite instantly and cause immense pain as well as discomfort which impairs the diver's ability to complete their descent and/or access safety equipment. After drowning, pulmonary barotrauma ailments have been termed as the most common cause of fatalities in divers. [16]. Onset of barotrauma may also cause panic and contribute to deaths of ill-informed divers as well as contribute to long-lasting repercussions such as tinnitus, loss of balance and loss of hearing. Symptoms of barotrauma are also commonly confused with decompression illness [6]. Decompression illness is caused due to formation of micro-bubbles of gases dissolved in blood or human body tissues. It occurs due to a reduction in ambient pressures and is common in high altitude diving.

The aforementioned risks are those that occur due to natural characteristics of oceans and water bodies as well as due to lack of training. Some of these hazards rarely occur and there are others that are more frequent. The overall risk of diving has however elevated in the recent years due to degradation of marine ecosystems. The degradation factors not only add to the existing hazards of diving but also prove disadvantageous for attempts of curbing existing hazards due to the changes caused in the marine ecosystem.

One commonly researched degradation factor is increased anthropogenic activities around coastal areas that produce a lot of underwater noise. A lot of studies show the negative impact of underwater noise on marine animals but divers are also bearing the brunt of this. The divers are regularly exposed to high levels of noise from ambient environments, self-generated breathing noise, operation of underwater tools, etc. Studies have shown that long term exposure to these noises causes accelerated hearing loss in divers [30]. Excessive ultrasound used by submarines and defense sector is also known to cause damage to human hears. Underwater noise also makes communication among divers and between divers and their vessels more difficult, causing interference and miscommunication.

Another effect of underwater noise is disturbance caused to marine creatures many of whom are predatory and cases of bites and venomous injections in divers have occurred over the years [6]. This is especially possible if divers have small amounts of skin exposed or reduced visibility which is also a degradation factor of the marine ecosystem.

Increasing temperatures of the water bodies are also disrupting the natural characteristics of the marine ecosystems. The risings temperatures not only worsen the risk associated with density and pressure underwater but also cause overheating/heat strokes to divers. On the contrary, exposure to excessively cold water leads to hypothermia which can produce loss of strength, shivering, loss of consciousness, etc. Excessive heat loss during diving also puts divers at risk of frost bites and muscular cramps [26]. These effects combined with the kind of suit (wet/dry) worn by a diver can also be hazardous.

Finally, pollution and litter as well as different other pollutants are increasing the hazards of diving. Divers often get entangled and trapped in nets and other various types of litter which can cause accidents and other fatalities. Apart from this, dumping of biomedical waste and other sewage in water bodies such as fecal matter exposes divers to infectious pathogens. Other types of biological pollutants include algae and bacteria introduced into the ecosystem from agricultural run-off or litter. There are also various chemical contaminants found in water bodies that pose a threat to divers. Chemical pollutants can be organic or inorganic. Some of these are soluble while some are not. Organic contaminants generally include pesticides and polychlorinated biphenyls, sediment leachates, hydrocarbons in the form of natural gas, coal, oil, fuel, etc. Inorganic contaminants include heavy metals, nitrates and nitrites, cyanide and fluorides. All of the chemical contaminants in high concentrations are injurious to health of divers. Many components found in pesticides/fungicides and wastewater have also been termed as carcinogenic. Radiological contaminates and warfare agents also pollute our water bodies. Radiological hazards find their way into the water bodies from accidents and oil spills. Both of these types of contaminants can also be carcinogenic and require proper shielding. Algal blooms developed from presence of unwanted chemicals in the water is also extremely dangerous for divers.

Recreational diving has been limited to specific areas of interest due to which aforementioned hazards can be eliminated however in case of unregistered diving and lack of public information on safe zones for diving, the risk still remains. Hazards from contaminated waters are most crucial for occupational divers for the defense sector and scientific diving.

Occupational diving requires entering polluted waters for several reasons such as damage analysis, cleaning missions, conducting research studies, etc. Diving, as previously mentioned, includes different types of immersion. Submersion in contaminated waters can cause injuries from the unknown chemicals present. Many diving suits deteriorate when exposed to certain chemicals thus further exposing the divers. A common example of this is exposure of rubber-based diving equipment to petroleum contaminated waters [28]. The petroleum products present cause the diving equipment to dysfunction. Similarly, presence of microscopic compounds in water droplets can also be harmful as they can be inhaled from the exhaust valve of the scuba regulator. Many of these compounds upon entering the nasal passage and bloodstream can lead to prolonged health problems. Moreover, condensation formed inside scuba masks can only be cleared by allowing surrounding water to rush into the mask which again exposes the diver’s nose and eyes to contaminants in the water [28]. Along with this, many toxic gases such as carbon monoxide [4] and nitrogen oxides dissolve in water which can lead to poisoning in divers. Common sources of gaseous pollutants are atmospheric contamination and exhausts from petrol and chemical industries. The different dissolved gases in the water bodies can also alter the gaseous composition of the marine environment which may contradict with the breathing apparatus of divers containing mixture of different oxygens. Differences in partial pressures of inspired gases in relation to the surrounding atmosphere can also prove to be toxic for divers.

Regulatory Status

Diving has become a global occupation as well as recreational sport. Given the dangers associated with diving, many countries have formed regulations concerning the health and safety requirements for being eligible to take part in diving. To list a few, there is:

- Diving Regulations 2009 and Occupational Health and Safety Act 85 of 1993 in South Africa. This act was developed by the Ministry of Labor specifically for occupational diving and does not apply to recreational divers or divers that do not use any equipment. The act outlines guidelines for diving contractors, instructors, life support technicians, divers, required medical examinations, training standards and assessments, etc. [20]. There are also specific codes for inshore, commercial and scientific diving.

- The Diving at Work Regulations 1997 in the United Kingdom. This regulation is aimed at occupational as well as recreational diving. It focuses on regulations to be followed by divers and diving contractors, requirements of relevant documentation such as project plans, medical fitness certificates and qualifications. It also emphasizes on ensuring clarity of responsibility and role assignment. [18]. There is also the Marine and Coastal Access Act 2009 which is required to be adhered to in case of adding or removing substances from water bodies.

- In the United States, under the Occupational Safety and Health Standards, a SCUBA diving standard has been defined outlining the conditions to be followed for carrying out commercial diving operations. The standards include guidelines for employers, divers, allowed depths for diving and different procedures to be followed for the diving exercise as well as for medical support. [19].

- Australia has developed the Safety in Recreational Water Activities Act 2011 (the SRWA Act) and the Safety in Recreational Water Activities Regulation 2011 (the Regulation). These are described in detail under the Recreational Diving, Recreational Technical Diving and Snorkelling Code of Practice 2011. The code comprehensively lists guidelines on risk management, control measures, requirements for use of different tools & equipment as well as guidance on hazards and hazardous areas. [21]

- The International Organization for Standardization (ISO) officially list the following standards in context of recreational diving and eligibility:
    - ISO 11121:2017 = This standard focuses on required contents in training programmes by different organizations for scuba experiences [22].
    - ISO 21417:2019 = Similar to the previous standard, this one also outlines requirements for training programmes however the focus in on educating divers on “environmental awareness and sustainable environmental practices in recreational diving activities” [23].
    - ISO 21416:2019 = This standard provides guidelines for “all stakeholders involved in recreational-diving-related activities on best practice to minimize negative impact on the aquatic environment and to optimize positive outcomes”. The aim is to enable the “stakeholders” to choose “service providers” that are most sustainable from an environmental point of view [24].

In regards to India, only the Andaman & Nicobar Islands government provides an official regulation for recreational SCUBA diving in the region to ensure safe diving practices for divers as well as the ecology [25]. The national standards body of India, Bureau of Indian Standards does not list any marine or underwater domain related framework in its database. Other legislations as per an official document of the Ministry of Environment, Climate and Forest Change such as The Coast Guard Act, Merchant Shipping Act and Water (Prevention and Control of Pollution) Act focus on limiting the pollution in the IOR from shipping vessels and industries [32].

Otherwise, as per the available data in the public resources there are no official regulations or guidelines related to diving. Articles published in “The Hindu”, which is a reputed news reporting organization, as well as by “IndiaBioscience”, a program funded by the Department of Biotechnology of Government of India and Ministry of

Human Resources and Development, talk about the lack of regulations, databases and guidelines for ensuring safe diving practices in regards to recreational as well as occupational diving [8][9].

Management of the Diving Operations

Diving operations, as mentioned previously, can be classified according to the purpose of diving i.e. occupational or recreational. Occupational diving can be further broken down to scientific diving, military or defence diving and maintenance diving. There are few fundamental diving protocols that are adhered to globally. These protocols have three parts to them – pre-dive, during the diving activity and post-dive. Briefly, these protocols can be described as follows:

- Pre-dive Procedures: A comprehensive diving plan is generated which includes details of objectives of the diving operation, technicalities of the equipment to be used, a risk hazard analysis of the environment in which diving will take place as well as a detailed map of point of entry, route to follow and point of exit. Briefings about the diving site, diving mode, emergency procedures and responsibilities of each team member in the diving team are also carried out. For occupational divers, job hazard analysis and expected complications are discussed. Safety checks on proper functioning all protective and, if required, occupational equipment is carried out. Thorough investigation of the diving site is done to ensure appropriate protective equipment and PPEs can be arranged for as well as any environmental risks can be accounted for. Along with this, fitness check-ups as well as qualification vetting for all personnel is mandatory and any protective equipment being used should match the safety standards defined by the government. Appropriate communication channels are also setup and tested with the diving vessels.
- Diving Procedures: Diving teams carry out a synchronized exercise as per the pre-decided plan. In case of emergencies, relevant first-aid conventions are carried out.
- Post-Dive Procedures: First course of action after a diving operation is physical check-ups of all divers. These are done to ensure there are no symptoms of any illnesses, traumas or exposure to harmful substances and are mandated by government acts in many countries. Apart from this, extensive record-keeping reports are filled out which contain details about the diving operation. In case of any accidents, separate logs are maintained for incident reports.

The above defined protocols are changed in special circumstances such as diving at night, diving below certain depths, harsh weather conditions, etc. Along with these protocols, specific equipment is used depending on the type of diving operation taking place. In general, following types of equipment are necessary for a successful diving operation:

- Personal diving equipment: This is the equipment that is carried by the diver or worn by the diver such as breathing apparatus, environmental protection suits, navigation & monitoring tools, stabilisation & movement equipment, visual & communication tools, safety equipment and personal accessories such as bags, camera, etc.
- Tools & Equipment for the entire diving team: These are generally protective equipment meant for first aid and staying connected with the team.
- Surface support equipment: This kind of equipment is generally supported by the diving vessel and is essential for facilitating diving, providing emergency help, enabling communication and providing support for any occupational equipment that may be required.
- Often times, special unmanned underwater systems may accompany divers for investigative and exploration purposes.

All aforementioned protocols and equipment are required to be up to date with the government regulations. All tools and equipment must also undergo maintenance as per official guidelines. Regulations regarding diving also outlines necessary qualifications of divers and minimum training to be eligible for certain types of scientific diving.

To facilitate better handling of diving hazards, many research groups have been working on incorporating upcoming technology such as artificial intelligence and machine learning into diving equipment and environmental analysis. Smart breathing monitoring systems, automated analysis of physiological conditions of divers using neural networks for pre and post dive check-ups as well as detecting existing conditions that may prove to be fatal for diving, decision support systems for environmental analysis, etc. are few examples.

In terms of the IOR, as previously stated there is no publicly available data on regulations and policies regarding managing diving operations and equipment. While there is an increasing use of upcoming technology for environmental analysis, no data to the best of our knowledge describes work regarding smart diving systems specific to IOR.

Research Directions

This research can be pursued further on the following gaps specific to the Indian Ocean Region:

1. Development of an application that provides information to prospective divers regarding safe diving zones, environment specific equipment, checklists for safety/fitness, etc. along with details of emergency procedures and option to report any incidents. Essentially a comprehensive support guide for safe diving.
2. Recommendation for creation of a special governing body that outlines different SOPs related to the underwater environment and diving. The governing body could also provide support for independent research groups

as well as help setup a public database regarding the marine environment and diving-related information. The governing body could also help establish certified training organizations to ensure proper training of divers and minimize risks.

3. Proposal for health & safety guidelines for occupational diving that define required medical certificates for divers, education/training qualifications, protocols for diving & standards for equipment.
4. Proposition for a dedicated task force on analysis of underwater degradation due to various factors. A draft on possible systems to maintain a public library on the same as well as provide accessibility of data to occupational diving organizations can also be suggested.
5. Analysis on acoustic degradation in the underwater environment and its subsequent adverse effects on divers.

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