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Invited Paper

Towards Blue Economy: A Perspective

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Abstract: The term 'Blue Economy' emphasizes essentially an ocean-dependent economic development to improve quality of life of people. India committed to advance the "Blue Economy" and several programs have been initiated to promote blue economy in the country. One of the important components of promoting blue economy is to have adequate information about sea bed and mineral resources, in the Exclusive Economic Zone (EEZ), Legal Continental Shelf as well as High Seas. Apart from placer minerals on the coast, we need to explore for minerals, such as manganese nodules, polymetallic sulphides and cobalt crusts in High Seas. The availability of gas hydrates on our continental shelf has huge potential to satisfy our ever-increasing energy requirements. We need to invest in developing technology and human resources to utilize these resources. At the same time, the development of offshore mineral and energy resources will need setting up of infrastructure facilities on the coast. As coastal zone is vulnerable to many hazards such as cyclones, storm surges, tsunamis, coastal erosion, sea level rise, etc., an assessment of coastal vulnerability to understand risks involved, has to be undertaken. Various environmental data will be required to utilize ocean resources. An institutional framework for implementing activities related to blue economy to be set up so that investments in building infrastructure, developing human resources, and setting up governance system shall pay rich dividends for future generations and ensure sustainability.

Keywords: Blue economy, polymetallic nodules and sulphides, gas hydrate, coastal zone management.

Introduction

Oceans provide energy, food and mineral resources, facilitate trade and commerce, control weather, climate and hazards as well as present an ecosystem to survive. Our economic dependence on ocean has been increasing and will continue to increase in future. Prof. Guntar Pauli was first to introduce the term 'Blue Economy' to reflect the needs of people for growth and prosperity in view of impacts of climate change (Pauli, 2010). The term 'Blue Economy' has been defined as an ocean-dependent economic development for improving quality of life of people while ensuring inclusive social development as well as environmental and ecological security. It means that there should be certain limitations on the technology-based economic development and emphasis should be on social obligations to protect and conserve coastal and marine ecosystems. The Third World Summit Conference UN+20 in 2012 had also focused on expanding the "Green Economy" to "Blue Economy" and subsequently UN advocated conservation and sustainable use of ocean resources as one of goals under Sustainable Development Goals (SDGs). UN has also declared 2021-2030 as the "Decade of Ocean Science for Sustainable Development." Hence, it is very apt to discuss about the role of geoscience in development of blue economy.

The major components of the Blue economy are 1. Sustainable use of living resources, 2. Exploration and utilization of minerals, hydrocarbons and develop renewable energy resources, 3. Development of deep ocean technologies for harnessing resources, 4. Development of shipping and ports to facilitate trade, 5. To encourage eco-friendly tourism along the coast and 6. Assessment of hazards and response mechanism (cyclone, tsunami, sea level rise, coastal erosion, etc.).

The issues related to geoscience such as surveying of sea bed, exploration of mineral and energy resources, and coastal zone management are briefly discussed in this article.

Survey of the Exclusive Economic Zone and Legal Continental Shelf

The marine geophysical survey of a sea bed is one of the prime requirements for assessing potential for mineral and energy resources. The United Nations Convention on the Law of the Sea (UNCLOS) established different maritime zones for coastal states with corresponding duties and obligations, viz. Exclusive Economic Zone (EEZ), Continental Shelf and High Seas (International Seabed area). The EEZ extends up to 200 nautical miles from baseline and Indian EEZ covers 2.02 million sq km. India has sovereign rights over the waters, sea bed and sub-soil for the purpose of exploring and exploiting, conserving and managing living and non-living resources and other economic activities. Multibeam bathymetry and geophysical surveys have been undertaken by the Earth System Science Organization (ESSO) – National Centre for Polar and Ocean Research (NCPOR), ESSO-National Institute of Ocean Technology (NIOT) as well as Geological Survey of India (GSI). These surveys mapped topographical and geomorphological features such as sea mounts, channel levees, abyssal plains, slumps, etc. Systematic samples were drawn and analyzed to understand resource potential. About 80 per cent of survey of EEZ has been completed and maps of 2° x 2° are under preparation (M. Ravichandran, Personal Communication).

The continental shelf comprises the seabed and subsoil of the submarine areas that extend beyond the territorial sea and as natural prolongation of land territory to the outer margin of the continental margin. India can assert their sovereign rights over resources of the legal continental shelf, up to an outer limit of 350 nautical miles from the baseline upon fulfilling certain conditions and based on the recommendations of the Commission on the Limits of the Continental Shelf (CLCS). A reconnaissance marine geophysical survey, viz. multi-beam bathymetry, gravity and magnetic profiling, and multi-channel seismic reflection and refraction, measuring 31,000 line km, along with 90 ocean bottom seismometer, on the continental shelf of India was carried out (Nayak, 2014). These surveys were conducted by ESSO-NCPOR, Council of Scientific and Industrial Research (CSIR) – National Geophysical Research Institute (NGRI) and CSIR-National Institute of Oceanography (NIO). These data were used to prepare a claim of about 0.6 million sq. km in the Arabian Sea and submitted the CLCS in 2010. The second submission to CLCS in the Bay of Bengal is yet to be done. All these data related to EEZ and CLCS have been organized as Marine Geo-scientific Database at ESSO-NCPOR.

The High Seas are areas beyond EEZ and beyond the limits of national jurisdictions. The exploration and exploitation of mineral resources of sea bed and ocean floor in the High Seas are to be undertaken after concurrence of the International Seabed Authority (ISBA) established under UNCLOS. Three categories of the deposits have been identified, polymetallic manganese oxide nodules (PMN), polymetallic sulphides (PMS) and cobalt-rich ferromanganese crusts (Co-Fe-Mn) by ISBA to undertake exploration surveys by nations. The details about the surveys undertaken by India are discussed in the next section.

Mineral and Energy Resources

The development of offshore mineral and energy resources is complimentary to replenish the country's requirements for its industrial and economic growth. The assessment of mineral and energy resources has been undergoing since last couple of decades, however, the exploration and assessment of these resources and development of suitable technologies need to be stepped up. Considerable investments in terms of human and financial resources are required to meet these challenges. Such investments will be beneficial to the country in the long run for sustained economic growth.

Mineral Resources: Coastal and offshore minerals offer many strategic metals, such as nickel, cobalt, copper, uranium, thorium, titanium, etc. India does not have resources for key metals such as nickel and cobalt and copper resources are dwindling. The reserves of these metals on land may not last more than few decades and we will have to depend on supplementary offshore resources. These minerals are distributed right from coast to deep sea, to the depth of 6000 m.

Coastal placer minerals, such as ilmenite, rutile, magnetite, garnet, zircon are extensively available on the Kerala, Tamil Nadu, Andhra Pradesh, Orissa and Maharashtra coasts and nearshore waters (Loveson and Misra 2004; Loveson et.al. 2005; Loveson et.al. 2007). The Geological Survey of India (GSI), Atomic Mineral Division (AMD) of the Atomic Energy Department (AEC) and CSIR-NIO have been involved in exploration and survey of these minerals. The reserves of ilmenite, rutile, garnet, zircon, kainite and sillimanite are estimated to be about 600, 30, 60, 35, 2 and 4 million tons, respectively, which is worth of approximately US $ 120 billion (Indian Mineral Yearbook, 2017). The enormous presence of offshore ilmenite and other placers deposits has led the Govt. of India to encourage offshore mining through "Offshore Area Minerals (Development and Regulation) Act 2002" and "Offshore Mineral Concession Rules 2016". The Ministry of Mines in 2010 have notified specified offshore blocks of 5' x 5' size, 26 in the Bay of Bengal and 37 in the Arabian Sea for exploration (The Gazette of India No. 1126 dated June 9, 2010). Many private companies have shown interest and have signed MoU with the concerned state governments such as Tamil Nadu and Orissa to utilise these resources. Various indigenous technologies for mining and beneficiation of these minerals have been developed.

Poly-metallic nodules are scattered on sea floor in the Central Indian Ocean (CIO) beyond the depth of 4000 m. India has exploration rights, as granted by the International Sea Bed Authority (ISBA) over 75,000 sq km in the CIO. India has been recognized as the 'Pioneer Investor.' It has entered into a contract with ISBA for exploration of polymetallic nodules (PMN) and is valid up to 2022. Detailed exploration geophysical and geological surveys have been carried out by CSIR-NIO since 2002. The first mining site of about 12.5 x 12.5 km has been identified. The environmental data for baseline conditions have been collected. The environmental impact assessment (EIA) has been carried by simulating mining and predicting its impacts as well as suggesting mitigation measures (Sharma, 2011). The total reserves are 380 million tons, comprising Mn, Ni, Cu, Co, etc. (Jauhari and Pattan, 2000). The total worth of these reserves initially estimated to be about US $ 45 billion (based on average metal process in June 2018). However, recent estimates by ISBA puts their worth to be around US $ 187 billion.

Metallurgical processes for extraction of metals, Mn, Cu, Ni, Co, have been developed using different approaches by CSIR-Institute of Mineral and Metals Technology (IMMT) and CSIR- National

Mineral Laboratory (NML). A pilot plant of 500 kg capacity was set-up at the Hindustan Zinc Ltd, Udaipur to demonstrate the hydro-metallurgical process for extraction of copper, nickel and cobalt. Efforts are to be initiated to extract other metals also.

The poly-metallic sulphides, associated with mid-oceanic ridges, have kindled lot of interest due to high concentrations of the base metals (Cu, Pb, Zn) and noble metals (Au, Ag. Pd, Pt). India has entered into an exploration contract in 2016 with the ISBA covering an area of 10,000 sq. km. for 15 years in the SW Indian Ocean. ESSO-NCPOR has been leading these efforts. Preliminary surveys have been undertaken to study various oceanographic, chemical, geological and biological studies to identify potential sites. The exploration work is under progress and analysis and interpretation of data/samples are underway.

The rare metals (metals having concentration of few milligrams per ton in the Earth's crust), such as cobalt (Co) which have applications in high-tech industries, are found in abundance on the seamount ferromanganese crusts. Cobalt is mostly associated with copper, nickel and arsenic. The first Co-enriched ferromanganese encrustations (SFMC) was reported in the equatorial Indian Ocean Seamount, called Afansiy-Nikitin sea mount (Banakar, *et al.* 1997; Parthiban and Banakar, 1999). The most dominant metals in SFMC are Mn, Fe, Co, Ni, Cu, V, Pb, Zn, followed by Rare Earth Elements (REE) and followed by Platinum Group Elements (PGE). These expeditions have revealed that Co content varies from 0.3 to 0.9 % while Pt ranged from 200-900 ppb (Banakar *et al.* 2007; Rajani *et al.* 2005). Cobalt being strategic importance, it is crucial for India to seek exploration rights in this region to understand their mode of occurrence, estimate their resources, assess economic potential and develop technology to harness them.

Energy Resources: The Ocean has been providing most of energy requirements of mankind. India, is one of the largest consumers of fossil fuel, however, indigenous production is only 30 per cent of requirement. Gas hydrates, ice-like crystalline form of methane (99.9%) and water, are considered as a major future hydrocarbon energy resource and occurs in shallow sediments along continental margins of India where water depth is more than 500 m. The volume of methane gas in the deep ocean located gas hydrates reservoirs of India is prognosticated to be 1900 TCM. It is presumed that only 10% recovery can meet India's energy requirement for 100 years (Sain and Gupta, 2008; Sain and Gupta, 2012). A detailed program for understanding formation of gas hydrate as well as development of technology to harness same has been launched.

Under the aegis of the Ministry of Earth Sciences, ESSO-National Institute of Ocean Technology (NIOT), CSIR-NGRI and CSIR-NIO are pursuing activities towards delineation and resource estimation at prospective targets. CSIR-NIO has commenced many cruises in Krishna, Godavari and Mahanadi basins and other places and subsequently generated a huge database on geological and geophysical information for gas hydrates exploration studies (Dewangan *et al.* 2010; Mazumdar *et al.* 2009; Muralidhar *et al.* 2006). CSIR-NGRI has set up a state-of-art Gas Hydrate Research Centre comprising inversion, processing, modelling & interpretation of seismic data for detection and assessment of gas hydrates along with laboratory studies to understand formation and dissociation kinetics to provide inputs for developing suitable production technology. The decade long research has led to characterize gas hydrate reservoirs, development of methods for quantification and assessment of gas hydrates, identification of prospective zones in the Krishna-Godavari, Mahanadi and Andaman offshore basins (Sain, 2017). The development of full waveform tomography (FWT) has facilitated estimation of critical parameters such as porosity, permeability, pore pressure and geo-technical properties that are required for the development of viable production technology. ESSO-NIOT has been engaged in developing numerical models towards extraction of methane gas from gas hydrate reservoirs. Various models for thermal simulation, gas hydrate reservoir modelling, methane gas bubble dissolution model, etc. have been developed and a patent has been obtained (Vedachalam *et al.,* 2016).

The National Gas Hydrate Program (NGHP), spearheaded by the Directorate of Hydrocarbons (DGH) and Oil and Natural Gas Commission (ONGC) have completed two drilling expeditions NGHP-01 and 02 in Mahanadi basin and near Andaman Islands, utilising Joides Resolution of USA and Chikyu of Japan, respectively, in KG basin. The expeditions have identified two distinct gas hydrate accumulations in the KG basin with layer type and fracture type settings with thickness ranging from 20-100 m, within 200 m below sea floor at 2200 m depth. ONGC has set up a Gas Hydrate Research & Technology Centre (GHRTC) at Panvel, Maharashtra for R&D works relating to exploration and exploitation of gas hydrate resources. The proposed NGHP-03 aims at pilot production testing for understanding of the environmental impacts.

Ocean Technology: India has been planning to harness ocean mineral and energy resources. This requires development of a set of equipments, viz., in-situ soil tester, remote operable vehicle, autonomous coring machine, autonomous vehicles, manned submersible and mining equipment. ESSO-NIOT is actively engaged in developing suitable technologies. The visual observation of sea floor, measurement of characteristics of sea bed and environs is one of the important requirement of exploration for minerals.

Remotely operated vehicle (ROSUB 6000) has multifunctional sampling tools operated with robotic arm, high-resolution video imaging systems, scientific payloads and multi-beam sonar and can operate up to 6000 m depth (Ramadass *et al.* 2020). ROV is proved to be very useful for collecting scientific data and seabed samples towards mineral exploration, seabed imaging, gas hydrate exploration, pipeline routing, submarine cabling, etc. A remotely operable soil tester (ROSIS) have been developed for obtaining soil properties and tested at 5500 m depth (Muthukrishna *et al* 2014). The strength of soft sea-bed, especially the bearing strength and shear strength parameters for designing mining equipment. An acoustic positioning system which facilitates deep sea positioning and track keeping has been developed.

Deep water Wire-line Autonomous Coring Machine (WACS) has been developed for obtaining core up to 100 m at the depth of 3000 m water depth for geotechnical investigations and assessment of ocean resources (Ramesh *et al.* 2020). The coring system has unique capability to collect gas hydrates with custom-built in situ pressure core sampler.

Polymetallic nodules are available in deep sea having pressure of 550 bar and very soft soils 2.5 kPa (similar to heavy grease). The development technology for mining these nodules is a major challenge and has been underway at the ESSO-NIOT. The system comprises seabed-based crawler, vertical riser and surface facility for collecting produced minerals. A mining machine, a tracked vehicle, developed and demonstrated at water depth of about 500 m, where nodules were collected, pushed and pumped to the mother vessel (Varshney *et al.* 2015). These results are being used to develop a mining machine system for 6000 m is being developed.

Freshwater from Sea: All developmental activities along the coast and in high seas, will require freshwater, which is scarce. Freshwater from sea is a very attractive solution; however, plants based on reverse osmosis technology are ecologically unfriendly. A Low Temperature Thermal Desalination, an environment-friendly technology that utilizes natural ocean thermal gradient, is found to be suitable for this purpose. Three plants, in Kavaratti, Agatti and Minicoy, each generating 100,000 l/day, based on this technology has been under operation on the Lakshadweep Islands (Nayak, 2010) during last 15 years. Water-borne diseases have reduced considerably on the Islands. Similar plants are being set up in remaining islands. Power plants also generate hot waste water and can be used to generate drinking water or boiler quality water. The technology was successfully demonstrated at the North Chennai Thermal Power Station (Jahihal and Prabhakaran, 2019). The technology is now being scaled up and a plant for 1.5 million l/day is being set up at the Tuticorin Power Plant. An offshore plant for generating 10 million l/day freshwater is being planned. The challenge is to design suitable seawater intake and appropriate ocean platform and experiments are underway. The successful implementation of this technology will ensure freshwater availability for developmental activities.

Coastal Zone Management

All above mentioned developmental activities will increase pressure on the coastal zone. Hence, an effective coastal zone management plan, comprising a regulatory mechanism for conserving coastal and marine ecosystem, ocean state advisory for safe shipping and navigation system, vulnerability assessment of coastal hazards and warning systems for these hazards, has been developed. In India the areas between high and low tides and 500 m from high tideline are declared as 'Coastal Regulation Zone (CRZ)' and in this zone, certain activities are restricted or prohibited in order to preserve and conserve coastal ecosystems. This regulation has helped to conserve vital and critical ecosystems, provide livelihood security to coastal communities and promote socio-economic development (Nayak, 2017). The management plans for the entire Indian Coast have been prepared which will help to build necessary infrastructure for 'Blue Economy'.

The information on sea state (sea surface temperature, currents, mixed layer depth, waves, tides, etc.) 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, etc. on a daily basis. A three to six-hourly forecast for waves (height and direction), sea surface temperature, mixed layered depth, depth of thermocline, surface currents are provided 5 days in advance for the entire Indian coast and Indian Ocean at various spatial scales (Balakrishnan Nair *et al.* 2013) and can be accessed on www.incois.gov.in.

The coast is also vulnerable to many hazards such as cyclones, storm surges, tsunamis, coastal erosion, sea level rise, etc. The prediction of landfall point has been is about 40 km and intensity is accurate in 85% cases (Goyal, *et al*, 2013) and forecast are provided at least 5 days in advance to all stakeholders. The prediction of associated storm surge to assess likely areas of inundation is very accurate. A state-of-the-art tsunami warning system, capable of receiving and analyzing seismic and sea level, in real time and provides advisories about travel time, and run up height at 1800 coastal forecast points within 10 minutes to all concerned within India and the Indian Ocean Rim countries (Nayak and Srinivasa Kumar, 2011; Nayak *et al*., 2020).

Coastal vulnerability maps (cyclone, tsunami, and sea level rise) for the entire Indian coast have been produced on 1:100,000 scale (www.incois.gov.in). The methodology is based on projected long-term rise in sea level, climatological data on tidal range and wave height, coastal elevation and slope, long-term shoreline changes (rate of erosion and accretion) along with geomorphological setting has been developed (Srinivasa Kumar *et al.* 2010). The vulnerability has been defined in terms of an index indicating likelihood of physical changes that may occur and the natural ability of coastal system to change environmental conditions. Such maps can provide base level information for coastal management.

Tourism is one of important economic activity on the coast. In order to promote a safe and environment-friendly tourism, the process of obtaining 'Blue Flag' certification from the Foundation for Environment Education (FEE), not-for-profit non-governmental organization, based in Denmark has been initiated. The Blue Flag criteria includes specific standards for the water quality, safety, environment management and education. India has submitted applications for eight beaches, viz. Shivrajpur (Gujarat), Ghoghla (Diu), Kasargod and Padubidri, (Karnataka), Kappad (Kerala), Rushikonda (Andhra Pradesh), Golden beach (Orissa and Radhanagar (Andaman and Nicobar Islands) for blue flag certification to FEE. It is expected that these beaches will promote high-value tourism in the country.

The Way Ahead

It is likely that the economic growth prospects in India beyond 2030 will be limited without large investments in coastal and ocean environments. Realizing the importance of the ocean resources, the Govt. of India has announced a 'Deep Sea Mission' in order to gain knowledge about resources in the Indian Ocean and development of technologies to harness them (MoES, 2018). Ocean environmental data will be crucial to make macro-economic decisions about the blue economy. Oceans will have to be managed and accounted for in the same way as other valuable assets on land for sustainable growth.

Large volume of scientific data of the Indian Ocean collected during last fifty years or so, has been organized around GIS as the Ocean Data and Information System (ODIS) (Rama Rao *et al.* 2018). However, these outputs are not stored / represented in formats, systems and structures that finance, economy or other decision-makers understand or can use. We need to develop a framework to bring together these disparate data sources by developing an accounting system for oceans resources and environment. These ocean data sets are to be integrated with environmental, social and economic data to develop an accounting framework as a part of strategy for ushering blue economy. Such exercise will help to strengthen "societal relevance" of ocean.

An institutional framework for implementing activities related to blue economy has to be planned and set up. Under this framework, the decisions about investments in building infrastructure, human resources, finances and governance system for ocean environment have to be made.

An effective communication with various stakeholders including policy makers about the scope and objectives of such development, which are relevant to society, should be established. The primary focus of ocean governance should be sustainable development through the utilization of ocean resources taking into account conservation needs and protection and preservation of the marine environment. Such a responsible stewardship of oceans will pay dividends for generations to come and renew our commitments to ensure sustainability of oceans and thus of the planet Earth, for the benefit of mankind.

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