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A Critical Review on Potentiality of Marine Resources of the Bay of Bengal and Indian Ocean: Bangladesh Perspective

Md. Bazlar Rashid*, Md. Abdul Aziz Patwary, Md. Shamsuzzaman, Md. Mizanur Rahman

Geological Survey of Bangladesh, Segunbagicha, Dhaka, Bangladesh

*****Email: bazlarrashid@ymail.com

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Abstract: The Bay of Bengal (BoB) is rich in resources (both living and non-living). Marine living resources include fisheries, mangrove forests, coral ecosystems, plankton, sea grass and seaweeds, etc. Whereas, non-living resources are oil, gas, gas hydrates, sea salt, heavy minerals, etc. Present study reveals that the oil and gas fields discovered in the BoB are parallel with exploration activities. Bangladesh part of the BoB includes the low exploration area, consequently only one producing gas field, whereas India and Myanmar discovered many significant gas and oil fields in their territory. India discovered gas hydrates in the BoB in 2016. In the Exclusive Economic Zone (EEZ) of Bangladesh, 0.11 tcf to 0.63 tcf gas hydrates were discovered in 2022, with assessment of 17-103 tcf of natural gas, though gas hydrates exploration at industrial scale is still a big challenge in the world due to stability, composition and distribution of gas hydrates in nature. Different types of heavy minerals are also present in the coastal parts of the country. The Indian Ocean has about 20% of the worldwide tuna production, though Bangladesh contributes very little of it. In the marine part of the country, 475 species of fishes are found compared to 250 species on land. BoB is very important for BIMSTEC countries and also for China and Pakistan in consideration of seaborne trade. Bangladesh can introduce modern cruises like other BoB countries to visit the coastal islands as well as Sundarbans mangrove forest contributing considerably to local employment and economic expansion. Marine organisms have unique nutritional value and contain many kinds of bioactive substances. At present, internationally recognized antibiotics of cephalosporin series, vidarabine antiviral drugs, and a series of sodium alginate marine drugs have been existing. Japan has invested manpower and material resources in seawater by extracting lithium and achieving progress. Japan, Germany, United States and Sweden have also have a certain scale of seawater extracting uranium experiment devices. Despite the challenges like lack of trained personnel, scientific equipment and poor ocean governance, Bangladesh essentially needs to take the opportunity to explore the potential marine areas.

Keywords: Oil and gas, gas hydrates, marine organisms, tuna, coastal tourism.

Introduction

The southern territory of Bangladesh has the Bay of Bengal (Fig.1). It is the biggest bay in the world, occupying ~ 2 million km², triangle-shaped, and situated in the north-eastern part of the Indian Ocean (Blakeley, 2010). BoB is rich in both living and non-living resources (Hussain et al., 2019; Khan, 2021; NOAA, 2021). Marine living resources include fisheries, mangrove forests, coral ecosystems, plankton, sea grass, and seaweeds, whereas non-living resources are oil, gas, gas hydrates, sea salt and heavy minerals (Hussain et al., 2019). These resources are vital components of the country's economy and for supporting livelihoods, trade, and various industries. BOB is home to various species of fish such as tuna, sardines, mackerel and shrimp which support the livelihoods of millions of people in the fishing industry. Offshore gas and oil reserves support energy security in the region. Gas hydrates, manganese nodules, and rare earth elements are potential future resources. Furthermore, shipping, trade routes, tourism, renewable energy (tidal power, offshore wind etc.) facilitate global trade and business, tourism employment and revenue, and sustainable power generation. However, Bangladesh explored a very small amount of resources in this Bay. It has only one producing gas field (Khan, 2021). Bangladesh efforts to lease the offshore blocks for mineral resources identification were hampered by unsettled maritime margins with Myanmar and India. After the solution of maritime boundaries (Anon, 2012a; Chowdhury, 2014), it gives opportunities to explore mineral resources and carry out other scientific studies.

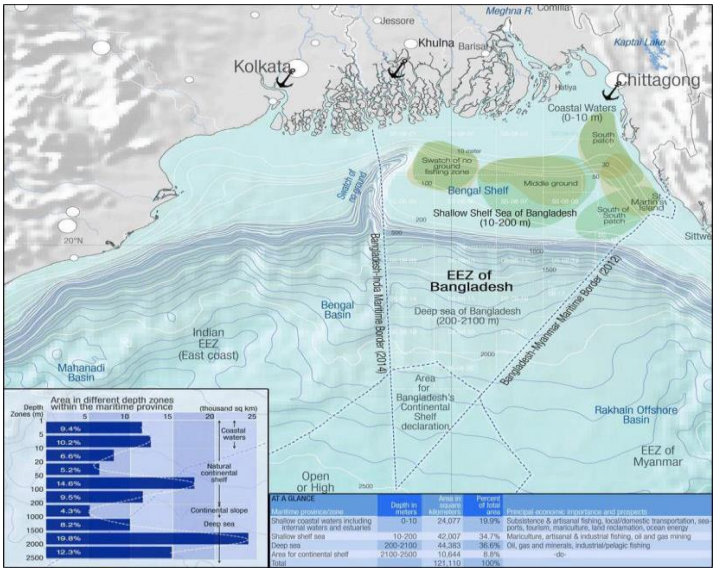

Fig. 1 Marine area of Bangladesh (Chowdhury, 2014).

Hydrocarbon and Mineral Resources

The Bay of Bengal is rich in mineral resources, including hydrocarbons, polymetallic nodules, and heavy minerals. These resources play an important role in the economics of the BoB nations such as Myanmar, Sri Lanka, Bangladesh and India.

Oil and Gas

Natural gas has played a crucial role as the primary energy source driving Bangladesh's rapid development. Bangladesh currently produces approximately 2,100 million cubic feet per day from 113 wells across 21 of its 29 discovered gas fields. Additionally, the country imports 700–800 mcfgpd of LNG from the global market (Bowles et al., 2024). The nation's gas resources are spread over 11 shallow offshore blocks, 15 deep offshore and 21 onshore blocks. So far, gas fields have mainly been concentrated in an onshore belt stretching from northeastern to southeastern Bangladesh, extending into the BoB. The Haripur gas field in Sylhet, discovered in 1955, was the country's first, while the most recent discovery, Ilisha-1 marks Bangladesh's 29th gas field (Bowles et al., 2024). Two offshore gas fields, Sangu and Kutubdia, have also been discovered. But the consumption of natural gas in the country has been much more than the discovery of natural gas. Over the past decades, both production and consumption have increased significantly. However, since 2016-17, gas production and supply have begun to decline, failing to keep pace with rising demand (Shetol et al., 2019). A shortage would have severe consequences for power plants, industries, and other sectors heavily reliant on gas. While the government is actively exploring Alternative energy sources, progress in this area remains limited. To prevent a severe energy crisis, urgent efforts are needed to expand gas reserves. Forecasts suggest that, without new or alternative reserves, Bangladesh could face a serious gas shortage beyond 2020 (Anon, 2012a). In this context, new discoveries will be essential to ensuring energy security.

India discovered many important oil and gas fields in the Indian Ocean and BoB (Blakeley, 2010; Anon, 2015). The Bengal Fan is the earth's biggest fluvio-deltaic-slope fan complex (Blakeley, 2010). In the BoB, geologically the Krishna-Godavari (KG) basin is the best implicit and the most investigated. After the 1990s, Myanmar also explored a number of gas fields in the Rakhine basin of the BoB like Yadana field, 1998 and Yetagun in 2000 (Blakeley, 2010; Anon, 2016b). However, Bangladesh has only one producing gas field. Geochemical study of sediments and discoveries of gas in the Rakhine Basin and the Mahanadi Basin strongly suggest hydrocarbon generation, eviction and trapping in the offshore Bengal Basin of the BoB (Khan, 2021). The hydrocarbon source rocks have elevated maturity level within the oil generation window for deeper sediments, and are characterized by marine deposition (Khan, 2021). Sedimentation has been controlled by the syndepositional structural growth, trench migration and converging crustal configuration. Recently, TGS-Schlumberger completed a 13,232 km 2D seismic survey covering both deep and shallow offshore blocks indicating promising prospects (Bowles et al., 2024). The offshore areas, particularly submarine fan and slope fan systems, show significant potential for gas discoveries to fulfill the future gas demand of Bangladesh.

Manganese (Mn) Nodules and Iron-Manganese (Fe-Mn) Crusts

Manganese is the ninth and iron is the fourth most plentiful element in the crust of the Earth (Glasby, 1984), and in the deep-sea vast amounts of Fe-Mn crust and Mn nodules occur in the Indian Ocean (Hein et al., 2016; Rashid et al., 2020). The elevated contents of Ni, Cu, Co, and Zn in Fe-Mn crusts and Mn nodules make these deposits a significant possible economic store for these elements. Since the 1960s, the Fe-Mn crusts and manganese nodules mining from the deep sea have been a topic of interest (Glasby 1970, 1977). However, there has still been no attempt to mine the deep-sea nodules and crust on a profitable scale (Glasby et al., 2013), even with a huge deal of venture in deep-sea mining over ~40 years. In the Indian Ocean, only a single big area of manganese nodules has been explored, with a region similar to that of the Penrhyn Basin of Peru (Hein et al., 2013). Here, each square meter of the sea floor holds around 5 kg of manganese nodules. The size of the nodules varying from that of a potato to a top of lettuce, contain mostly manganese, as their name suggests, but also Ni, Fe, Ti, Co, and Cu. The concentration of Pt, Ru, and Rh are among the highest measured in marine Fe-Mn deposits (Hein et al., 2016). Chauhan (2003) identified the presence of ferromanganese micronodules and associated Mn and trace metals within the terrigenous sediments of the middle fan region of the BoB. He reported that Mn accumulation rates range from 307–219 mg cm^2 kyr^{-1} in sediment cores with a sedimentation rate of 20–17 cm kyr^{-1}, but decline significantly to 34–17.7 mg cm^2 kyr^{-1} in cores where sedimentation rates are 3–4 cm kyr^{-1}.

Gas Hydrates in the Bay of Bengal

In September 2014, India agreed to collaborate to explore gas hydrates potential in his territory in the BoB (Anon, 2016d), and in 2016 they discovered gas hydrates in the KG Basin of the bay with joint international expedition team of scientists from India, Japan and USA (Anon, 2016c; Anon, 2016d). This discovery is to be several of the biggest and most concentrated gas hydrate accretions yet found in the globe (Anon, 2016c; Anon, 2016d). According to USGS, this is the first discovery of its kind in the Indian Ocean that has the potential to be producible (Anon, 2016d). In the Bangladesh part of the BoB, the country has also discovered a potential reserve of 0.11 tcf to 0.63 tcf gas hydrate, which is value 17-103 tcf of natural gas, in the EEZ of Bangladesh (Anon., 2022).

Heavy Minerals in Coastal Areas of Bangladesh

Placer deposit of heavy minerals like magnetite, ilmenite, zircon, garnet, rutile, leucoxene, kyanite and monazite, occur in various parts of the coastal zones of Bangladesh (Bari, 1981; Majlis et al., 2011; Ahsan et al., 2017; Mahmud et al., 2013; Hossain et al., 2024), and the country could benefit from these deposits. The placer deposit was first discovered in Cox's Bazar by then Geological Survey of Pakistan in 1961. After the systematic survey carried out by different organizations so far several economically significant heavy mineral deposits have been identified at Cox's Bazar-Teknaf coastline and at various offshore Islands like Kutubdia, Moheshkhali, Sonadia, Matarbari and Nijhum islands, and also at Kuakata coast (Majlis et al., 2011; Ahsan et al., 2017; Mahmud et al., 2013; Hossain et al., 2024). It has also a high prospect in the paleo beaches of shallow offshore areas of the BoB which was deposited before the sea transgression and is now underwater.

Renewable Energy at the Marine Part of Bangladesh

Ocean offers enormous potential for the generation of renewable energy - wind, wave, tidal, biomass, thermal conversion and salinity gradients (Alam, 2014). The 2020 report by the International Renewable Energy Agency (IRENA), the estimated resource potential for electricity generation from all marine renewable technologies ranges between 45,000 and well over 130,000 terawatt-hours (TWh) per year. Bangladesh is mostly dependent on fossil fuel for energy generation. Renewable energy might save a lot of foreign currency on one hand and on the other hand, the country might also contribute to environmental protection using less fossil fuel. The country has a huge potential of renewable energy resources (Uddin et al., 2019). Its extended coastline has the potential prospect of tidal energy (Ahmad et al., 2018). There is a limited resource of ocean wave power in the BoB (Kowser et al., 2014). The energy is wave dominated and the wave energy can be a potential source of energy from April to October in Cox's Bazar coast and a considerable amount can be generated (Kowser et al., 2014). Ahmed et al. (2018) stated that the tidal amplitude is larger on the south-east part of Bangladesh coast and gradually decreased to the western component of the coast. Wind energy is more reliable as it is totally free and also free from pollution (Saifullah et al., 2016). Uddin et al. (2019) mentioned that mini and micro wind generation sites are available for electricity

generation. Saifullah et al. (2016) mentioned that a near shore wind farm at coastal zones of Bangladesh is possible to generate power.

Bangladesh also has a huge potential of using solar energy as countries like Spain and Germany use solar energy with half of the solar radiation received by Bangladesh (Khan et al., 2012). In Bangladesh, photovoltaic (PV) cells are a popular technology for using solar energy mainly in the rural areas, hilly areas, and also coastal areas (Uddin et al., 2019). Khan et al. (2012) mentioned that annual solar radiation availability in the country is as high as 1700 kwh/m^2.

Marine Fisheries

The BoB basin contains some of the most populous regions of the earth. Nearly a quarter of the world's population is concentrated in the eight countries that border the Bay (Amrith, 2013). Approximately 200 million people live along the BoB coasts, and a major proportion is partially or completely reliant on its fisheries (BOBLME, 2015). Bangladesh's marine waters are home to a diverse range of commercially significant species, including 36 shrimp species, 475 finfish species, 16 crab species, and 165 seaweed species (Tora et al., 2022). Bangladesh, among the total production of marine catch, gill net and hooks and lines (long lines) fishing contributes 59.58% and 2.21%, respectively, to which tuna exploitation by long lines contributes less than 0.5% and in gill nets fishing less than 1.0% in artisanal fishing. In industrial production, tuna fish contributed only 2.22 % (DoF, 2012-2013; Anon, 2019). Bangladesh oceanic tuna catches are far below the potential estimated (Anon, 2011). The Indian Ocean, having about 20% of the global tuna production, is the second largest proportion of the principal tuna market in the world (FAO, 1997). Japan and Korea are the major fishing countries in the Indian Ocean. Tunas are in great demand throughout the world market due to their outstanding meat quality (FAO, 1997; Fernandez-Polanco and Llorente, 2016). The Indian Ocean tuna economy is estimated by some to be worth 6 billion USD (IOTC, 2013), although Bangladesh contributes very little of it due to a lack of up to date fishing vessels, lack of stock evaluation and scientific management strategies. Overall, marine fisheries contributed 15% of Bangladesh's total fisheries production, which reached 4.621 MT in 2020-2021 (Tora et al., 2022). However, in the coastal areas of this region, the fish stocks depleted due to being overfished by other countries (Islam, 2003; Vivekanandan et al., 2005; Aung, 2014; Macusi et al., 2011; WOR, 2013; Scholtens, 2016). Illegal, unreported and unregulated (IUU) fishing exacerbates the problem of overfishing and threatens the livelihoods of fishers and other stakeholders (WOR, 2013).

Seaweed

Globally, seaweeds have emerged as promising marine resources (Islam et al., 2019). With over 20,000 species identified worldwide (Sobuj et al., 2024), only about 1.1% are commercially utilized. Among them, 145 species are used for food, while 110 species are harvested for phycocolloid production. Their diverse applications highlight their significant potential across various industries. Total 193 seaweed species together with 19 commercially significant species, belonging to 94 genera are found in the Bangladesh coast (Sarker et al., 2016). Sobuj et al. (2024) stated that 26 commercially valuable seaweed species are found in Bangladesh's coastal areas, including 8 species of green seaweed (Chlorophyceae) (30.77%), 10 species of red seaweed (Rhodophyceae) (38.46%), and 8 species of brown seaweed (Phaeophyceae) (30.77%). Approximately 5,000 metric tons of seaweed biomass is available (Sarker et al., 2016). Seaweed species such as *Ulva*, *Caulerpa*, *Sargassum*, *Padina*, *Gracilaria*, and *Hypnea* offer a wide range of benefits and applications across various industries, including food, pharmaceuticals, cosmetics, animal feed, biofuel production, wastewater treatment, agriculture, and bioremediation (Sobuj et al., 2024). Their bioactive compounds, antioxidant properties, and antimicrobial effects make them valuable resources for sustainable development. In the country, seaweed sauce and salad has been utilized by Mog people as food. Annually 6-9 metric tons of wet seaweeds (*Hypnea spp*.) harvested near St. Martin Island by 400 seaweed collectors. Different functional food, value added food, and personal care products have been prepared by Government institutions, NGO and in the private sector (Sarker et al., 2016). Investing in seaweed-based industries and advancing sustainable cultivation methods can unlock the vast potential of these marine resources, contributing to the growth of a sustainable blue economy. Harnessing their commercial applications not only drives economic development but also supports environmental sustainability. Furthermore, this sector plays a crucial role in achieving the country's Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger), Goal 3 (Good Health and Well-being), Goal 13 (Climate Action), and Goal 14 (Life below Water).

Navigation in the Bay of Bengal

Seaborne trade has been a driver of the economic growth of different nations (UNEP, 2016; Pascali, 2017). The South China Sea to the Indian Ocean and the Middle East is one of the significant sea line communications. For ship movements, Asia remained the key global loading and unloading area in 2013, with a 41 percent share of total loading and 58 percent of unloading (UNEP, 2016). Of global seaborne trade, dry cargo accounted for the largest share, 70.2 percent, followed by tanker trade (UNCTAD, 2014). Asia had 15 of the world's 20 leading container ports in 2011-2013. All the top ten ports are located in Asia and 11 of the top 20 in China (UNCTAD, 2014). Report from Wikipedia (2017), the BoB, the port of Chittagong in Bangladesh, handles over 2 million TEUs of container traffic. The Port of Chennai in India handles over 1 million TEUs of container traffic. Ports which handle over 100,000 TEUs of container traffic include the Port of Calcutta, Tuticorin Port Trust, the Port of Yangon, Port of Mongla and Port of Vizag. Chattogram is the busiest seaport on the BoB coastline, followed by Chennai, Kolkata, Tuticorin, Yangon, Visakhapatnam, and Mongla (Anon, 2017a,b). Sittwe Port and Hambantota are other important ports in the region.

Shipping is considered as the most secure, cheap, efficient and environmentally friendly means of bulk transportation (Alam, 2014). As a coastal country, Bangladesh needs to increase its facilities and capacities thus the large carriers may come to the port with bulk containers. Bangladesh relies greatly on exports, particularly pharmaceuticals, garments, and agricultural goods to global markets including Europe, USA, and Asia. The shipping industry provides jobs in shipbuilding, ports, and logistics. Therefore, Bangladesh may develop the shipping network in a way that all the trades of export and import goods for Bangladesh are carried by the Bangladeshi flagged ships. Moreover, Bangladesh's location near key sea routes in the BoB allows it to be a regional shipping heart.

Coastal Tourism

Coastal tourism has become an integral part of modern life, with its roots tracing back to Roman times when the first seaside villas were built in the southern Apennine Peninsula (Baitalik and Majumdar, 2015). Since the end of World War II, tourism in coastal areas has seen continuous growth. In Asia, tropical coastal tourism is one of the key industries, contributing considerably to economic development and home employment (UNEP, 2016). However, earlier the coastal tourism in the area was largely unplanned, resulting in damaging ecological and socio-cultural impacts (Wong, 2013). Some Southeast Asian nations like Indonesia, Malaysia, and Thailand earn huge amounts of money from coastal tourism (Mazumder et al., 2013). Andaman coast is the biggest hub of tourism in the area (Wikipedia, 2017). There they introduce modern cruise tourism to visit the coastal islands. In Bangladesh, Cox's Bazar boasts one of the world's longest unbroken sandy beaches (Fig. 2a and b) stretching approximately 120 km in length and 100 to 500 meters in width (Ahsan et al., 2017). Kuakata Sea Beach is another popular tourist destination of the country (Fig. 2c) as it offers a rare panoramic view of both sunset and sunrise. Additionally, the Sundarbans, the largest mangrove forest (Fig. 2d and e) on Earth, spans 10,200 km², with around 6,000 km² in Bangladesh and 4,200 km² in India as reserved forest. The Sundarbans was designated a UNESCO World Heritage Site in 1997 (UNESCO, 2010, 2011).

Besides these, there are so many beautiful coastal islands in Bangladesh, particularly Saint Martin's Island, Moheshkhali Island and Sonadia Island (Fig. 2f). Bangladesh can introduce modern cruise tourism to visit these islands with Sundarbans, Saint Martin's Island, Sonadia Island to earn huge amounts of foreign exchange, contributing considerably to local employment and economic expansion.

Seawater Desalination and Chemical Resources

An increasingly popular remedy for Bangladesh's water shortage, particularly in coastal regions, is seawater desalination, namely with Reverse Osmosis (RO) technology through which freshwater can be obtained by desalination. The United States and Japan are pioneers for the production of seawater desalination production equipment, they accounted for 30% of seawater desalination machines of the market (Guan, 2017). Seawater desalination technology has been applied in Israel and other Middle East countries, and it becomes the basic water for some countries with serious water shortages (Fu et al., 2015). Each year the total amount of global direct use of seawater as industrial cooling water is ~ 600 billion cubic meters (Guan, 2017), replacing the massive precious freshwater resources. Japan's total manufacturing cooling water (60% to 80%) comes from the sea each year is as high as >300 billion m^3 (Guan, 2017); in the US ~ 25% of industrial cooling water is directly from the sea, annual utilization is ~ 120 billion m^3 (Guan, 2017); in Britain, France, the Netherlands, Italy and other Western European countries every year, the direct use of seawater reached more than 250 million cubic metres (Guan, 2017). The coastal regions of

Fig. 2 Few popular tourist destinations in the coastal part of Bangladesh a,b) Cox's Bazar sea beach; c) Kuakata sea beach; d,e) Sundarbans mangrove forest; f) Sonadia island.

the BoB face freshwater scarcity (Rashid et al., 2023; Ashrafuzzaman et al., 2022) and have significant potential for sea water desalination. Moreover, over extraction of ground water leads to saline water imposition, making desalination an important substitute. The BoB region has a big coastal population as well as rising urbanization increases demand for water in domestic, agricultural and industrial sectors. Moreover, inconsistent monsoons, rising sea levels and cyclones threaten conventional water sources Rashid et al, (2022, 2023a,b; Rashid, 2023). Therefore, seawater Desalination can convene potential demands, reducing pressure on freshwater sources. In India, Chennai has two main desalination plants, where they supply ~ 200 million liter drinking water per day. Limited small scale desalination projects also run in Sri Lanka and Myanmar. In Bangladesh, some small-scale desalination plants run in Cox's Bazar and other coastal areas. However, the desalination project is costly. Therefore, renewable energy and environmentally friendly advances in technology can make desalination a key solution for sustainable water resources management in the region and also in Bangladesh.

Conclusion

The Indian Ocean and the BoB are rich in resources. It holds huge potential for future growth. Despite its immense potential, early resource exploitation was nominal due to a lack of awareness and technology. Therefore, for the proper utilization of these resources, it is necessary to take sector wise long term proper planning and coordination fisheries and aquaculture, oil and gas reserves. Specialists from appropriate sectors essentially need to be involved to get the maximum and positive results about the resources. Support from the government is also an essential component for the development of the blue economy in Bangladesh. Government needs to invest and also needs to invite the private sector for the research and development of the resources.

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