From ocean science to sustainable blue economy

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Blue economy is defined as the ocean dependent economic development to improve the quality of life of people while ensuring inclusive social development as well as environmental and ecological security. India has committed to advancing the blue economy. The knowledge about fishery resources, sea bed, marine minerals and energy resources and vulnerability to natural hazards is a pre-requisite for the growth and development of the blue economy. The marine fish catch has been a major source of income for one million fishers in India. The technological development for product development to be addressed for commercialization of deep-sea fishery. Geophysical surveys have provided information about coastal placer minerals, gas hydrates on continental shelf and manganese nodules, hydrothermal systems and cobalt crusts in high seas. The investment in developing technologies and human resources for harnessing these resources is being made. The coastal and marine area spatial planning to be employed to understand risks involved and accordingly, developmental activities to be planned. The economic growth prospects beyond 2030 will be limited without large investments in ocean environments. An accounting system to be developed to bring together disparate data sources, both economic and environmental. An institutional framework for implementing activities related to blue economy to be set up. Investments in sustainable development of oceans will pay rich dividends for future generations and benefit humanity.

Keywords: Blue economy, coastal zones, institutional framework, ocean sciences, sustainable development.

Introduction

THE ocean, which covers almost 70% of the Earth's surface, is the most important component of the Earth system and makes the planet habitable for humans biota and sustaining biodiversity. Oceans control weather and climate, and provide food, energy and mineral resources. Thus, oceans should be viewed as a natural capital, livelihood provider, driver of innovation and good business[1]. Pauli[2] advocated an ocean-dependent economy to continue to prosper in the era of climate change and termed it as 'blue economy'. Realizing the importance of oceans, the UN Conference of Sustainable Development in 2012 stressed broadening the scope of the green economy to the blue economy. The latter is essentially an ocean-dependent economic development for improving the quality of life ensuring inclusive social development, along with environmental and ecological security[3].

The 2030 Agenda for the United Nations (UN) Sustainable Development Goal 14 also clearly recognized that social and economic development depends on sustainable management of the coastal and ocean environments and their resources. To achieve this goal by 2030, the UN has declared the current decade as 'The Decade of Ocean Science for Sustainable Development', to provide a common framework to ensure ocean science support for countries to achieve the 2030 Agenda for Sustainable Development.

These commitments reflect a growing understanding of how marine, coastal and other natural environments contribute to socio-economic development. Scientific research has identified a complex array of biophysical goods and services that marine and coastal environments provide to people. Economic and social research has identified multiple values of these environments and measured their contributions to human health, well-being and development.

Despite considerable progress, current efforts to better understand and manage oceans and coasts fall far short of the level of change required to achieve the 2030 Agenda's vision of sustainable development. This challenge prevails in most countries. Many of the benefits and opportunities provided by oceans and coasts are poorly understood, and are being missed or lost. Marine and coastal ecosystems, and the valuable goods and services they provide are being rapidly degraded because of pollution, overfishing, climate change, habitat destruction and other factors.

India is committed to advancing the blue economy and several programmes have been initiated to promote this sector in the country. The Economic Advisory Council to the Prime Minister (EAC-PM), Government of India (GoI) has provided a policy framework for sustainable utilization and management of living, mineral and energy resources through coastal and marine spatial planning[4]. The major aspects of blue economy discussed in this article pertain to sustainable use of living resources, coastal and marine ecosystems, exploration and utilization of minerals, energy and water, eco-friendly tourism, assessment of hazards and response mechanism, and sustainable coastal management. The economic benefits from living and non-living resources likely accrue in the short-to-medium term and medium-to-long term respectively. It is necessary to set up an institutional mechanism for multi-stakeholder participation in promoting blue economy. The investment in blue

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economy is essential for sustainable growth and development.

Sustaining fishery resources

Marine fishery is a major food resource for protein. About 4 million people are dependent on marine fishery and allied services. India's potential yield estimates are 4.4 million metric tonne (MMT) (www.dof.gov.in) and fishery landings vary between 2.7 and 3.8 MMT annually[5]. To reduce catch per unit effort, potential fishing zone and sea condition advisories, based on ocean colour, sea surface temperature, height and wind are provided daily to the fishers[6,7]. These multilingual advisories have helped the fishers to reduce search time, save on fuel costs and improve the catch per unit effort. The saving in fuel costs also has an environmental benefit. The average carbon dioxide (CO_2) emission is reduced by 0.16 tonnes for each tonne of fish caught[8]. This service is provided to more than 90% of the fishers and almost 600 fish landing centres. A saving of Rs 17,500 was accrued by the fishers per trip according to the National Council of Applied Economic Research, New Delhi[9].

At present, ~91% of the fish stock is healthy and ~87% is sustainable in the Indian waters[5]. To continue to sustain the fisheries, prediction of pelagic fishery stock is essential, so that fishing is carried out within the biological sustainable yield. The variation in inter-annual yield depends on the understanding of the physical, chemical and biological systems. A species-specific, short-term and annual fish stock prediction model based on physical and biogeochemical interactions in the early life-history of fishes coupled with physical models needs to be developed.

The warming of the sea is likely to affect the pelagic fishery. Sardine and Indian mackerel occur primarily in the highly productive upwelling regions of the west coast of India. It has been reported that until 1985, the entire catch was mostly from the Kerala–Karnataka (Malabar) coast. In recent times, oil-sardine and Indian mackerel catches have been increasing between latitude 14° and 20°N (Goa, Maharashtra, Tamil Nadu and Andhra Pradesh), while decreasing on the Malabar coast[10]. It is necessary to model the northward regime shift so that predictions can be made for assessing likely yield.

Deep and distant water fishery has a huge potential and is yet to be fully utilized. The deep-sea potential of finfish and shellfish is about 1.7 million tonnes and is almost unexploited[11]. The harvesting of tuna is only about 12% of its potential[11]. Exploratory surveys in the Indian Exclusive Economic Zone (EEZ) have established the potential of demersal fishery between 200 and 1000 m, and myctophid resources[12]. There is good potential to use myctophids as food for livestock, poultry and aquatics. There needs to be focus on harvesting, post-harvesting technologies and product development for successful commercial ventures in deep-sea fishery.

Abundance and biocomposition of deep-sea fish fauna (200–2000 m depth) have been established. The current estimates of potential are of the order of 3.3 million tonnes. New grounds (>200 m) for finfish and shellfish, and a deep-sea ground (>600 m) rich in Chimaera and shark have been identified by the Earth System Science Organization (ESSO), Centre for Marine Living Resources (CMLRE), Kochi, Kerala, India.

Cage culture in marine, coastal and estuarine regions is one of the promising avenues for increasing marine fish production in India. Technology for cobia, sea bass and silver pompano has been developed and economic viability has been established[13]. Efforts need to be made for the adoption of these technologies by the fishers. Experiments to develop ornamental fish breeding and culturing in the Lakshadweep Islands have been successful and have provided a source of income to the women of Agatti Island. This needs to be upscaled for commercial production[12]. The discovery of bioactive molecules and development of new drugs from flora and fauna occupying the deep sea floor (bacteria, fungi and actinomycetes), hydrothermal vents, frozen shelves, etc. have been initiated under the 'Deep Ocean Mission' of the Ministry of Earth Sciences, GoI (www.cmlre.gov.in).

Coastal and marine ecosystems and biodiversity

Coastal ecosystems, mangroves, coral reefs and seagrasses are vital for sustaining fisheries, other biota and services such as bioprospecting, biotechnology, tourism and coastal protection. Knowledge about their structure, function and vulnerability to climate change and anthropogenic pressure is a critical need[14]. Mangroves have been monitored using satellite data by the Forest Survey of India since 1987. The area under mangroves has increased from ~4000 to ~5000 km^2. The economic services provided by mangroves include fishery, fuel, fodder and timber valued at about USD 3300 per ha per year[15]. Apart from supporting services provided by mangroves like carbon sequestration, protecting shorelines are yet to be valued. Their role in carbon sequestration, storage and resultant carbon credit is critical. The carbon stock estimated is ~52.5 million tonnes[16]; thus increasing the area under mangroves not only helps in mitigating the impacts of climate change, but also earns carbon credits and benefits of ecological services.

Coral reefs mainly occur in the Gulf of Kachchh, Malvan coast, Lakshadweep Islands, Gulf of Mannar, and Andaman and Nicobar Islands. These ecosystems are productive and provide valuable economic products and services, and hence need to be preserved. The economic services provided by coral reefs include fishery, biodiversity, tourism, etc. and these are yet to be valued in India. In Indonesia, total economic value of each hectare of coral reef has been estimated at USD 3 million[17]. Hence any degradation or destruction of this ecosystem not only leads to ecological loss, but also economic loss. Ocean acidification along with increasing temperature and consequent reduction in oxygen can affect the coral reefs and coral reef fishery. It will be difficult for single-celled algae and pteropods to calcify. There is need for understanding of the carbonate system and prediction of pH levels at different Intergovernmental Panel on Climate Change (IPCC) scenarios, and their likely impact on the biota.

The information on biodiversity is crucial and is likely to be affected by anthropogenic activities and impact of global warming on the seas. The loss of marine biodiversity has been estimated to be 100–1000 times more than what could be considered natural. Can the earth sustain the current rates of loss? The impact of loss of marine biodiversity on other processes needs to be understood. Hence, detailed records of marine life and changes need to be meticulously recorded. The Census of Marine Life and the International Ocean Biogeographic Information System (OBIS) have provided information on marine life by pooling all information and making it available through a portal through an internationally accepted data protocol. At present, IndOBIS has records of 150,000 species, including new records of several species (www.indobis.in). The focus is on understanding the structure, function and vulnerability of the ecosystems. We need to ensure a healthy ocean environment for sustained benefits of successive generations.

Coastal pollution

Harmful algal blooms (HABs) affect fisheries, mariculture, aquaculture, tourism and thus the blue economy. The Indian coast has been experiencing increasing incidences of diatoms, dinoflagellates and cyanobacteria blooms. HABs induce incidences of mass mortality and morbidity of marine biota. The Algal Bloom Information Service (ABIS), ESSO-Indian National Centre for Ocean Information Services (INCOIS), Hyderabad has been providing daily advisories to all stakeholders[18]. Considering its impact on fisheries, it is necessary to develop an early warning system, so that advanced information on areas likely to be affected by HABs can be provided to the fishers.

The impact of spatial distribution of marine litter including microplastics on human health, coastal and marine ecosystems, fisheries and biota needs to be assessed in view of increasing coastal industrial development, manufacturing, ports, etc. Physical, chemical and microbiological parameters (total of 54) for water and sediments have been monitored at 50 priority sites for the last 25 years (www.nccr.gov.in). Increased nutrient inputs to coastal waters due to rise in coastal population and agriculture intensification have been observed at many sites. This has led to decreasing oxygen levels in coastal waters, although not at alarming levels. To plan for sustainable development, a model integrating coastal pollution along with land use, socio-economic conditions and impacts of climate change needs to be developed[19].

Tourism

India has been bestowed with many spectacular beaches attracting tourists. The identification of ‘Blue Flag’ beaches has improved the footfall on them. India has been actively pursuing a ‘Blue Flag’ certification process based on the conditions of beach, safety, water quality, environmental education, etc.[20]. This certificate is issued by the Foundation for Environmental Education (FEE), Copenhagen, Denmark. The process ensures development along with environmental education for preserving coastal and marine ecosystems, and thus provides insights into the health of a beach. Twelve ‘Blue Flag’ beaches have been identified on the Indian coast. It has been realized that the footfall has drastically increased on these beaches after certification. More beaches must be brought under this category to promote eco-friendly and sustainable beach tourism.

Coastal and ocean mineral and energy resources

The transition from fossil fuels to a renewable energy-based economy in the 21st century will require critical metals such as nickel, cobalt, lithium, titanium, rare earth elements (REEs) and Platinum Group of Elements (PGEs). In India, large-scale deposits of these metals are either of low grade or dwindling. The dependence on coastal and offshore minerals which are distributed from near the coast to 6000 m depth will increase in the future. According to an estimate, the demand for cobalt and nickel is likely to be of the order of 2 and 5 lakh metric tonnes respectively[21].

India has rich deposits of placer minerals, ilmenite, rutile, garnet, zircon, kyanite, sillimanite, monazite and magnetite on the Kerala, Tamil Nadu, Andhra Pradesh, Odisha and Maharashtra coasts, and nearshore regions[22]. The reserves of ilmenite (600 million tonnes (MT)), rutile (30 MT), garnet (60 MT), zircon (35 MT), kyanite (2 MT), sillimanite (4 MT), monazite (12.5 MT) are worth USD 120 billion[23]. The Ministry of Mines, GoI, has notified offshore blocks of $5' \times 5'$ size for exploration. Many private companies have signed a Memorandum of Understanding (MoU) with the concerned State Governments for the exploration of these deposits. Indigenous mining and beneficiation techniques have been developed by the CSIR-National Institute of Oceanography (NIO), Goa, CSIR-Central Mechanical Engineering Research Institute (CMERI), Durgapur and CSIR-Central Institute of Mining and Fuel Research (CIMFER), Dhanbad. The mining of these deposits must be initiated and industrialized.

The ocean contains vast resources of mineral deposits such as polymetallic nodules, polymetallic sulphides and ferro-manganese crusts. They contain not only large quantities of polymetallic nodules (Mn, Cu, Ni and Co) scattered in the Central Indian Ocean Basin (CIOB) beyond the depth of 4000 m, REEs and platinum[24]. The International Seabed Authority (ISA), Jamaica has granted exploration rights to

India covering 75,000 km^2 in CIOB. The estimated reserves of polymetallic nodules are 380 MMT (ref. 25). The estimated reserves of manganese, nickel, copper and cobalt are 15, 5, 2 and 2.5 MMT respectively. The total value of these reserves is estimated by ISA as USD 187 billion. Beneficiation processes to extract manganese, copper, nickel and cobalt have been developed by CSIR-Institute of Minerals and Materials Technology (IIMT), Bhubaneswar and CSIR-National Metallurgical Laboratory (NML), Jamshedpur. Efforts should be initiated to extract REEs and platinum from these deposits.

The mid-oceanic ridges in the Indian Ocean have base metals, copper, lead, zinc and noble metals, gold, silver, palladium and platinum, around the hydrothermal vents. India has exploration rights in a 10,000 km^2 area in CIOB granted by ISA. The exploration activities have been coordinated by ESSO-National Centre for Polar and Ocean Research (NCPOR), Goa. Preliminary geological, chemical, physical and biological surveys are on to locate possible areas of hydrothermal deposits (https://ncpor.res.in).

Cobalt is a critical mineral in high-tech industries and has strategic importance. In 1997, India had reported a Co-enriched ferro-manganese crust on the Afansly–Niktin Seamount in the Indian Ocean[26,27]. This crust has manganese, iron, cobalt, nickel, copper, vanadium, lead and zinc followed by REEs and platinum. The cobalt and platinum content is 0.3–0.9% and 200–900 ppb respectively[28,29], and appropriate beneficiation technology needs to be developed. A contract for exploration for cobalt to be obtainned.

Seawater and brine are untapped sources of critical metals and elements. Advances in industrial ecology, material-flow analysis and water purification can recover these metals[30]. Experiments should be initiated to extract metals from seawater by academia and research institutions.

To harness these mineral resources, sustainable technologies for exploration and mining need to be evolved and implemented. The observation and measurement of seabed characteristics and the environment are the main requirements for exploration. A remotely operable vehicle (ROSUB 6000) having multi-beam sonar, high-resolution imaging system, a robotic arm for sampling and other scientific payloads[31], a remotely operable soil tester (ROSIS) for measuring mechanical properties of soil[32], deep-water wire-line autonomous coring machine (WACS) for obtaining a core of 100 m, up to 3000 m water depth has been developed[33]. Mining of the polymetallic nodules using crawler and riser system is under development[34]. The development of various technologies, including manned submersible has got a major boost under the 'Deep Ocean Mission' of the Ministry of Earth Sciences, GoI.

As development along the coast and ocean increases, the requirement for freshwater will also increase. Freshwater from the sea is an attractive solution; however, plants based on reverse osmosis technology are ecologically unfriendly. Low-temperature thermal desalination (LTTD), an environment-friendly technology that uses a natural ocean thermal gradient, first demonstrated at the North Chennai Thermal Power Station[35], is an ideal solution. LTTD-based plants of capacity 100,000/150,000 l/d are in operation on Kavaratti, Minicoy and Agatti Islands. Six more plants are under construction. The challenge is to set up offshore plants that have the capability of generating freshwater of 10 million l/d. Collective investments in designing seawater intake and ocean platforms, finances and human resources are required.

Ocean energy

Oceans are likely to play a critical role in energy transition. As we phase down the use of fossil fuels for energy generation, we need to consider the ocean from new energy sources. The recent exploration of gas hydrates (ice-like crystalline forms of methane and water) has been promising. Prospective zones have been identified in the Krishna–Godavari, Mahanadi and Andaman offshore basins. The total volume of methane gas estimated is 1900 trillion cubic meters[36,37]. The Oil and Natural Gas Commission, GoI, has carried out investigations in the Krishna–Godavari basin and identified gas hydrate accumulations. Technology development for the exploitation of this resource is underway. Experiments to utilize offshore wind, thermal, wave and currents to generate energy are underway. The economically viable plants to utilize offshore wind are likely to commence during the next few years.

Sustainable management of the coast

The increasing activities of the coast will need a robust coastal zone management plan to ensure development along with securing the health of coastal habitats. The sustainable management of coasts involves integration of timely and up-to-date information on coastal wetlands, coastal erosion, deposition and sediment transport, natural hazards and their impacts, water quality, and fisheries and other biota[38]. India is one of the few countries in the world to have detailed maps of coastal habitats, mangroves, coral reefs, coastal land use and shore change for the entire country's coastline. Baseline estimates of the extent of wetlands, mangroves and coral reefs in the country have been provided for macro-level planning[38]. In India, coastal areas are governed by the Coastal Regulation Zone Notification-2011 of the Ministry of Environment and Forest, GoI. This notification restricts or prohibits certain industrial and construction activities between high and low tide lines and 500 m from high tide lines. The coastal zone management plans for the entire coastline of India have been made to implement these regulations.

Coastal regions are vulnerable to many hazards such as cyclones, storm surges, tsunamis, coastal erosion, sea-level rise, marine heat waves, etc. Such extreme events have been increasing due to the impacts of climate change. To safeguard investments on the coast and protect the lives of people, early warning of impending danger should be provided. Early warning systems for cyclones, tsunamis and coastal floods are in place[39–42]. The identification of vulnerable areas along the coast due to episodic events and sea-level rise for India's coastline on a 1 : 25,000 scale has been carried out for the assessment of risks due to increasing sea-level rise and other hazards.

Information on sea state is required for economic activities such as shipping, fishing, oil and gas production. Numerical models have been customized to forecast waves, ocean currents, sea surface temperature, mixed layer depth and tide predictions[43]. This information facilitates smooth operations for fishing, shipping, ports and other offshore activities.

It is now proposed to adopt coastal marine spatial planning, which is a science-based tool of analysis of coastal states to address specific coastal/marine area management for sustainable development. Such planning has been done for Puducherry and Lakshadweep Islands (www.nccr.gov.in).

The way forward

India is committed to blue economy and has taken several steps to ensure its implementation. The following actions are required to herald an era of blue economy in the country.

Long-term sustaining and systematic observations which record vital signs of the oceans, their changes and causes at various spatial and temporal scales need to be ensured. Building capacity for sustained observations is a key to understanding physics, biogeochemistry, biology and ecosystems. These observations are crucial for developing models for providing effective services to various sectors such as fisheries, safe navigation for shipping, port development, advisories for hazards, monitoring ocean health, conservation, sustainable use of marine resources, facilitating human activities and coastal marine area spatial planning.

Satellite observations on ocean colour, sea surface temperature, wind and height have provided new dimensions to observations, and are required for information on ocean, weather and climate. Hence their continuity and timely availability must be ensured. *In situ* observations, through moored buoys, drifting buoys, argo floats, high frequency radars, gliders and ship-based observations have provided high-resolution observations, and need to be continued.

Measurement of trace elements and isotopes is important as they play important roles in the ocean as nutrients and tracers of contemporary and past processes. Their sources and sinks and biogeochemical cycling need to be understood to explain the spatial and temporal productivity variations in the oceans.

Collection of such data would require large investments in satellites, research vessels, moored buoys and autonomous vehicles for observing and sampling ocean water columns. Investments in financial and human resources are a critical requirement.

A detailed geological, geophysical and bathymetric survey of the EEZ, covering 2 million km^2 is a high priority. Second, a detailed assessment of the seabed of the continental shelf must be undertaken. We have only submitted a partial claim under the Commission on the Limits of the Continental Shelf. The full claim should be submitted at the earliest. Third, the availability of cobalt and nickel in the high seas needs to be explored, and exploration rights must be obtained from ISA.

The large volume of data on the Indian Ocean collected during the last 60 years or so, provides information on physical, chemical and biological characteristics of oceans and coasts on various spatial and temporal domains that are vital for research and meeting the Sustainable Development Goals; they are organized into an Ocean Data and Information System (https://incois.gov.in). To integrate data from diverse observing platforms and model outputs, 'Digital Ocean' must be developed to provide ocean data and their visualization on a single platform through web-based services. Efforts have been initiated in this regard by ESSO-INCOIS, Hyderabad.

The development of Digital Ocean will facilitate integration of economic data with environmental data, critical for making macro-economic decisions[20].

An accounting system for oceans is to be developed by bringing together different datasets of economic activities and ecological services. A framework must be designed by supporting research projects to academia. Such exercise will help strengthen the 'societal relevance' of the oceans.

Development of ocean climate change advisories through seasonal to decadal timescale predictions of sea-level changes, cyclone intensity and frequency, storm surges and wind waves, primary productivity, oxygen minimum zone, pCO_2 levels, changing fishery and fish stock, and ocean health as envisaged in the 'Deep Ocean Mission' of the Ministry of Earth Sciences, GoI, should be a priority.

There are many stakeholders in developing the blue economy, such as earth sciences, environment, forest, agriculture, fisheries, mining, shipping, ports and industries. An effective institutional framework for implementing activities related to blue economy must be set up. The investments in building infrastructure, human resources, finances and governance systems will pave the way for climate-resilient blue economy, and ensure sustainability of oceans for the benefit of the people.

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