Abstract

The inshore region of the Bay of Bengal is one of the less-studied regions of the world ocean in terms of sustainability of Blue Economy while being one of the most exploited bodies of water to benefit a considerable chunk of the Indian population. For the first time, thirty-six years of in situ data at two locations in the northwestern Bay preferably in the lower Gangetic delta region has been analyzed to identify long-term trends in salinity. The salinity values obtained for Jharkhali and Haldia, situated in the lower Gangetic delta region exhibit extreme contrasting profiles. Jharkhali shows an increasing trend, whereas Haldia shows a pronounced decreasing trend of salinity with the passage of time. The results point towards the vulnerability of Jharkhali station towards corrosion of engineering structures, which might exert a negative impact on the sustainability of Blue Economy in this region.

Keywords: Bay of Bengal, Blue Economy, Corrosion, Jharkhali, Haldia,

I. Introduction

The blue economy is an emerging concept, which is expected to provide a new dimension to the GDP of the nations. This concept has now been aligned with the economic and trade activities and emerges from a need to integrate conservation
and sustainability in the management of living and non-living resources of the marine environment. Needless to say that sustainability of the Blue Economy stands on the pillars of effective management of water resources (preferably estuaries, bays, seas, and oceans) and their biodiversity. The domain of Blue Economy includes several economic activities that are strongly related to marine and estuarine ecosystem such as maritime transportation, shipbuilding, coastal tourism, fishing, aquaculture, etc. (Table 1)

Table 1: Productive Economic Sectors in Blue Economy

| No. | Sector                                      | Related Industries                                                                 |
|-----|--------------------------------------------|-----------------------------------------------------------------------------------|
| 1   | Marine living resources                    | Fisheries (primarily fish production)                                             |
|     |                                            | Secondary fisheries and related activities (e.g., processing, net, and gear making, ice production, and supply, boat construction and maintenance, manufacturing of fish processing equipment, packaging, marketing, and distribution) |
|     |                                            | Aquaculture                                                                       |
|     |                                            | Marine biotechnology and bio-prospecting for pharmaceutical products and chemical applications |
| 2   | Non-living resources (non-renewable)       | (Seabed) mining for extraction of minerals                                         |
|     |                                            | Oil and gas                                                                       |
|     |                                            | Desalination for Freshwater generation                                            |
| 3   | Renewable natural forces (wind, wave, and tidal energy) | Generation of (off-shore) electricity                                               |
|     |                                            | Power plants are based on renewable energy like solar energy, wind energy, tidal actions, ocean thermal energy gradient, etc. |
| 4   | Shipping                                   | Shipping and shipbuilding                                                          |
|     |                                            | Maritime transport                                                                 |
|     |                                            | Ports and related services                                                         |
|     |                                            | Coastal development                                                                |
|     |                                            | Tourism and recreation                                                             |
|     |                                            | Ship wrecking and ship waste recycling                                             |
| 5   | Marine and coastal biodiversity and monitoring environmental health | Carbon sequestration through blue carbon (coastal vegetation)                       |
|     |                                            | Waste Disposal for land-based industry                                             |
|     |                                            | Coastal habitat protection and restoration                                         |
|     |                                            | Environmental monitoring related instrument development units                      |

The success of Blue Economy, therefore, depends on the growth of coastal industries and several marine-based activities like fisheries, shipping, ports, marine logistics, coastal and recreational tourism, oil and natural gas extraction, seabed mining, etc. [V], [VII], [VIII].

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It is evident that 70% of the surface of the earth is covered by oceans and several other aquatic ecosystems thus providing a strong base for the development of the world economy in terms of GDP. However, the contribution of the Blue Economy has not been accurately quantified in the domain of GDP. A rough estimate oscillates around a figure of 3-5% in global GDP (Table 2).

**Table 2: Estimates of annual contribution to global Blue Economy**

| Estimation of Annual contribution (U$)                                                                 | Methodology                                                | Source |
|------------------------------------------------------------------------------------------------------|------------------------------------------------------------|--------|
| 3-5 trillion global ocean economic activity                                                          | Estimates only                                             | [I]    |
| 6-21 trillion economic value of ocean goods and services                                            | Estimates only                                             | [X]    |
| 3 trillion economic market value of marine and coastal resources                                     | Estimates only                                             | [II]   |
| 2.5 trillion gross marine product                                                                   | Average top-down analysis extrapolating the percentage of economic contribution | [III]  |
| 1.5 trillion value-added ocean-based industries in 2010 33% offshore oil and gas, 26% ocean and coastal tourism, 13% ports, and 11% marine equipment | Developed database of country supplemented by literature    | [VI]   |

The infrastructure needed to sprout Blue Economy in different countries of the world requires huge investment for their development and maintenance.

Salinity is one of the important variables that determine the shelf life of several engineering structures and establishments associated with Blue Economy (like ports, harbours, hotels, recreational units, shipbuilding yards, aquaculture farms, oil rigging machinery, etc.). From the chemical point of view, seawater can be considered as an aqueous solution of several types of salts of different major elements/ radicals (Table 3). The various salts present in the seawater provide an average salinity of 3.5% [IX].

**Table 3: Major components of oceanic water**

| Component       | Concentration (mg/kg of seawater at 35% salinity) |
|-----------------|-----------------------------------------------|
| Calcium         | 412                                           |
| Magnesium       | 1,294                                         |
| Nitrogen        | 15                                            |
| Potassium       | 399                                           |
| Silicon         | 2.9                                           |
| Sodium          | 10,760                                        |
| Strontium       | 7.9                                            |
| Bicarbonate     | 145                                           |
| Boron           | 4.6                                           |
| Bromide         | 67                                            |
| Chloride        | 19,350                                        |
| Fluoride        | 1.3                                           |
| Sulphate        | 2,712                                         |

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Differences in the salinity level at regional and local scales may be due to geological setup (like siltation), anthropogenic activities, etc. that often create significant spatial variation, which may have a far-reaching impact on coastal engineering structures present in ports, tourism units, aquaculture farms, shipyard, oil industries, etc. On this background, the present research aims to evaluate the salinity profile in two stations of the lower Gangetic delta region namely Haldia and Jharkhali, and forecast their values during 2050 using Artificial Intelligence (AI) to visualize the sustainability of Blue Economy in these two stations that house tourism units, fish landing stations, ports and oil industries.

II. Materials and Methods

The surface water salinity was recorded in both the selected stations during high tide using an optical refractometer (Atago, Japan) and cross-checked in the laboratory by employing Mohr-Knudsen method [IV]. The correction factor was found out by titrating the silver nitrate solution against standard seawater (IAPO standard seawater service Charlottenlund, Slot Denmark, chlorinity = 19.376%). Our method was applied to estimate the salinity of standard seawater procured from NIO and a standard deviation of 0.02% was obtained for salinity. The average accuracy for salinity (in connection to our triplicate sampling) is ± 0.28 psu.

With this surface water salinity data of 36 years of Jharkhali and Haldia, we carried out a time series modeling to visualize the trend of the variable using a nonlinear autoregressive model (NAR) treating seasonal salinity values as inputs (Fig 1).

![Fig 1. Non-linear Auto Regression (NAR) model for evaluating the trend of surface water salinity in the selected stations of the lower Gangetic delta.](image-url)
III. Results and Discussions

Artificial Intelligence (AI) is the biggest technological revolution of the 21st century. In this case, human intelligence is simulated by computer systems and encompasses learning, which is the collection of information, rules for proper use of the set of collected information, reasoning which is a step to reach the inferences, and self-correction. AI seeks to build machines that are programmed to think like humans and mimic their actions.

It is practically the evolution of machines based on a series of experiences followed by adapting with time. Every application of artificial intelligence begins with large amounts of training data, vastly increased processing power that comes from Graphics Processing Units (GPUs) in place of Central Processing Units (CPUs), decreasing cost of storage and the exponential growth in data volumes, together with the emergence of open-source platforms, forms a potent combination of technologies and capabilities that provides a very powerful foundation to AI.

The data sets on aquatic salinity of two stations in the lower Gangetic Delta (namely Jharkhali and Haldia) present two contrasting pictures. We find an increasing trend of salinity at Jharkhali situated in the central sector of the deltaic complex, whereas Haldia, being a port – cum - industrial complex in the western sector exhibits a decreasing trend in salinity. The nonlinear autoregressive model (NAR) run with the seasonal training of salinity data for more than three decades clearly shows that the hard engineering structures at Jharkhali are extremely susceptible to corrosion on account of the increasing trend in salinity which might touch 30.52 psu during premonsoon (Fig. 2), 28.01 psu during monsoon (Fig. 3) and 31.42 psu during postmonsoon (Fig. 3) during 2050.

**Fig 2.** Predicted aquatic salinity for Jharkhali estuarine water during premonsoon using Nonlinear Autoregressive Neural Network Model; real-time data from 1984 – 2019 has been used to train the model
Fig 3. Predicted aquatic salinity for Jharkhali estuarine water during monsoon using Nonlinear Autoregressive Neural Network Model; real-time data from 1984 – 2019 has been used to train the model

Fig 3.i. Predicted aquatic salinity for Jharkhali estuarine water during postmonsoon using Nonlinear Autoregressive Neural Network Model; real-time data from 1984 – 2019 has been used to train the model

Jharkhali is situated in the central part of the Indian Sundarban delta. The tourists from different corners of the world enter to enjoy the beauty of the mangrove forest of Indian Sundarban through the gateway of Jharkhali. The area has several concrete buildings for accommodations and tourism. A high saline environment can accelerate the corrosion of these structures. Corrosivity of natural water is directly proportional to salinity and thus the structures in Jharkhali are more prone to corrosion, which may retard the pace of success of Blue Economy in this region. On contrary, the corrosion risk at Haldia due to salinity is significantly lower (Fig. 4 -6), which is a positive sign in the domain of sustainability of Blue Economy.

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**Fig 4.** Predicted aquatic salinity for Haldia estuarine water during premonsoon using Nonlinear Autoregressive Neural Network Model; real time data from 1984 – 2019 has been used to train the model.

**Fig 5.** Predicted aquatic salinity for Haldia estuarine water during monsoon using Nonlinear Autoregressive Neural Network Model; real time data from 1984 – 2019 has been used to train the model.

**Fig 6.** Predicted aquatic salinity for Haldia estuarine water during postmonsoon using Nonlinear Autoregressive Neural Network Model; real time data from 1984 – 2019 has been used to train the model.

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IV. Conclusions

The following conclusions can be drawn from the obtained results:

1. The salinity values obtained for Jharkhali and Haldia, situated in the lower Gangetic delta region exhibit extreme contrasting profiles. Jharkhali shows an increasing trend, whereas Haldia shows a significant decreasing trend with time.

2. The nonlinear autoregressive model (NAR) carried out by training the seasonal salinity values generated interesting outputs concerning the salinity of 2050. For Jharkhali the predicted salinity is 30.00 psu, whereas for Haldia the value is 2.76 psu. These values are the mean of three seasons in the region of study.

3. As the degree of corrosion is directly proportional to ambient aquatic salinity, therefore the engineering structures at Jharkhali require an adequate corrosion protection system to enhance the shelf life of these structures. An anti-corrosion system involving the proper selection of materials (like fly ash bricks instead of normal bricks) as well as application of adequate paint systems added by cathodic protection is to be taken into consideration for protecting these structures that are the success pillars of Blue Economy at local scale.

Conflict of Interest:

There was no relevant conflict of interest regarding this paper.

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