Submission

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MESSAGE FROM THE CHIEF ADVISER

I am delighted to be a part of the first volume of the new peer-reviewed journal 'Journal of Earth and Ocean Science (JEOS)'. The JEOS will be published every year in the month of September by the Faculty of Earth and Ocean Science of Bangabandhu Sheikh Mujibur Rahman Maritime University, Bangladesh.

I am even more delighted, since we have been able to publish this journal in the midst of a global pandemic, overcoming many disruptions and challenges along the way. I express my sincerest thanks to the chief editor, the esteemed reviewers and the editorial board who have made relentless efforts to publish this important journal

The UN Decade of Ocean Science for Sustainable Development (2021–2030) offers an overall framework for ocean literacy actions and presents an unprecedented opportunity for cross-organizational and multi-sectoral collaboration in pursuit of global sustainable development goals., Bangladesh should participate in all the activities of the Implementation Plan of the Ocean Decade, which will help us to strengthen our foundation for Blue Economy, thereby achieving the desired goals of Vision 2041 set by the Hon'ble Prime Minister Sheikh Hasina. It is felt essential that, as the only specialized public maritime university in Bangladesh, BSMRMU be actively involved in the overall implementation of the Decade Plan in Bangladesh. It may serve as the organizational center for marine scientific and academic initiatives towards achieving the Sustainable Development Goals and Delta Plan 2100. In this context, JEOS will become the primary platform for oceanographers, ocean researchers, technologists, academicians, policy makers, and stake holders to share findings and publish all aspects of ocean science and technology in Bangladesh and beyond. I hope JOES will help to contribute and disseminate news about Bangladesh's efforts during the Decade.

I am hopeful that JEOS will provide a multidisciplinary forum to investigate inshore, offshore and coastal environments, oceanography, hydrography, marine geology, marine biotechnology, oceanic environment, marine pollution, strategy, science and technology, including current and complex issues and related studies in earth and ocean science affairs, which will lead us to new horizons. Researchers, analysts, and policy makers will be benefited by the findings of the articles of this annual peer reviewed journal. I finally expect a continuous contribution from the authors and the regular publication of JOES.

I hope that JOES will maintain a high level of ethical integrity, ensuring authenticity and scientific diligence in each of its research articles. In that view, I wish to see the Editorial Team continue to expand their horizons even beyond our frontiers, so that we are enlightened more by the knowledge and experience of reputed academicians and professionals at the global level.

Rear Admiral M Khaled Iqbal, NBP, BSP, ndc, psc, MPhil (retd)
Vice-Chancellor
Bangabandhu Sheikh Mujibur Rahman Maritime University, Bangladesh

EDITOR'S NOTE

The world is firmly gripped by the COVID -19 pandemic; academicians and researchers, and general people
all over the world are also struggling with this event. Research has been affected to some extent and uncertainty about research funding and completion of the projects has been observed. With all these uncertainties, it is highly praiseworthy that we could successfully publish this vol. 1 of the Journal of Earth and Ocean Science (JEOS). Also, it is a moment of immense pride that this issue is going to be published when we are entering into the UN Decade of Ocean Science for Sustainable Development (2021–2030). It offers an overall framework for ocean literacy actions and presents an unprecedented opportunity for cross-organizational and multi-sectoral collaboration in pursuit of global sustainable development goals.

Bangabandhu Sheikh Mujibur Rahman Maritime University Bangladesh (BSMRMU) is a premier maritime university in Bangladesh, whose motto is to achieve maritime excellence, through sharpening the storm of intellectual passion within the maritime community. The JEOS is going to be one of the pioneer journals in Bangladesh in earth and ocean science research/ sectors which will truly embody the qualitative products of faculties and students of BSMRMU as well as other maritime researchers all over the world. It contains original research works dealing with the theory and practice of marine science and studies. The journal seeks to foster the exchange of new ideas and information. The scope of this journal covers a full range of research, analysis, design, operation, support, technology and policy related to marine science issues are included within the scope such as Marine Spatial Planning (MSP), Marine Protected Areas (MPA) and Marine Biotechnology.

It is hoped that the articles published in this volume will contribute largely to the research on marine science issues and benefit the maritime communities both at home and abroad. The standard of the articles is evaluated on technical quality, relevance and importance of materials, the interest of readers and timeliness through peer review. Independent experts have provided the authors with critical commentary and suggestions to improve their final papers prior to publication. The authors had to certify that submitted manuscripts had not been published previously or submitted for publication elsewhere, and did not violate any security, proprietary or copyright restrictions.

The Editorial would not be completed if we do not record our gratitude to the Chief Adviser, Rear Admiral M Khaled Iqbal (retd), Vice-Chancellor, BSMRMU, whose invaluable guidance was always with the Editorial Board. We forward our deepest appreciation to the distinguished reviewers for their hard work and relentless support. We also thank the Advisory Board for their valuable guidance and support. Despite all efforts, toils and sincerity, unintentional errors in whatever form may not be unlikely in the appearance of the Journal. We fervently beseech the readers to pardon us of such unnoticed slights. Comments on the journal, articles as well as editorial policy are welcome and will be considered. We hope that the journal will prove its worth to a reader with an investigative mind, an intellectual zeal, assiduous learning and academic yearnings.

Instr Commodore M Jashim Uddin, (H), BN
Dean, FEOS and Chief Editor, JEOS

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Notes for the Contributors

Journal of Earth and Ocean Science (JEOS) welcomes submissions in all areas related to oceanography, hydrography, marine geology, marine biotechnology, oceanic environment, marine pollution, strategy, science and technology including current and complex issues in earth and ocean science affairs. JEOS also welcomes book reviewers, comments on projects, cases and judgements. Authors are requested to submit typed papers in prescribed format both soft (e-mail or portable memory device) and hard/printed copy to the Editorial Board. JEOS is a peer reviewed journal. The papers/ articles must be an original piece of work. The author should have declared that the article has not been published and/or not submitted for publication elsewhere earlier and is not in consideration for publication anywhere else. The papers/articles shall be written in English (Standard British) and typed on a standard A4 size paper. Letter font shall be of Times New Roman size 12 points. The papers/ articles shall have an abstract (Font Times New Roman size 11 points and style italic) followed by keywords. The Chicago style (published in the Manual, latest edition) shall be written and reference style of the papers/articles for the journal. The papers/ articles shall acknowledge the sources as references. The papers/articles shall be submitted along with a signed copy of copyright form and certificate regarding plagiarism in specific format available at BSMRMU website (www.bsmrmu.edu.bd/joutnal-jeos)

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Pharmacological prospects of *Cladophoropsis* sp. seaweed

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Abstract

Currently, researchers in medical and pharmaceutical disciplines have been looking for alternative drug sources for better specificity and less cytotoxicity and thus, heavily depend upon natural medicinal plants, seaweeds, marine micro-algae, etc. to fulfill the pharmaceutical demands. In marine habitats, both seaweed and microalgae serve as the component of bioresources, but a very few of those are explored as a source of food, fodder, medicine and valuable chemical ingredients. In the backdrop of current concept of 'Blue-Economy', the algal resources of the Bay of Bengal deserve a scrutiny, so that their potentiality could be identified and used. The present review has been aimed to explore the various marine algal use over a global scale. Of the algal bioresources, the Genus: Cladophoropsis Børgesen *includes green filamentous marine algal species growing naturally in the coastal belt of the Bay of Bengal. The present review reveals that the species is promising with its pharmacological values due to antimicrobial, anti-cancer, anti-oxidant, cytotoxic, anti-aging activities and so on. So, to ensure its future use, an attempt has been made to compile the latest pharmacological information on Cladophoropsis* sp. *based on recently published scientific information. This review study will pave the way to satisfy the substantial pharmacological knowledge on Cladophoropsis* spp.

Keaywords: *Cladophoropsis* sp., pharmacology, Bay of Bengal, seaweeds, marine algae.

1. Introduction

Seaweeds represented a virtual component of the marine ecosystems and are important natural resources from the oceans (Rosemary et al., 2019; Ismail, 2017). Marine algae may be microscopic or macroscopic and usually grow in the pelagic and benthic regions of the seas. Among the benthic forms, some are microscopic but appears as attached green layer on pebbles, stones, submerged portion of mountain walls, etc. Still there are some multicellular macroscopic benthic forms which are large enough to be recognized by naked eye (Salehi et al., 2019; Bhadury P., 2004) and are regarded as the kingdom Protista. They are broadly classified into three groups – brown algae (Phaeophyta), green algae (Chlorophyta), and red algae (Rhodophyta) (Rothe, 2012).

Mostly, the macroscopic forms i.e., seaweeds are being used as food, raw material for cosmetic, pharmaceutical, medicinal and industrial purposes, high contents of vitamins, carotenoids, essential fatty acids, minerals, polysaccharides and proteins alongside with their significant ecological and environmental role in the nature (Salehi et al., 2019; El- shazoly and Fawzy, 2018). Some invasive macroalgae produces many bioactive compounds for their adaptation, which are of great pharmacological values (Morshedul, 2020; Máximo et al., 2018).

Decreasing natural resources and food security became the global concern now a days. Billions of people suffer from malnutrition and as an additional support of natural drug, people are looking for alternative sources. In this context, marine macro-algae seem to be the promising solution to meet the growing demands and requirements (Aroyehun et al., 2019). The costs of the seaweeds have been predicted and calculated that are about US$10 billion per year through the products of direct or indirect human uses (FAO, 2013; Bixler and Porse, 2011). The largest consumers of seaweeds as food are Japan, China and Korea and they consume about (5%) of green algae, (66.5%) of brown algae and (33%) of red algae in

their daily diets (Ismail, 2017). However, the demand for seaweed as food has changed with migration around the world such as in some parts of the USA, South America, Ireland, Iceland, Canada, Scotland, France and so on. Moreover, seaweeds are used as a source of hydrocolloids (McHugh, 2003), animal feed (Hasan & Chakrabarti, 2009), fertilizer (Salehi et al., 2019), cosmoceuticals (Thomas & Kim, 2013), neutraceuticals and health supplements (Salehi et al., 2019; Pal et al., 2014; Parthiban et al., 2013; Manivannan et al., 2008), detoxifiers (Kumar, 2011), biofuel (Sharma et al., 2018), wastewater treatment (McHugh, 2003) and so on.

The growing demands allow the scientists to find out new variants of seaweed species for human welfare. Species under the Genus: *Cladophoropsis* Børgesen, usually grow in the coastal marine habitats, possesses number of pharmaceutical as well as nutritional values. Though there are adequate natural sources of drugs, but scientists are still looking for more effective ones with least side effects and more specific to its target. Keeping this objective in mind, an attempt has been taken in this review to compile the pharmacological impact of *Cladophoropsis* spp. based on scientific literature survey.

2. Marine algae in Bangladesh

The first classical work on the marine algae of Bangladesh was published by Islam (1976). In his book, a total of 165 species under 77 genera of marine algae were reported from the St Martins Island in the Bay of Bengal and from the adjacent areas. Thereafter, the Encycolpedia of Flora and Fauna of Bangladesh covered all the marine algal species from the groups blue-green, green, brown, diatoms, dinoflagellates, and red-algae published until 2008 in Bangladesh (Siddiqui et al., 2007; Ahmed et al., 2008, 2009). Sarker et al. (2016) reported that there are 193 seaweed species in Bangladesh belonging to 94 genera including 19 commercially important ones. He also reported that most of the species having commercial importance remain unutilized except a few are consumed by the ethnic peoples of the area. About 60 seaweed species are found in Sundarbans, 155 species can be found in Cox‘s Bazar, 140 species are available in St. Martin‘s Island between from October to April, but they are mostly abundant in January to March (Sarkar et al., 2016). A survey on sub-littoral seaweeds in St. Martin‘s Island reported that there at least 37 seaweed taxa- 11 under Chlorophyceae, 14 under Phaeophyceae and 12 under Rhodophyceae- on that island and their distribution, abundance and diversity depend on temperature, locations etc. (Billah et al., 2018). Although this study was published in 2018, the samples were collected in January to June, 2007. A later survey in April, 2013, which was published in 2015, reported two new taxa under Phaeophyceae (Aziz et al., 2015). The presence of 197 seaweed species (95 red algal species, 46 green algal species and 56 brown

algal species) in Bangladesh was mentioned (Aziz et al., 2015). So, it might be said that the reports on seaweeds as well as marine micro-algae of Bangladesh are far from complete, rather, new reports may always be added to the existing list.

Cultivating and exporting edible seaweeds can earn a lot of foreign currencies for Bangladesh (Bhattacharjee et al., 2014). In addition, one of the opportunities of integrated aquafarming here can be the production of value-added products such as biofuels from seaweeds (Shefat et al., 2018). The poor coastal community of Bangladesh may boost their income by cultivating seaweeds, but no such successful large-scale seaweed mariculture system is established here right now and the local inhabitants have no idea when such an industry can be a possibility (Islam, 2017). Socio-economic factors (political and legal system, economic demand and production cost), biological factors, environmental factors, technological and scientific knowledge can influence the fate of seaweed cultivation (Ahmed et al., 2005). Lack of scientific knowledge, proper technology and skilled manpower are some of the major challenges of such projects in Bangladesh (Ahmed et al., 2005). Fortunately, some studies are now identifying sites suitable for seaweed cultivation in Bangladeshi coastal areas. For example, feasibility of seaweed culture, especially the cultivation of red seaweed *Hypnea* spp., *Halymenia durvillei* Bory, *Gracilaria canaliculata* Sonder, *Asparagopsis taxiformis* (Delile) Trevis in St. Martin Island, Bakkhali, Inani coast of Cox‘s Bazar and in some other places of the coastal region is being carried out (Hoq et al., 2016; Islam et al., 2017; Hossain et al., 2020). Till now, only very few reports with pharmacological efficacies have been scientifically reported using the seaweed samples from the Bay of Bengal, Bangladesh (Rahman et al., 2021; Islam et al., 2020; Ahsan et al., 2020).

3. Bioactive compounds of seaweeds

Seaweeds produce a variety of products with antifungal activity including algal gambieric acids A and B, phloroglucinol, phlorotannins, rutacridone epoxide, lipoprotteins, and lactones (Pérez et al., 2016; Cheung et al., 2014; Lee et al., 2010; Meepagala et al., 2005;). Seaweeds contain stable and labile antioxidants compounds such as ascorbic acid, glutathion carotenoids etc. (Kakinuma et al., 2001; Yan et al., 1999). Fucoxanthin, astaxanthin, carotenoid, phenolic acid, flavonoids, tannins are potential antioxidant and exhibit higher antioxidant activities (Jayabarath et al., 2015) and have potential role in preventing radical formation chelating metal ions, improve the internal antioxidant system under stress conditions and protect the body from (ROS) caused progressive diseases and also β-carotene activity against cancer diseases (Ismail, 2017). Also Phenolic and Flavonoids compounds found along with ascorbic acid and α-tocopherol

(El-shazoly et al., 2018). Phlorotannins show great pharmaceutical potential (Rosa et al., 2019) and polyketides, peptides, shikimic acid derivatives shows potential apoptotic effect (Ercolano et al., 2019).

4. Pharmacological activities of seaweeds

Seaweeds have potential antibacterial, antiviral, antioxidant, immunomodulatory, immunostimulating, hypolipidemic, cytostatic, antithrombotic, anticoagulant, antiinfection, antitumor, antiangiogenesis, pro-apoptotic potential, antiinflammatory, antihelmintic, antihypertensive, antifouling, antidiatom, antimacrofouling antiallergic, antiprotozoal, antimelanin forming, antifeeden, antiulcer, antityrosinase, antiangiogenic, antituberculosis, antidiabetes and prevent hepatitis, give neuroprotection, hyaluronidase enzyme inhibition, telomerase inhibiting activity, MMPs inhibition activity, cure bone related disease among other positive effects in the organism (Morshedul, 2020; Ercolano et al., 2019; Noorjahan et al., 2019; Rosemary et al., 2019; Saha et al., 2018; El-shazoly, et al, 2018; Ismail, 2017; Mayer et al., 2017; Xu et al., 2017; Pérez et al., 2016; Cheung et al., 2014; Pal et al., 2014; Thomas, et al., 2013; Kim et al., 2005; Kanegawa et al., 2000).

5. Characteristics of *Cladophoropsis* sp.

Cladophoropsis sp. is a marine green alga (**Fig. 1**) with cushions or mats composed of erect, brush-like tufts, tightly or loosely entangled filaments or knitted filaments, knots of fickle morphology, related to sponge tissue, cross-wall at branch can be absent, present or occasionally present, tenacular cells are generally absent but occasionally present in some species (Leliaert et al., 2011; 2009). Typically it grows on intertidal to shallow subtidal rocks that are surf-exposed and are attach by rhizoids (Leliaert et al., 2011) and also found in rocky coastlines throughout the tropics and subtropics as well as on coral reefs (Van Der Strate et al., 2002; Kooistra et al., 1992) and seen feed by Damselfish (Hinds et al., 1987).

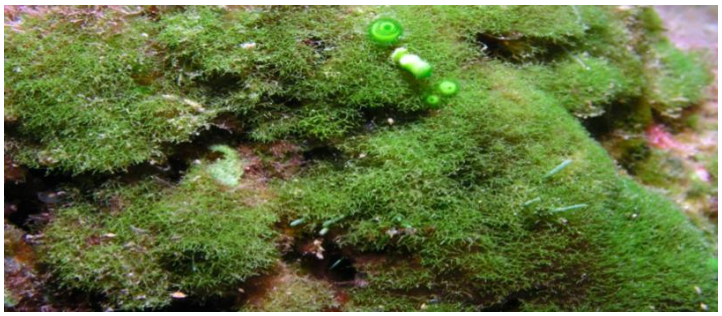

Figure 1: *Cladophoropsis sp*.

(www.guamreeflife.com/species-id-v2/algae/green-algae/#!enviragallery7232-7241)

In Bangladesh, under the genus *Cladophoropsis*, only one species has so far been reported from the St Martin's Island of the Bay of Bengal. It is *Cladophoropsis robusta* Setchell & N. L. Gardner (Islam, 1976; Ahmed, 2008). Thallus forming tufts with profuse and irregularly branched filaments, basal cells acting as nodes, younger branchlet aseptate, cells short with thin walls, vegetative cells measure at maximum 96 µm in diameter and 107 µm long (Islam, 1976).

6. Pharmacological potential of *Cladophoropsis* spp.

The phylogenetic tree based on 18S rRNA gene sequence analysis shows that significant complex morphological characteristics of the algal Genus: *Cladophoropsis* matches mostly with genus *Valonia*, *Cladophora*, *Chaetomorpha*, *Siphonocladus* and *Microdictyon* (Kapraun 2007; 2005). Species within the genus *Cladophoropsis* have had a long history of baffling confinement. The allozyme studies have shown little variation and also in *Cladophoropsis membranaceae* (Hofman-Bang *ex* C. Agardh) Børgesen, but the relationship between reproductive strategy and population structure rarely explored (Van Der Strate et al., 2000; Sosa et al., 1999; Kooistra et al., 1991). They observed high molecular weight DNA using an axenic batch culture of *C. membranacea* from Tenerife, a study conducted by using samples from Canary Islands.

6.1. Cytotoxic and anti-cancer/anti-tumor activity

Accumulating data suggest that there are a number of pharmacological potentials of *Cladophoropsis* spp. (**Table 1**). Recently, Islam et al. (2020) showed a significant cytotoxic effect using both ehtanolic and methanolic extracts of *Cladophoropsis* sp. isolated from the Bay of Bengal and they performed this study by using brine shrimp lethality assay. *Cladophoropsis* sp. is one of the most active algae in terms of cytotoxic effects on cancer cell lines (Erfani et al., 2015; Shalaby, 2011). Some *Cladophoropsis* sp. shows selective cytotoxicity against cell line and in Murine Leukemic model (Harada et al., 1998; Harada et al., 1997). (Harada and Kamei, 1997) described that, *Cladophoropsis vaucheriaeformis* (Areschoug) Papenfuss extract have most prominent selective cytotoxicity to Murine leukemic cell lines. At a low concentration of 50 µg/ml, MeOH extract of *C. vaucheriaeformis* shows strong cytotoxicity against L1210 cells, low cytotoxicity to NIH-3T3 cell line and no cytotoxicity to any human leukemic cell lines tested in that study. At a higher concentration of 100 µg/ml, it showed strong cytotoxicity to HL60 and MOLT-4 cell lines (human leukemic cell lines) and Murine leukemic (L1210) and normal cell lines (NIH-3T3). As it shows activity at lower concentration, they didn't find selective cytotoxic activity over 100 µg/ml.

Methanolic extract of *C. vaucheriaeformis* showed high viability (86%) to normal cells (NIH-3T3), showing selective cytotoxicity to tumor cell (L1210) and showed its cytostatic activity instead of cytocidalic activity. They also assumed to have novel and valuable antitumor substance with no clinical side effects of *C. vaucheriaeformis* (Harada et al., 1997). Harada & Kamei (1998) further investigated that methanolic extract of *C. vaucheriaeformis* exhibited cytotoxicity more selectively to L1210 cells at concentrations ranging from 50-100 μg/ml. The maximum cytotoxicity was found at the concentration of 50 μg/ml at which the growth of L1210 cells was hindered completely and no mortality was found in NIH-3T3. This was also indicated that *C. vaucheriaeformis* might contain a unique and low or no side effect antitumor substance that is of low molecular weight and soluble in MeOH with selective cytotoxic activity against L1210 cells. Erfani et al. (2015) assumed that *Cladophoropsis* sp. could be a good candidate for obtaining novel anticancer substances. Besides, it was the most active alga having highest cytotoxic effects on the investigated cancer cell lines. The IC_{50} values were 66.48 ± 4.96, 150.86 ± 51.56 and >400 μg/ml for ethanolic extract of *Cladophoropsis* sp. against MDA-MB-231, MCF-7 and T-47D cells respectively. *Cladophoropsis* sp. exhibited an 80% cell growth inhibition on MDA-MB-231 cells at the concentration of 100 μg/ml. They also found more potent cytotoxic effects on estrogen negative breast cancer cell line in comparison to estrogen positive cells, which suggest that the extract of *Cladophoropsis* sp. may have an estrogen receptor/ progesterone receptor-independent mechanism for their cellular growth inhibition.

Table 1: List of pharmacological potentials of *Cladophoropsis* spp.

Species	Pharmacological activity	Solvent of extract	References
Cladophoropsis sp.	Cytotoxic	Ethanol & Methanol	Islam et al., 2020
Cladophoropsis sp.	Cytotoxic & anti-cancer/anti-tumor	Ethanol	Erfani et al., 2015
Cladophoropsis sp.	Cytotoxic & anti-cancer/anti-tumor	—	Shalaby, 2011
C. vaucheriaeformis	Cytotoxic & anti-cancer/anti-tumor	Methanol	Harada et al., 1997
C. vaucheriaeformis	Cytotoxic & anti-cancer/anti-tumor	Methanol	Harada & Kamei, 1998

Cladophoropsis sp.	Antioxidant	Ethanol & Methanol	Islam et al., 2020
Cladophoropsis sp.	Antioxidant & pro-oxidant	—	Santoso et al., 2004
Cladophoropsis sp.	Anti-oxidant, lipid peroxidation inhibition, Vitamin C supplement	Ethanol	Moein et al., 2015
Cladophoropsis zollingeri (Kützing) Reinbold	Anti-oxidant	—	Kim et al., 2005
C. gracillima E.Y. Dawson	Anti-bacterial	Methanol	Allen & Dawson, 1960
C. membranaceae	Anti-bacterial	—	Wiebe H.C.F. Kooistra et al., 1991
C. zollingeri	Anti-bacterial	—	Kim et al., 2005
Cladophoropsis sp.	Anti-fungal activity	Ethanol	Mickymaray & Alturaiki, 2018
C. membranacea	No anti-fungal activity	—	Welch, 1962
C. zollingeri	Anti-aging	Methanol	Kanegawa et al., 2000

"—" not mentioned.

6.2. Anti-oxidant activity

Islam et al. (2020) also clarified the significant antioxidant effect of the *Cladophoropsis* sp. using DPPH antioxidant scavenging method (Islam et al., 2020). Antioxidant activity was also reported by another group using samples from another sea and they showed that polyphenols present in *Cladophoropsis* sp.

shows potential antioxidant activity and act as pro-oxidant (Santoso et al., 2004). MeOH extracts from seaweeds contained many kinds of polyphenols. In the absence of ferrous ion, MeOH extracts from *C. vaucheriaeformis* significantly promoted POV of the emulsion by 3 h incubation as compared to control but the chelating ability of MeOH extracts from seaweeds excluding *C. vaucheriaeformis* increased in accordance with the period of incubation (Santoso et al., 2004). Moein et al. (2015) tested the antioxidant properties of *Cladophoropsis* sp. and other algae by determining the reducing power, NO radical scavenging, inhibition lipid peroxidation, phenolic contents and also protein content. 90% Ethanolic extract of *Cladophoropsis* sp. showed the highest reducing power ability (concentration 1.48±0.04 mg/ml with absorbance 0.5). The lipid peroxidation inhibition was 79.29%, which was higher compared to the standards, BHT (66.86%) and Vit C (64.06%) after 10 days. The total Phenolic content was as high as 2.19± 0.08 mg/g (higher than the standard), 19.5±3.3% NO radical scavenging and protein content 2.49±0.113 g/100g of *Cladophoropsis* sp. biomass was also highest among the others. They considered the Algae as a potential source of food. Kim et al., (2005) found that *C. zollingeri* shows potential high antioxidant activity.

6.3. Anti-bacterial activity

Methanolic extract of *C. gracillima* shows positive inhibition on bacterial growth of *B. subtilis, S. aureus* and *M. smegmatis* and negative inhibition on *E. coli* and *P. aeruginosa* (Allen et al., 1960). *C. membranaceae* creates axenic algal culture on treatment with cefotaxime (Kooistra et al., 1991). Kim et al. (2005) found that *C. zollingeri* shows potential antibacterial activity against *E. coli, B. subtilis* and *S. aureus* with the inhibition zone (diameter) of 3.00+0.32, 9.00+0.02 and 5.00+0.24 mm respectively. They also found that seaweed extracts exhibiting high phenolic content had broad activity against the target microorganisms.

6.4. Anti-fungal activity

Excellent hindering potency was shown by *Cladophoropsis* sp. against diversified fungal pathogens that may be advantageous to combat fungal infections and to recover from the chronic asthmatic states (Mickymaray et al., 2018). Previously *C. membranacea* showed no significant fungal inhibition or stimulation (Welch, 1962) but later on some of the ethanolic fraction of *Cladophoropsis* sp. showed better in the reticence of the growth of fungi *Aspergillus niger* van Tieghem, *Candida albicans* (C.-P. Robin) Berkhout, *Mucor* sp., *Paecilomyces* sp. with a moderate zone of inhibition (Mickymaray et al., 2018). The minimum fungicidal concentration and MIC values of the ethanolic fractions of *Cladophoropsis* sp. were

observed to be 125–1000 μg/mL and 125–500 μg/mL, respectively with a midway zone of inhibition (10.6–11.6 mm) (Mickymaray et al., 2018).

6.5. Anti-aging properties

Marine algae extracts shows potential telomerase inhibiting activity. MeOH extract of *C. zollingeri* showed the potential telomerase inhibiting activity (Kanegawa et al., 2000). By using nonradioisotope telomeric repeat amplification protocol (Non-RITRAP) assay using human leukemia MOLT-4 cells, they confirmed that the methanolic extract from this species strongly inhibited telomerase activity, which supports anti-aging role of this seaweed.

7. Conclusions

Mostly, research on marine products has major unexploited potential with possible significant advantages. *Cladophoropsis* spp. has huge potential as a pharmacological agent to develop alternative safe drug. Deep research on this seaweed would pave the way of new window for further investigation of biologists to unveil various novel bioactive compounds for human welfare. The Bay of Bengal, the vast ground of our marine resources has yet to be explored and the application of biotechnology to marine biodiversity remains poorly developed. Systematic and comprehensive investigation and research are also essential.

Identification of the more potent anti-microbial, antioxidant and cytotoxic components as well as other potential bioactive compounds isolated from marine seaweed *Cladophoropsis* spp. and further studies of their molecular structure, mode of action, selection dosses will contribute a significant progress for pharmacological applications, which will also help to extend the field of blue economy concept. The next door-step of the current research should be to bring into account the single species of the marine Genus Cladophoropsis, *C. robusta* which grows naturally in the St Martins Island of Bangladesh. The species could be collected, verified, and tested for its various pharmacological properties via establishing axenic culture.

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Author contribution

MMA, conceived the idea, searched the literature, supervised the review work, wrote and edited the initial and final draft; **TI**, searched the literature; **MNH**, edited the manuscript.

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Reality of climate change and global warming vis-á-vis natural hazards and its impact in maritime development

Professor Aftab Alam Khan

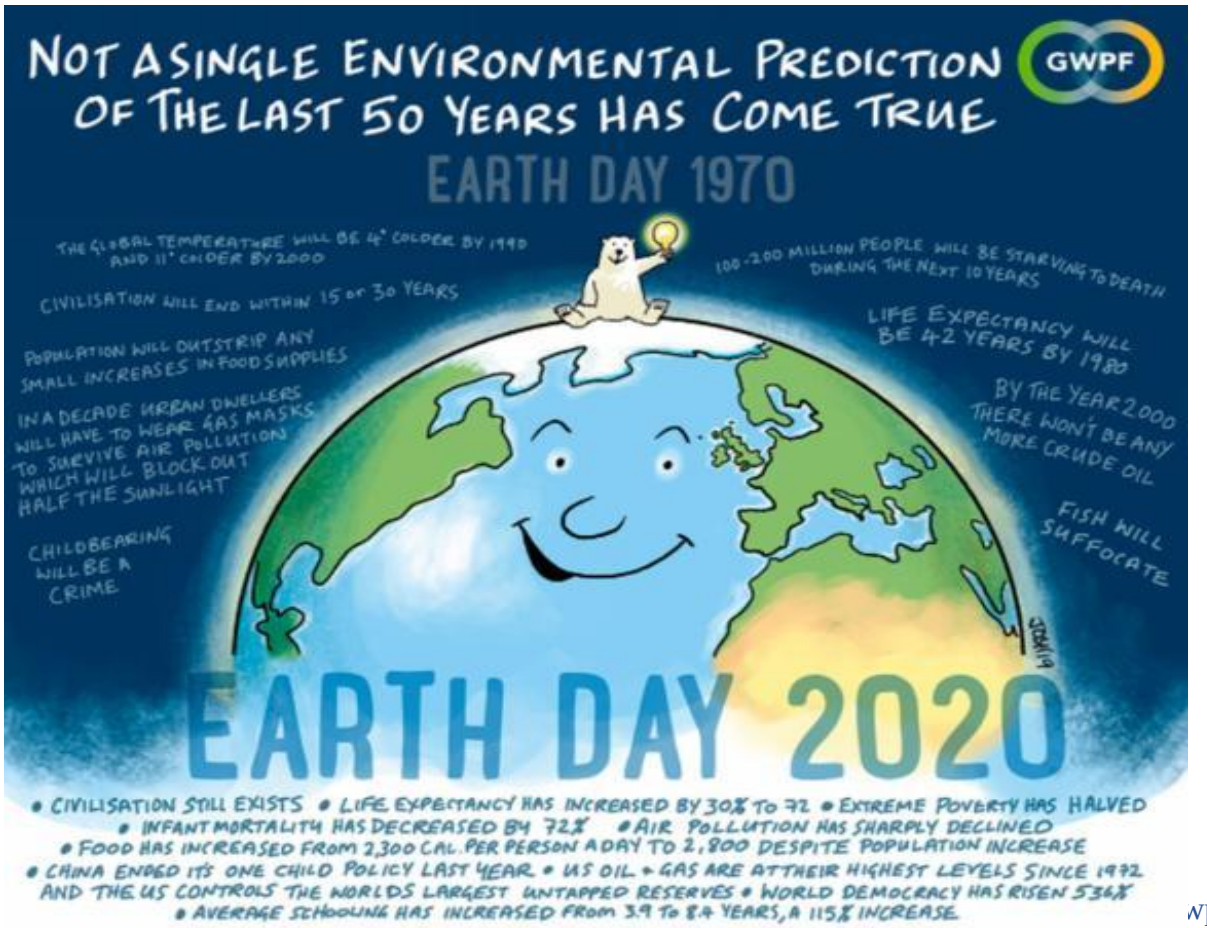
Abstract

Fossil fuel burning is blamed for global warming and climate change and responsible for the occurrence of all natural hazards. Geopolitical and pseudo-science based 'prediction of disaster' claims 'disaster to humanity' if CO_2 concentration in the atmosphere from fossil fuel burning is continued. The present global notion displays an increased atmospheric temperature of 2^oC more than the temperature of the pre-industrial time by 2100 AD. Understanding the science of climate change, present study has determined that climate system bear no significance to fossil fuel burning, global warming and natural hazards. Climate change is an independent universal phenomenon that prevailed in the past geologic time and cycled between glacial and inter-glacial phases. Global warming-related hazards are the result of the changes in the atmospheric and ocean circulation derived from increased water vapor concentration in the atmosphere influenced by the solar radiation based global warming. Climate change in the global context is not a science but a concept that may circulate international diplomacy and domestic politics. The most crucial element of human civilization profoundly depends on the application of transparent science and technology. If science and technology are driven by the mixture of ignorance and power, that will lead to disaster. Greenhouse gas concentrations in the atmosphere do not interfere with the climate system. Climate system is not related to and does not depend on the anthropogenic interference. Major threats to the holistic maritime development are not the climate change, but the natural hazards both geological and atmospheric including pollution.

Key words: Climate Change; Global Warming; Natural Hazards; Maritime Development.

1. Introduction

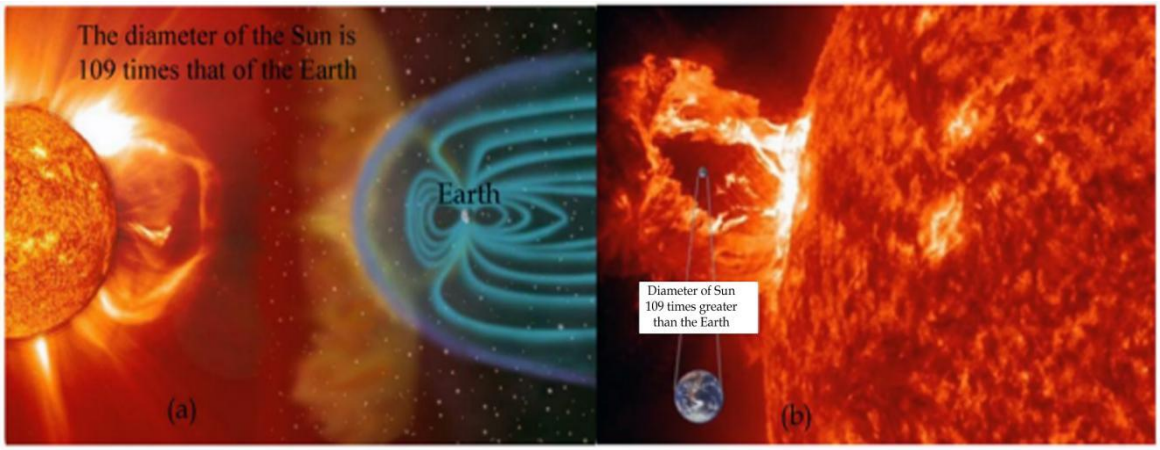
Climate system interacts with the changes in the atmosphere, ice, ocean, land surface and vegetation. These changes occur due to the external forcing such as Earth's orbital force and Sun's strength. CO_2 has been wrongly targeted as the most heat trapping greenhouse gas due to global warming. Concentration of greenhouse gas in the atmosphere is increasing due to the temperature rise, but there are several greenhouse gases that occur in the atmosphere. The most dominant greenhouse gas in the atmosphere is the water vapor with the present concentration of about seventy percent responsible for most heat trapping. Climate change fantasy has failed to bring any good to the Earth since its ratification in 1994. Zero emission of CO_2 has remained a slogan, on the other hand, global energy demand has increased many folds for the population of more than seven billion increased from one and half billion during pre-industrial time.



wpf.com/earth-day-track-record-none-of-the-doomsday-predictions-of-the-last-50-years-have-come-true/

Not a single climate impact prediction so far came true in the last 50 years (Earthday 2020) https://www.thegwpf.com/earth-day-track-record-none-of-the-doomsday-predictions-of-the-last-50-years-have-come-true/. Climate change related cartoon of predictions are shown in the Figure 1. Concern of global warming is not an environment. International climate policy is not a environmental policy.

Instead, climate change policy seems to exploit the world's wealth depriving and destroying humanity. Climate is determined by the atmospheric circulation and by the interaction of large scale ocean currents. Hence, we can divide the entire Earth in several climatic zones such as polar, desert, tropical, sub-tropical and equatorial climatic zones. All these climatic zones occur within the single "inter-glacial" period of climate cycle. In order to attribute all the existing climatic zones of the earth to "climate change" concept, it is necessary to change all the climatic zones to another climate zone. But, what we see that all the climatic zones of the earth are unique in their occurrence. Further, according to the IPCC, climate change



ımissioning of nd vise versa. *namic system, oceans, land, over the last* ncertainties in eological and evelopment of the maritime sector. Climate is not changing in the scope of its definition. Rather, pattern and trend of the atmospheric hazards are changing. Do we call it a climate change? Climate system, as defined in the third IPCC Working Group I Assessment Report is an interactive system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, forced or influenced by various external forcing mechanisms, the most important of which is the Sun (Fig. 2)(Courtesy: https://spaceplace.nasa.gov/spaceweather/en/). Hence, it needs changes in all the components of climate system viz., atmosphere, hydrosphere, cryosphere, land surface, biosphere, and external forcing mechanisms. Solar flares and coronal mass ejection (CMEs) are the most powerful explosions in our solar system. Coronal mass ejections can blow out from the Sun, interfere with Earth's magnetic fields, and cause auroras of light circling the North and South poles. Global warming can stem from an increase in the sun's activity signifying the weather-climate system which is powered by solar energy (Fig. 2).

Figure 2: (a) Coronal mass ejections from the Sun interfering Earth's magnetic fields. (b) Global warming stems from an increase in the sun's activity signifying "weather-climate system" powered by solar energy. (Credit: NASA/Walt Feimer).

2. Solar Activity and Global Warming

Our Sun is a huge ball of electrically-charged hot gas. This charged gas moves, generating a powerful magnetic field. The Sun's magnetic field goes through a cycle, called the solar cycle. The solar cycle is the cycle that the Sun's magnetic field goes through approximately every 11 years. Solar activity increases with the increasing sunspots. Most of the visible surface of the Sun has a temperature of about 5400°C. The temperature of a sunspot is still very hot though—around 3,600°C. The magnetic fields are so strong that they keep some of the heat within the Sun from reaching to the surface. During the solar cycle there is a phase of solar minimum and heat radiation from the Sun into the space become maximum which can induce heat in the atmosphere for temperature rise. On the otherhand, Earth can experience cooling during solar maximum. Solar flares and coronal mass ejections (CMEs) are the most powerful explosions in our solar system. Giant eruptions on the Sun, such as solar flares and coronal mass ejections (CMEs), also increase during the solar cycle. These eruptions send powerful bursts of energy and material into space that can have effects on the Earth. Solar flares release a lot of radiation into space. If a solar flare is very intense, the radiation it releases can have effects on Earth. Solar scientists are now increasingly forecasting a period of very low activity that will commence in the next few years (by around 2020 to 2025). This will lead to climate cooling like Little Ice Age condition.

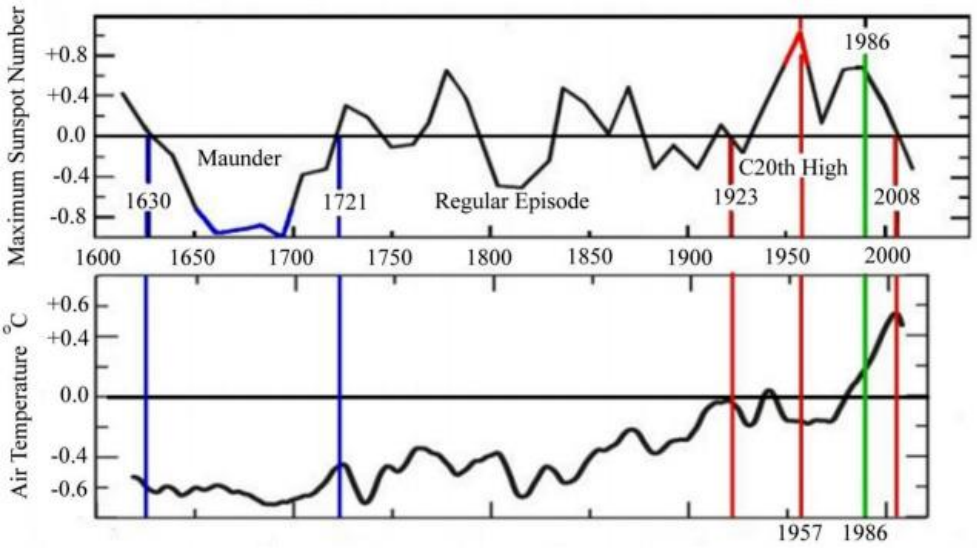


Figure 3: 350yr record a) Maximum sunspot numbers b) Northern hemisphere land-air temperatures. 1630-1721 Maunder Minimum (blue bars), 1923-2008 C20th Maximum (red bars), 1957 peak (red), 1986 transition (green bars). (Based on data of De Jager et al (2010) redrawn by Matthews and Matthews, 2014).

According to De Jager et al (2010) climate research wrongly assumed atmospheric pan-evaporation at sea as over land and ignored salinity and temperature dependence of density of the seawater. In situ

observations show two different heat capture and evaporation regimes exist dependent on surface temperature and salinity. The tropical North Pacific is temperature dominant, but other tropical oceans are salinity dependent. Incident solar radiation is cyclical and greenhouse gas (GHG) heat-capture is exponential and cumulative. The rate of GHG-caused climate change is disputed and not quantitatively evaluated. A target limit of total atmospheric temperature rise of <2°C is based on doubling of total carbon emissions from the long-term stable 280ppm to 560ppm. Further, De Jager et al., (2010) showed three grand episodes in sunspot numbers calibrated to total solar irradiance: the 1630-1721 Maunder Minimum, the Regular Episode, and 1923-2008 C20th Maximum. The rising temperature trend coincided with the abrupt falling trend in solar irradiance/sunspot numbers (Fig. 3) indicating solar influence of global warming. Earth temperature is also influenced by intermittent wobbling, change in tilting, axial obliquity, aphelion, perihelion, eccentricity, declination, polar wandering of the Earth in the solar cycle related to Milankovitch cycle (Fig. 4). Milankovitch cycle was hypothesized by Milutin Milanković in the 1920s, who was Serbian geophysicist and astronomer that describe the collective effects of changes in the Earth's movements on its climate over thousands of years. Variations in eccentricity, axial tilt, and precession can result in cyclical variation in the solar radiation reaching the Earth. According to Berger (1988) quote, "among the longest astrophysical and astronomical cycles that might influence climate (and even among all forcing mechanisms external to the climatic system itself), only those involving variations in the elements of the Earth's orbit have been found to be significantly related to the long-term climatic data deduced from the geological record", unquote.

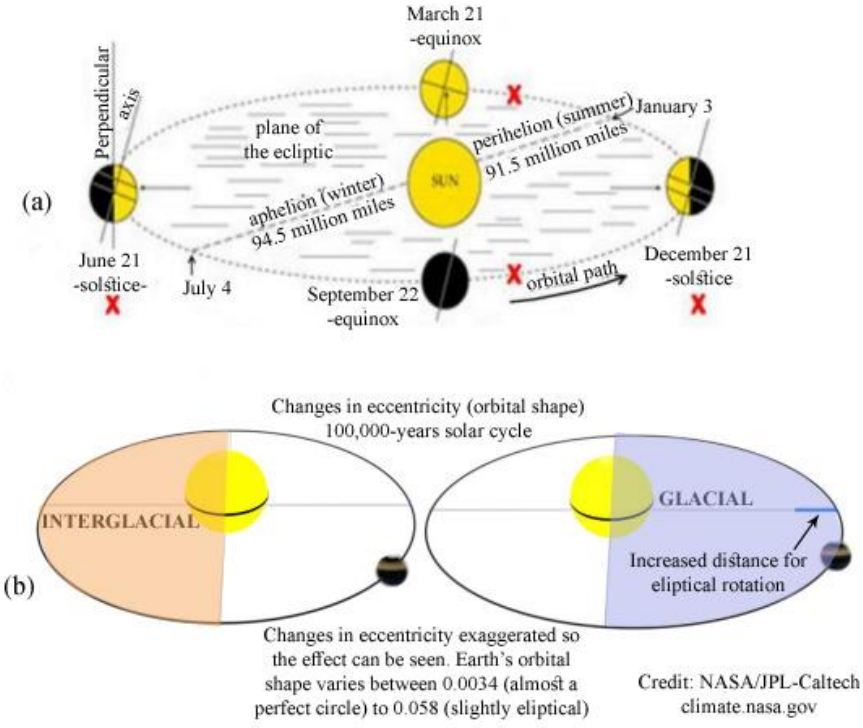


Figure 4: (a) Eccentricity is the shape of the Earth's orbit around the Sun in 365 days regardless of tilt of the earth. Warmer Earth (Summer season) when orbital distance from the Sun is less and the portion of

the rotation becomes oval. (b) Similar eccentricity pattern occurs for the entire solar system as the solar cycle in 100,000 years wherein half of the time of the solar cycle remains in the contraction mode for interglacial period; and half of the time remains in the expanding mode for glacial period.

Eccentricity is the shape of the Earth's orbit around the Sun in 365 days regardless of tilt of the earth. Warmer Earth (Summer season) when orbital distance from the Sun is less and the portion of the rotation path becomes oval. Winter season occurs when the portion of the orbital distance from the Sun is greater and portion of the rotation path becomes elliptical (Fig. 4a). Earth's axis of rotation is tilted as it rotates around the Sun, known as obliquity. Obliquity angle varies between 22.1^{o} and 24.5^{o} perpendicular to the Earth's orbital plane in about 20,500 years. Greater the Earth's axial tilt angle, more extreme the weather due to more solar radiation received by the Earth during summer when it is tilted toward the Sun. Similarly, eccentricity pattern occur for the entire solar system in about 100,000 years wherein half of the time of the solar cycle remains in the contraction mode for interglacial period; and half of the time remains in the expanding mode for glacial period (Fig. 4b). Earth's orbit around the Sun is accountable for all atmospheric hazards those occur within the global climate system but can not change the climate. Hence, the changes in the weather pattern, and, atmospheric and ocean circulation are dependent on the changes in the global temperature caused by the orbital fluctuations in response to the solar cycle.

3. Global Warming Quandary

Global warming is a slow increase in the average temperature of the earth's atmosphere. An increased amount of the energy (heat) that strikes earth from the Sun is trapped in the atmosphere and do not radiate out into the space. Global warming is the phenomenon of increasing average airtemperature of certain time period in comparison to the previous average temperature of the same time period i.e. "temperature anomaly".

According to IPCC (2013) the interval between 1880 and 2013 was the time of increased global average surface temperature of approximately 0.8°C. It is predicted that by the end of 21st century the global mean surface temperature would increase by 0.3 to 5.4°C. However, an average temperature rise of 0.8^{o}C between 1880 and 2013 can not justify the measure of global warming. Global temperature record of the last four thousand years exhibit distinct downward trend of the temperature anomaly (Fig. 5a). Figure 5a shows the records of local temperature variability on multi-centennial scales of the entire Holocene period since 8000 years with an average temperature marked as thick dark line. An inset plot compares the most recent two millennium of the average to other recent reconstructions. The inset plot clearly demonstrates no temperature rise. The graph in the Figure 5a is posted in the website https://commons.wikimedia.org/wiki/File:Holocene_Temperature_Variations.png.

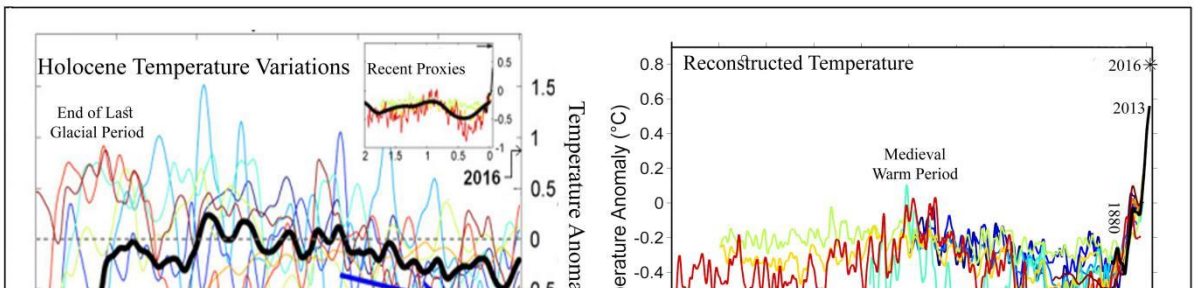


Figure 5: (a) This image is a comparison of 10 different published reconstructions of mean temperature changes during the 2nd millennium by Robert A. Rohde (2005) posted at http://www.globalwarmingart.com/wiki/File:1000_Year_Temperature_Comparison.png. Actual Medieval Warm Period (MWP) and Little Ice Age (LIA) show in all the curves. Source of the graph by Ray Kraft with references to the following links:
https://commons.wikimedia.org/wiki/File:Holocene_Temperature_Variations.png
https://en.wikipedia.org/wiki/File:Ice_Age_Temperature.png
https://en.wikipedia.org/wiki/Global_temperature_record
https://www.currentresults.com/Environment-Facts/changes-in-earth-temperature.php
(b) The figure shows eight records of local temperature variability on multi-centennial scales throughout the course of the Holocene, and an average of these (thick dark line). The data are for the period from 10000 BC to 2000 AD, which is from 12000 BP to the present time. An inset plot compares the most recent two millennium of the average to other recent reconstructions.(Source: https://www.iceagenow.info/temperatures-have-been-falling-for-8000-years/). (Eight different data sources of the graph are : 1. dark blue, sediment core ODP 658, Ref. Zhao et al., 1995; 2. blue, Vostok ice core, Ref. Petit et al., 1999; 3. light blue, GISP2 ice core, Ref. Alley, 2000; 4. cyan, Ref. Thompson et al., 2002; 5. yellow, sediment core PL07-39PC, Ref. Lea et al., 2003; 6. orange, pollen distributions, Ref. Davis et al., 2003; 7. red, EPICA ice core, Ref. EPICA, 2004; 8. dark red, composite sediment cores, Ref. Stott et al., 2004)

The graph in the figure 5a is prepared by Robert A. Rohde, the lead scientist for Berkeley Earth, from publicly available data and is incorporated into the Global Warming Art project. Most, but not all, of the original data is available from https://www.ncdc.noaa.gov/data-access/paleoclimatology-data. Paleo-temperature reconstruction in the Figure 5b demonstrate that 400 years before present global temperature attained a peak cold condition representing a “little ice age” and about 1000 years before present attained a “medieval warm period”. Figure 5b further shows that the present global temperature in comparison to eight records of local temperature variability does not cross the “medieval warm period”. Temperature rise of 0.8^{o}Cbetween 1880 and 2013 in 133 years is only 0.3% signifying the Earth to maintain a very stable temperature condition. Over the last 100 years, the average temperature of the air near the Earth’s surface has risen a little less than 1° Celsius (0.74 ± 0.18°C). This rise in temperature is likely to be responsible for the conspicuous increase in storms and raging forest fires. Increased magnitude of floods, on the other hand, is not due to the global warming and so-called climate change but for rapid deterioration of channel geometry to flow of water of abrupt influx of rain water. Data between 1998 and 2016 from

NASA shows an uniform amount of rain fall globally. Hence, an increased rainfall and inland flooding can not be attributed to climate change impact.

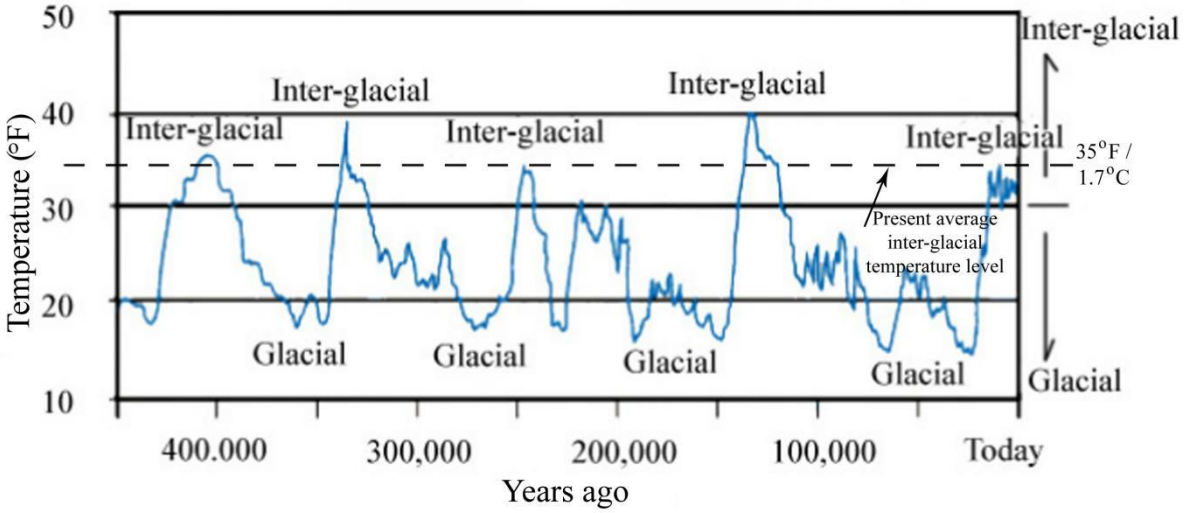


Figure 6: Global warming and cooling of climate system, intrinsically related to the glacial and inter-glacial period having distinct variations in temperature and other related weather components within each period. (Source: Kawamura et al., 2007).

Present world is passing through the interglacial period since approximately last 12,000 years (Fig. 6). The Last Glacial Maximum (LGM) ended around 22,000 BP. Records of the last 450,000 years clearly show that 'global climate change' occurred between glacial and inter-glacial periods (Fig. 6).The climatic group of Köppen (1884) is occurring since Last Glacial Maxima (LGM) with concurrent timing of 22.1±4.3 ka and 8±3.2 ka in the Northern Hemisphere and 22.3±3.6 ka and 7.4±3.7 ka in the Southern Hemispheres that matches with Earth's wobble happens over two cycles of 19000 and 23000 years (Campisano, 2012).While, the abrupt climate events of the last deglaciation are well defined in ice core records from the polar regions of both the hemispheres. Based on 104 high-resolution paleoclimate records to characterize the timing and spatial pattern of climate change during the last deglaciation indicates relatively concurrent timing of the Last Glacial Maximum (LGM; peak glacial conditions) and the Altithermal (peak interglacial conditions) in the Northern Hemisphere (22.1 ± 4.3 ka and 8.0 ± 3.2 ka) and Southern Hemisphere(22.3 ± 3.6 ka and 7.4 ± 3.7 ka) (Shakun and Carlson, 2010). This suggests that both the hemispheres were synchronized by greenhouse gases, local insolation, and/or Northern Hemisphere induced ocean circulation changes. The magnitude of the glacial–interglacial temperature change increases with latitude, reflecting the polar amplification of climate change, with a likely minimum global mean cooling of~(−4.9 °C) during the LGM relative to the Altithermal. Further, temperature has been relatively stable over the last two thousand years before 1850, with regionally varying fluctuations such as the 'Medieval Warm Period' and the 'Little Ice Age' (Figure 5b). The paleo-temperature reconstruction in the Figure 5b demonstrates that 400 years before present global temperature attained a peak cold

condition representing a “little ice age” and about 1000 years before present attained a “medieval warm period”. However, both ‘Medieval Warm Period’ and ‘Little Ice Age’ of the temperature anomaly curve (Fig. 7b) is absent in the temperature anomaly curve (Fig. 7a) posted at https://www.theguardian.com/environment/2010/feb/02/hockey-stick-graph-climate-change.

Three observational aspects are very clear in the temperature anomaly curve of the Figure 7a, i) the ‘hockey stick’ shape graph of abrupt linear rise in temperature after 1960,ii) the absence of global temperature record representing ‘Medieval Warm Period’ and ‘Little Ice Age’, and iii) distinct difference in the pattern of the temperature anomaly curve between year-by-year data from tree rings, corals, ice cores, historical records and year-by-year data from thermometers. The anomalous rise in the temperature anomaly in the Figure 7a is questionable. The magnitude of the glacial–interglacial temperature change increases with latitude, reflecting the polar amplification of climate change. The short term zig zag of temperatures over the past 100 years have been either cold or hot not just one way. For example in the 1930s temperature was high to cause world record droughts and then in the 1960s temperatures became record cold. IPCC predicted the rise in temperature was based on a range of possible scenarios that accounted for future greenhouse gas emissions since greenhouse gases are considered as heat trapper for global warming.

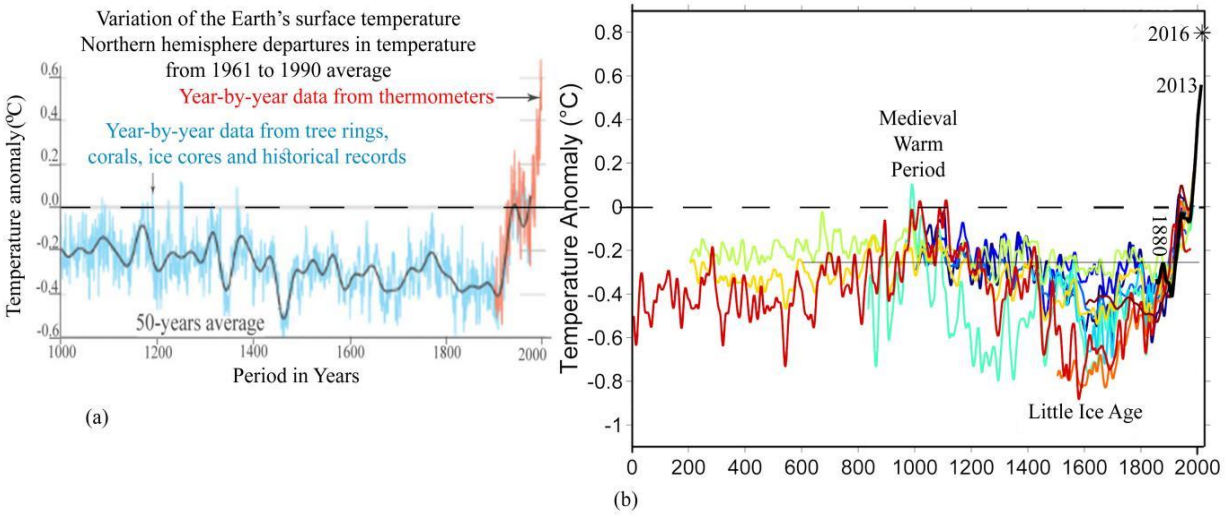


Figure 7: The fake temperature rise after 1998 shown by 'hockey stick' graph collected proxy temperature data from tree rings, lake sediments and ice cores. Both MWP & LIA of the curve shown in the figure 7b are deleted to show typical “hockey Stick” curve of temperature rise after 1998. This curve is posted at https://www.theguardian.com/environment/2010/feb/02/hockey-stick-graph-climate-change

4. **Fossil Fuel, CO_2 and Global Warming**

Studies of Antarctic ice core by Petit et al (1999) and Kawamura et al (2007) is presented in the Figure 8 that reveals global distribution pattern of temperature in celsius, CO_2 in ppmv and dust in ppm for the last 400,000 years. All the graphs in the Figure 8 clearly demonstrate that the peak temperature variation (ΔT) has attained earlier than the peak of CO_2concentration level in the atmosphere signifying no CO_2

contribution for temperature rise. On the other hand,peak dust concentration in the atmosphere attained much earlier than the peaks of temperature rise and CO_2 concentration signifying contribution by the factor other than fossil fuel burning both for temperature rise and CO_2 concentration. Further, rise in the dust concentration is directly correletable to the peak fall in temperature signifying major obstruction of solar insolation due to dust cover atmosphere. As dust concentration has reduced, both temperature and CO_2 have increased signifying an external forcing for the increase. A critical observation in the graphs of the Figure 8 for the last 18000 years reveals that none of the three components of the graphs are correletable. The most significant relation of temperature, CO_2 and dust concentration during the last 18000 years revealed that the dust concentration is due to volcanic activities that occurred much ahead of CO_2 concentration in the atmosphere providing evidence of CO_2 concentration from the volcanic eruptions. Simultaneously, CO_2 increment shows a negative correlation with temperature i.e., temperature shows almost flat for the last 10000 years but CO_2 continued to rise (Fig. 8).

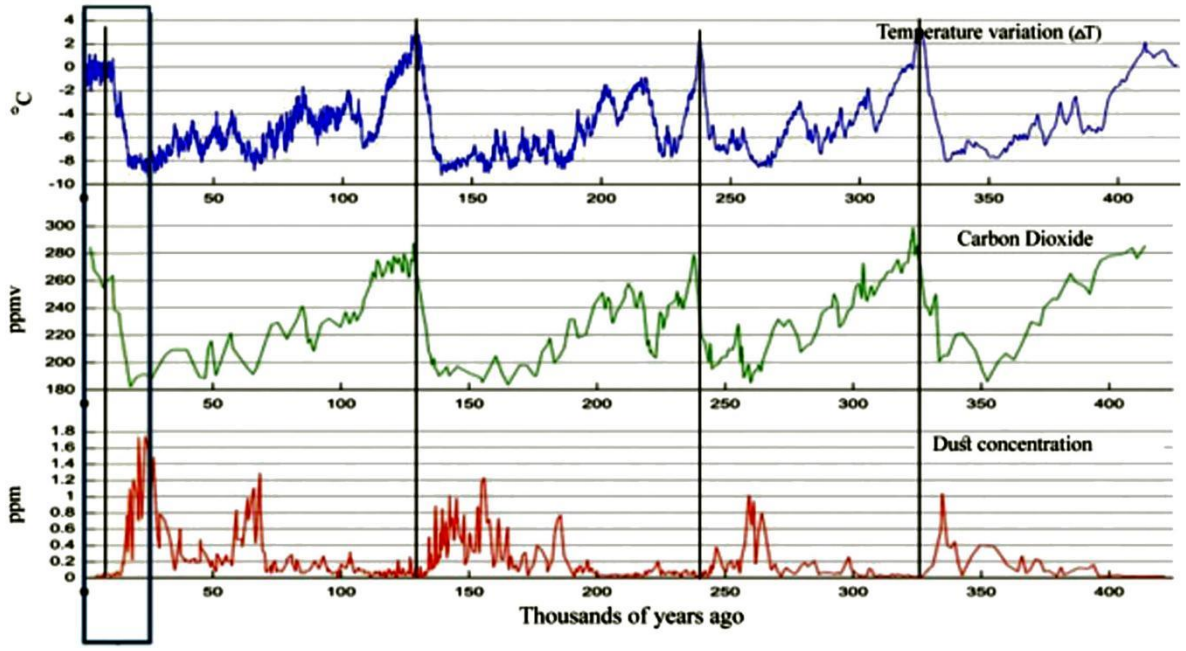


Figure 8: Graph of reconstructed temperature (blue), CO_2 (green), and dust (red) from the Vostok ice core for the past 420,000 years. A temperature cycle of 100,000 years is clearly envisaged. For the last 400,000 years peak CO_2 concentration in the atmosphere attains later the peak of temperature rise while dust concentration was much earlier than both CO_2 and temperature signifying causes other than CO_2 emission for global warming. (Source: Petit et al., 1999; Kawamura et al., 2007)

If CO_2 rise is responsible for the global temperature rise, then why temperature remained flat within the fluctuation level between +1°C and -2°C for the last 8000 years? The global temperature shows an uniform pattern for the last 11000 years (Fig. 9). Further, the observed temperature anomaly pattern for the last 8000 years (Fig. 5a) shows a downward trend signifying a probable "little ice age" in future. Hence, it is evident that the global warming claim is not due to the fossil fuel burning and the source of CO_2 in the atmosphere is not the fossil fuel. On the otherhand, CO_2 is not the principal greenhouse gas in the

atmosphere. The principal greenhouse gas in the atmosphere is the water vapor which varies between 36 to 69 percent, while, carbon dioxide (CO_2) ranges between 9 to 26 percent only. So, it is clear that water vapor plays the most dominant role as the heat trapper and global warming. The science behind the dominance of water vapor in the atmosphere is directly related to the solar insolation that can heat up surface water of the oceans for an accelerated evaporation and condensation in the atmosphere that results in an increased precipitation rate. Hence, an increased precipitation rate and rainfall causing continental flood does not mean a climate change and global warming. Since the last about 11000 years after the glacial period at the beginning of climate optimum, the Earth has witnessed almost flat temperature record with an insignificant changes of temperature between highs and lows (Fig. 9).

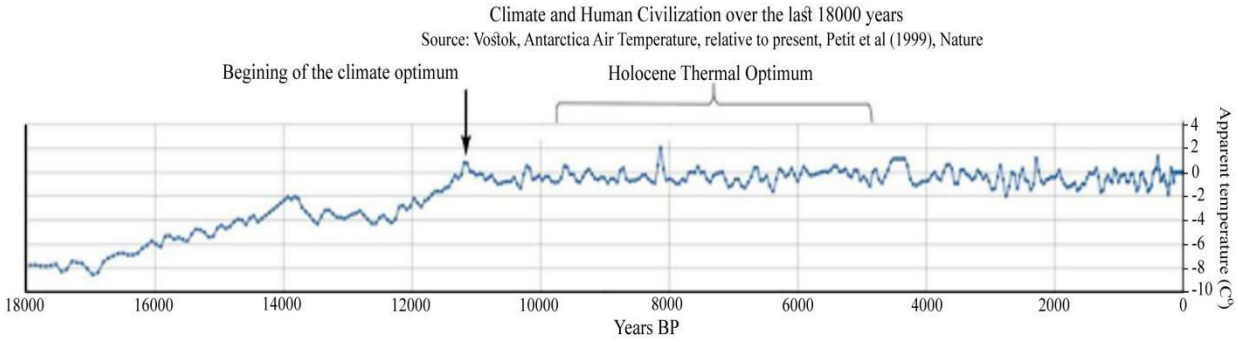
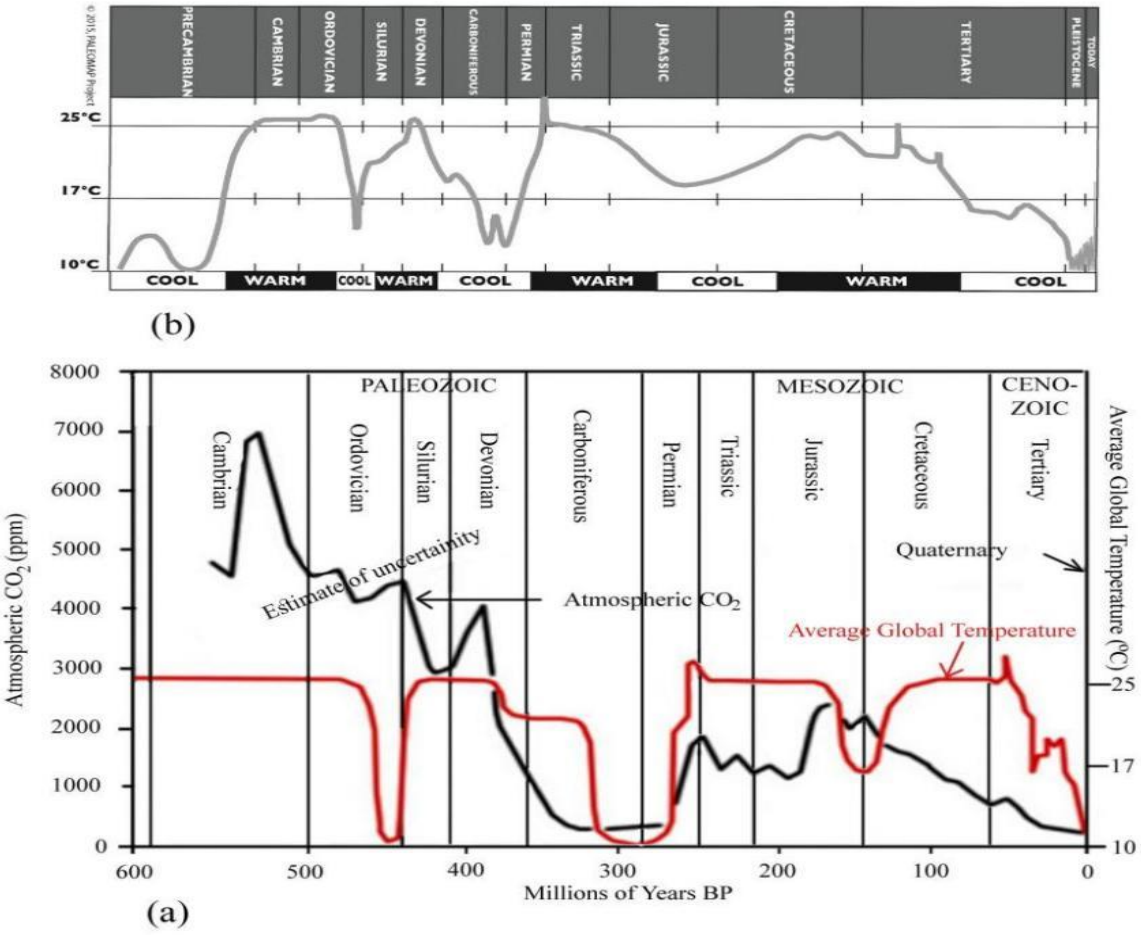


Figure 9: Since the beginning of the Holocene climate optimum global temperature remained by and large flat alongwith frequent rise and fall of temperature. (Source: Petit et al., 1999). Source of the curve posted in the following website.
https://andymaypetrophysicist.files.wordpress.com/2015/11/younger_dryas_to_present_time_line_updated2.pdf

About 10,000 years ago the perihelion (Earth closest distance to the Sun) occurred in the Northern Hemisphere summer and the summers were warmer and more humid than we see today (Fig. 4a). This was the beginning of the Holocene Thermal Optimum. Average near surface temperatures of the northern hemisphere during the last 10,000 years exhibit several warm and cold periods including the present warm phase (Dansgaard et al., 1969) The global warming scam by Vincent Gray (2008) posted in the blog clearly demonstrated that the present global warming is much below the entire mid-Holocene period for about 8000 years defying the claim of fossil fuel burning for the predicted global warming. The mid-Holocene period for about 8000 years dominance of warm period has taken a downward trend and the Earth seemingly heading towards another little ice age that prevailed at about 400 years ago (Fig. 5b). Reconstruction of the past 5 million years climate history based on oxygen isotope fractionation of benthic $\delta^{18}O$ records in deep sea sediment cores fitted to a model of orbital forcing from 57 globally distributed sites (Lisiecki and Raymo, 2005) reveals that the temperature derived from Vostok ice cores following Petit et al. (1999) has a decreasing trend since 3 million years BP. This findings may indicate that global

climate change interval between glacial and interglacial period is approximately 100 thousand years. Data on global temperature and atmospheric CO_2concentration over the geologic time of 550 Ma show very high CO_2 values during the early Paleozoic, a large drop during the Devonian and Carboniferous, high values during the early Mesozoic, and a gradual decrease from about 170 Ma to low values during the Cenozoic (Berner and Kothavala, 2001). On the otherhand, average global temperature attained maximum 25^{o}C and minimum 10^{o}C.Current global average temperature is around 12^{o}C. An interesting observation of the graph constructed by MacRae (2008)for CO_2 concentration in the atmosphere and the average global temperature for the last 550 Ma show no correlation between the two (Fig. 10a).

CO_2 concentrationin the atmosphere and the average global temperature are the two independent variables showing by and large an opposite relationship between the two providing strong evidence and support that *fossil fuel* is never responsible for the global temperature rise and an increased CO_2 concentration level in the atmosphere. Reconstruction of the average global temperature is made by the paleogeographer C.R.



project (Fig. o Berner and ıer than today was ten times ın for 550 Ma concentration 's ago. Hence, viz., (i) 2^{o}C to for the global

Figure 10: (a) Carbon dioxide (CO_2) level is represented by the black line, and the temperature is represented by the red line for the last 600 million years (Source: Data from Berner and Kothavala, 2001; Graph from MacRae,2008). Carbon dioxide does not show any correlation with temperature. CO_2 fallen steadily for more than 150 million years, while the planetary temperature stayed at 22°C until about 30 million years ago. (b) Reconstruction of average global temperature is made by the paleogeographer C.R. Scotese and posted in the website http://www.scotese.com/climate.htm under a Paleomap project

5. **Reality of climate change**

An understanding of climatology requires an integrated study of solar physics, geology, geochemistry, sedimentology, tectonics, palaeontology, palaeoecology, glaciology, meteorology and oceanography.None of the above disciplines encompasses anthropology or anthropogenic processes. Hence, primarily it is necessary to disregard any anthropogenic relation with climatology. Climatology is the study of climate science which is based on the scientific data of the factors that control climate system. At the primary stage, climate sounds some phenomena or natural events associated with water, wind, and temperature. The source of water and wind is the atmosphere, while the Earth's temperature largely depends on the solar activity. Hence, the Earth's atmosphere and the solar activities are inter-related. Since the variability of temperature of the Earth greatly depends on the rotational pattern and the distance of the Earth with respect to the Sun, the atmospheric water vapor is very much conducive to the heat radiation. Similarly, temperature rise of the surface water of the ocean can increase evaporation rate and enhances the water vapor concentration in the atmosphere. Study of the Earth's atmosphere alone tells us nothing about the future climate. Just over forty years ago in 1975, Geochemist Wally Broecker from Lamont-Doherty Geological Observatory, now Lamont-Doherty Earth Observatory in New York published a paper entitled "Climatic Change — Are We on the Brink of a Pronounced Global Warming?" in the journal 'Science' Broecker (1975). The terms "climatic change" and "global warming" both are used more or less interchangeably. There is no information about the past century's history of global temperature. The graph of surface temperatures from Goddard Institute for Space Studies (GISS) Surface Temperature Analysis (GISTEMP) ending in 1974 does not correlate with the curve of Broecker (1975). Broecker predicted an overall 20th Century global warming of 0.8ºC due to CO_2 and worried about the consequences for agriculture and sea level. However, no adverse consequences have occurred in agriculture, and sea level did not rise even after twenty years of declaration of global warming and sea level rise.

“Climate” refers to the average weather in terms of the mean and its variability over a certain time-span and a certain area. Classical climatology provides a classification and description of the various climate regimes found on Earth. Climate scientists have gathered detailed observations of various weather phenomena such as temperature, precipitation, and wind; and their related influences on the ocean currents and in the chemical composition of the atmosphere. These data indicate that the influence of human interference since at least the beginning of the industrial age has been over emphasized into very fabric of climate change. Climate is determined by the atmospheric circulation and by its interactions with the large scale ocean currents. Climate varies naturally on all time-scales. During the last million years or so, glacial and interglacial periods have alternated as a result of variations in the Earth’s orbital parameters and other geological influences. But no scientific evidence exists supporting climate change due to human interference. According to Köppen (1884); and Rubel and Kottek, (2010) climate is classified into five main climate groups, with each group is based on the seasonal precipitation and temperature pattern. The five main climatic groups of Köppen (1884) are the tropical, dry, temperate, continental, and polar. Weather pattern may change with the changes of rainfall intensity, and the duration of cold and hot period. Intense rain fall may cause flooding, longer spell of high temperature and no rainfall may lead to severe drought, sudden temperature rise in the mountainous region of high latitudes may cause GLOF (glacial lake outburst flood) due to snow melts and avalanches. Temperature rise of the atmosphere can heat ocean surface, popularly known as thermal expansion, that can generate more water vapor due to the evaporation of the ocean water. At the initial stage of atmospheric temperature rise, air gets lighter and moves to the higher altitude subsequently filled by relatively heavy air from the surrounding. Simultaneously, heated ocean surface that form light air can mix with incoming heavy air from the surroundings forming increased water vapor. If the atmospheric temperature increases then the lighter air will move upward more rapidly developing a gap and the surrounding heavy air will move inward faster to fill the gap, thus can produce turbulence or spiral atmospheric motion. When spiral motion is added to the evaporated water vapor, it can form cyclone in the ocean or without water vapor on land can form tornedo. So, it is the temperature that plays an important role in such atmospheric process. The intensity of temperature rise of the atmosphere can increase the intensity of the formation of cyclone or/and tornedo. Hence, such changes of the atmospheric behavior is not defined as climate change. Pacific Ocean surface temperature changes may develop El Nino and La Nina that affect ocean circulation and may last for several years. These extreme weather events are simply a variations in the weather pattern and do not signify climate change. Köppen-Geiger climate classification based on temperature and precipitation observations for the period 1951–2000 and digital world maps for the extended period of 1901-2100 to depict global trends in observed climate and projected climate change scenarios demonstrate an estimate of the shifts of climate zones within the 21st century by considering different IPCC scenarios (Rubel and Kottek, 2010). It is

found that the largest shifts between the main classes of equatorial climate (A), arid climate(B), warm temperate climate (C), snow climate (D) and polar climate (E) on global land areas are 2.6–3.4 % (E to D), 2.2–4.7 % (D to C), 1.3–2.0 (C to B) and 2.1–3.2 % (C to A) respectively.The findings strongly support that climate change does not occur in human time frame rather spatial climate zone of the earth may shift by insignificant percentage which is natural.

Climate of the Earth as a whole depends on the factors that influence the radiative balance, such as, the atmospheric composition, solar radiation and volcanic eruptions. Impacts of volcanic eruptions on climate is important because it allows to make seasonal and inter-annual weather forecasts following large eruptions, provide support for nuclear winter and allows to separate the natural causes of inter-decadal weather pattern change from anthropogenic causes (Robock, 2004). Based on Antarctic ice cores, more detailed information is available now about the four full glacial cycles during the last 450,000 years. There had been palaeo-climate changes several times in the geologic past wherein earth had undergone climate change between glacial and interglacial cycle (Fig. 6; Kawamura et al., 2007). Each glacial and inter-glacial phase further shows intra-phase temperature changes that may cause extreme weather events.Graph in the figure 6 clearly demonstrates that in the last 420,000 years all the global temperature level during inter-glacial period was much higher than the present temperature level (Petit et al., 1999). It is also clear from the graph that the temperature change from glacial to interglacial phase is abrupt while temperature change from interglacial to glacial is gradual. The global temperature pattern of 420,000 years further exhibits the duration of present temperature level much longer and flat. The last most recent abrupt rise of temperature from glacial to interglacial did not occur due to any anthropogenic reason and it must have required a natural forcing. Ruddiman (2013) opined that the early industrial era (~1850) of large-scale human contribution (the Anthropocene) is debated whereas the early-anthropogenic view recognizes large impacts thousands of years earlier. Early forest clearance has caused much greater pre-industrial greenhouse-gas emissions and global temperature changes than those proposed within the industrial paradigm. Atmosphere allows short-wavelength sunlight to reach the Earth's surface but prevent the escape of long-wavelength thermal infrared radiation back to space. Most of this heat-trapping work is done by water vapor, but without other greenhouse gases the water vapor would condense and precipitate out of the atmosphere, turning the Earth into an icy ball with a cold and dry atmosphere. This mechanism seems most likely an acceptable scientific explanation for glacial-interglacial climate cycle. Carbon dioxide (CO_2) is the most important non-condensing greenhouse gas. It can raise the temperature of the atmosphere enough to maintain Earth's blanket of water vapor. Climate change is caused by the factors such as variations in solar radiation received by the earth, plate tectonics, volcanic eruptions, and the temperature variations causing mini-ice ages and warm phases within each climate cycle. All these factors may change weather pattern temporarily but can not change climate.

6. Natural Hazards and Maritime Development

Natural hazards are the main factors responsible for hindering sustainable maritime development and blue economy. Secondly, climate change that cycles between glacial and inter-glacial periods in hundred thousand years is not related to present-day scenario of natural hazards. Natural hazards, both geological and atmospheric are intrinsically related to the geological and atmospheric processes. Geological process is controlled by the forces of tectonics, sedimentation, crustal motion, earthquakes, tsunami, volcanic activity, sea level rise and all other hazards in the ocean basins. Similarly, atmospheric hazards are regulated mainly by the atmospheric temperature, pressure, wind circulation and ocean circulation. Maritime related other potential hazards are: coastal erosion, mud diapirism, high formation pressure, slope instability, submarine landslide, turbidites, shallow gas escape, natural gas hydrates, sedimentation induced sand bar formation causing backshore flooding, water logging and chock point development. Sedimentation, sand-bar formation and chock point development are the major causes for the deterioration of navigation routes and ocean-hinterland connectivity. The development strategy in the maritime sector should be addressed based on the performance of each hazard that may cause widespread damage. When Mount Pinatubo erupted in the Philippines June 15, 1991, an estimated 20 million tons of sulfur dioxide and ash particles blasted more than 20 km high into the atmosphere. The eruption caused widespread destruction and loss of human life. Gases and solids injected into the stratosphere circled the globe for three weeks. Volcanic eruptions of this magnitude can impact global weather pattern, reducing the amount of solar radiation reaching the Earth's surface, lowering temperatures in the troposphere, and changing atmospheric circulation patterns. Large-scale volcanic activity may last only a few days, but the massive outpouring of gases and ash can influence weather pattern for years. Sulfuric gases convert to sulfate aerosols, sub-micron droplets containing about 75 percent sulfuric acid. Following eruptions, these aerosol particles can linger as long as three to four years in the stratosphere (Kirchner et al., 1999; Stenchikov et al., 1998). Among the most common atmospheric hazards cyclone, storm surge, back shore flooding, saline water encroachment, coastal erosion are the most important. Coastal belts globally are under potential threats of these natural hazards. For a sustainable maritime and blue economy development, an essential paradigm shift in the understanding of so-called climate change impact to real hazard potentiality reduction is required. Globally, each maritime zone has its own unique hazard vulnerability. It is essential to evaluate and address each such hazard separately to incorporate in the planning for sustainable development in the maritime sector. Very seldom the real threats to the maritime development due to environmental pollution jeopardizing the entire ecosystem and biodiversity of the coastal belt is highlighted. Although, every development projects incorporate environmental impact assessment (EIA) component but the implementation of the EIA remains far behind the scene. In reality, all kinds of

pollution are far more the potential to evolve a long-term disaster to the maritime sector than an instantaneous geological and atmospheric hazards. Geological hazards occur relatively at a slow rate than the atmospheric hazards. Although, CO_2 emission, global warming, polar ice melt and sea level rise are the most concerned issues of the climate change, scores of studies evidently found that none of the above hazards signify climate change. Khan (2019) revealed that sea level will not rise due to global warming and polar ice-melt because global sea level is perfectly maintained by the angular momentum and centrifugal force of the earth's spinning and rotation. It is not prudent to relate natural hazards with the climate change concept. Neither, inland and back-shore flooding is the result of climate change.

7. **Conclusions**

Holistic maritime and blue economic development shall not be achieved in the context of climate change quandary. Climate is determined by the atmospheric circulation and by the interaction of large scale ocean currents. Climate is not changing in the scope of its definition. It is not prudent to attribute natural hazards with climate change fantasy. It is not the "climate change" rather "natural hazards", both geological and atmospheric, are the principal factors those may cause major adverse impact on to the holistic development in the maritime sector. Earth temperature / global warming is influenced by the intermittent wobbling, change in tilting, axial obliquity, aphelion, perihelion, eccentricity, declination, polar wandering of the Earth in the solar cycle. CO_2 concentration in the atmosphere and the average global temperature are the two independent variables with an opposite relationship between the two providing strong evidence and support that *fossil fuel* is not responsible for the global warming and an increased CO_2 concentration level in the atmosphere. Threats to ocean environment, ecosystem, biodiversity, habitat, pollution, and ocean related atmospheric hazards are needed to address scientifically and not by only concept and imagination. Climate system interacts with the changes in the atmosphere, ice, ocean, land surface and vegetation. These changes occur due to the external forcing such as Earth's orbital force and Sun's strength. Holistic maritime development are based upon four basic factors, a) the oceans are the source of all life on earth, b) any further degradation of the environment and/or ecological damage is unaffordable, c) sustainable exploration and exploitation of resources, both geological and natural, are necessary for the long-term survival and, d) good governance, transparency, safety and security in all activities related to maritime and blue economy development are of fundamental requirements.

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Impact of marine pollution in coastal areas of Chittagong and guide lines for mitigation

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Abstract

A combination of human activities are responsible for marine pollution. It affects the health of the ocean and makes the coastal area vulnerable. Developed and developing countries both are affected by marine pollution. Coastal regions and ecosystems are facing diversified environmental pressure throughout the world. Rampant discharge of industrial effluents, untreated sewage, oil spills, plastics, chemicals and other hazardous pollution from ship breaking yard continually affect Chittagong coastal area. Wide range of pollution in the coastal environment of Chittagong threats to the livelihoods of coastal communities and associated industries pose a serious health risk to humans through contaminated seafood and affects marine ecosystems. In this paper, the effort has been made to examine the issues concerning marine pollution, identify the effect of pollution in the environment and suggest preventive measures for minimizing pollution in this selected area through careful management. The study is depended on data collected from both primary and secondary sources. Primary data were collected using structured questionnaires and in-depth interviews with top management engaged in maritime activities, the industrial sector, as well as marine professionals. Secondary data were sourced from published books, documents, reports, articles, and the internet. This study describes the major sources of pollution in this area and try to finds out the possible effects on the coastal environment. Poor laws and lax implementation are the major causes of pollution. In the end, this study states some recommendations for minimizing this problem. Those includes introduction of green tax, enhancement of safety culture, installation of upgraded technologies, adaptive management, cross-border cooperation, etc.

Keyword: Marine pollution, coastal environment, integrated management

Introduction

Bangladesh is a riverine country. She stands in dignity with her dense population and is boarded by Indian states to the west, north, and east. The southern part is open to the Bay of Bengal by sharing a boundary with Myanmar to the south. Chittagong is in the southeastern part of Bangladesh with the blessings of the Bay of Bengal. About 734 Km coastline of Bangladesh, Chittagong has a coastline of 245 km with a 125 km long natural unbroken sandy beach. (Khan et al., 2019). The combination of Mountain View and sea beaches make this area more remarkable.

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The second largest city and also known as the port city of Bangladesh and one of the busiest port which handles 92% export-import trade of Bangladesh. According to CPA report, it handle 3,764 ship in 2019-2020 (CPA Ship Handling Statistics, 2019-2020). This port is also used by India, Nepal, and Bhutan for transshipment. So pollution from the ship is a serious threat to the Karnaphuli River and chittagong anchorage area through handling, transportation, ballast and bilge water, accident and also dumping of wastes. Besides merchant's vessels, naval vessels, fishing vessels, trawlers, river crafts and mechanized boats are also a source of different types of pollution. Karnaphuli is the main river of the Chittagong. The whole city is located on the banks of the river.

Pollution status in Chittagong

The coastal environment of Chittagong is contaminated by oil tanker traffic, harbor operations and effluents discharged from petroleum processing. Sewage disposal by the rivers contains higher concentration of Oxygen Demand and causes eutrophication, which can makes dead zone for fish. The coastal environment of Bay of Bengal has also been affected by industrial discharges, waste from agricultural and human activities like deforestation and irrational expansion of coastal shrimp farming, etc. resulting in ecological degradation. Overfishing and dumping of discarded fishes and fishing nets in these areas are becoming a threat to the resourcefulness of the fishing grounds. Metal pollution and toxic organic compounds are the hazards for human health and environment. The primary sources of marine pollution which may create impact on Chittagong coastal environment basically comes from maritime activities, people living in the coastal areas and industries along with coastline that can be causes of intentional accidental pollution. Sources of marine pollution that is happening in Chittagong are described below:

1. Ship source pollution
2. Land based pollution

Ship source pollution

Shipping is one of the marked sources of the pollutants that pollute the waterways of Chittagong. There are different sorts of unfriendly impacts due to these pollutions. In Bangladesh due to the lack of applicable laws and resource deficiencies of the concerned government departments, pollution by shipping has become common incident. For such operation of the vessels, the marine environment has been exposed to massive pollution. The factor that related with Ship based pollution are discussed below

Pollution from fishing vessel

The fishing vessel is a main source of pollution in Chittagong. A total of 205 registers fishing trawler are running through the Karnaphuli River. They continuously dumping waste, garbage, sewage, Bilge Water, Materials washout from Deck and Engine Room, Processing wastage, solid materials (can, plastic bottle), discarded food waste, galley wastage, rotten fish, etc. other item such as discarded Fishing Nets cause harm to the marine environment or create a navigational hazard. As well as fishing hampers the marine Biodiversity in coastal areas by overfishing, ghost fishing, bottom trawling, etc. There is no sewage treatment plants in fishing vessels, so all vessels discharge sewage directly in river water. According to IMO standard all fishing vessels over 400 gross tonnage are required to be fitted with oily water separator which ensures the oil content is less than 15 parts of oil to one million parts of water (15ppm). Fishing vessels over 400 gross tonnage must comply with the discharge regulations (Australian Maritime Safety Authority, 2020) In most of cases this means that oily mixtures (diesel, hydraulic fluids and bilge water with any concentration of oil) must be stored onboard for disposal at port waste reception facilities. But there is no oily water separator used on this vessels which are over 400 gross tonnage and there is no port waste reception facilities in Chittagong and these vessels are not surveyed for the anti-pollution arrangements. So all these fishing vessels keep on polluting coastal areas continuously.

Pollution in Chittagong outer anchorage

Because of draft restrictions in the river, the entrance of vessels over 20,000 DWT cannot enter into Karnaphuli River. Most of the foreign vessel waiting at the anchorage area for transshipment of cargo. By taking advantage of lax law and implementation some of the ships dump waste materials in the outer anchorage of the ports by defying international regulations. Not only foreign ship, local ship and fishing vessel also use outer anchorage as a safe dumping zone where any other international port would have imposed heavy penalties or even seized and blacklisted ships if found violated marine laws or polluted the sea.

Oily-water discharge from ship

Due to ship operation spills of lubricating oil, fuel oil, grease and water etc. are collected in bilge area. The resulting emulsified water and oil, if pumped into the sea or river where oily-water separator is not fitted it will cause oil pollution. If oily water separator is not fitted or inactive then direct discharge of oily water mixture is against the international regulations. Also the cleaning process of crude oil tanks of large oil tankers contribute to marine pollution because cleaning process contains detergent, solid matters, rusty scales from corrosion are discharged overboard.

Accidental Spillage during Terminal Loading

The malfunctioning of valves, pumps and rupture of pipes or operational fault can cause oil spillage during loading or unloading of crude oil at oil terminals, oil refinery, related industries and oil storage site. Canals, rivers and surroundings are reported to be polluted by releasing oil, oily water and sludge. Loading bunker oil or lubricating oil for vessels and operational purposes spills may also occur. An undetermined amount of oil spill occurred in Chittagong port area due hose rupturing in 2016. The tanks overflow could happen if someone is not watching the level of oil loading into the ship's tanks.

Tanker accidents

Oil spills are most commonly associated with ship based pollution. There are always risk of collision, grounding, explosion or fire, which are normal incidents faced by oil tankers, chemical and gas carriers. The exploration, exploitation and transportation of oil, gas have a devastating impact resulted in various accidents. Effective measures are usually taken to combat this spillage when it occurs. In order to show the vulnerability of Chittagong marine environment a number of vessel casualties and other oil spill records are examined. These oil spillages had adverse effects on the environment.

Table 1: oil spills record in Chittagong coastal area last decade (Compiled by researchers)

year	Source of oil spills	Causes of incident	Place of incident	Amount(in tons)
2019	Oil tanker	Collision	Karnaphuli channel (Padma jetty)	10
2019	Freight train	Derailed	Halda canal	25
2016	Oil tanker	Collision	Karnaphuli channel (dangarchar)	5 to 6 tons
2016	Jetty	discharging pipe ruptured	Karnaphuli river near port area	undetermined
2015	Freight train	Derailed	Kithabchar canal	24
2014	Freight train	Derailed	Sitakunda (canal)	66
2013	Freight train	Derailed	Karnaphuli channel (near the kalurghat)	33
2011	Oil tanker	Sunk	Karnaphuli channel (Dolphin jetty)	180

Anti-fouling Paints

Anti-fouling paint is a specialized paint used to the ship's hull to prevent or slow the growth of marine organism which can affect the vessel performance and durability. This paint also act as a barrier of hull corrosion. But these chemical have contaminated the marine environment and even human. These chemical releases a poison into the water by falling off from old ship. Some antifouling chemical such as, TBT, which was one of the active components used in anti-fouling and leading to indirect impacts on marine wildlife further up the food chain. Human also face health hazard after eating contaminated food. TBT has hormone disrupting properties and at low concentration it causes genital change of snail and deformation of oyster. It also can causes of severe damage to reproduction or immune systems.

Figure 1 : Removing paint from ship (picture captured by researcher)

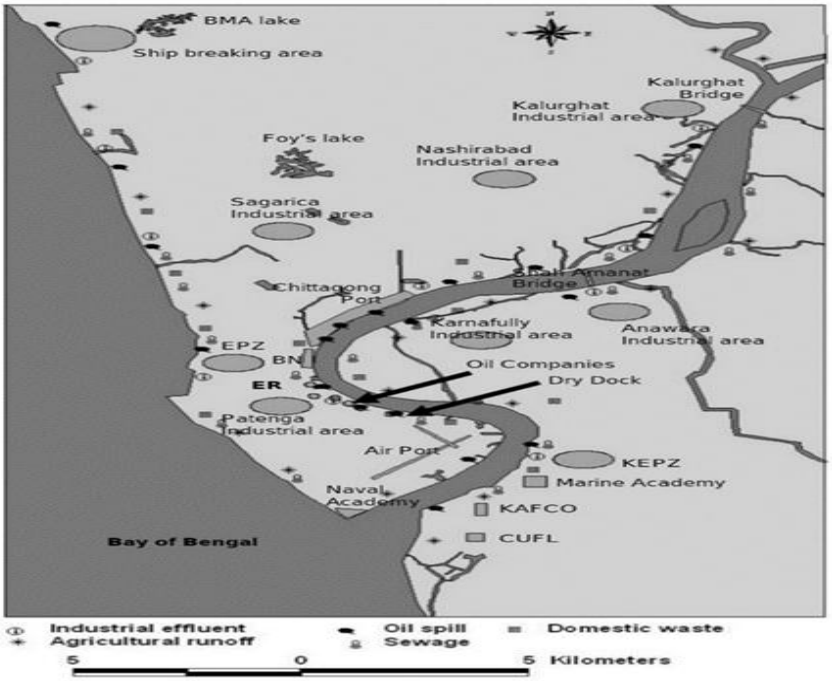
Sound pollution

The noise produced by ships, submarines, offshore operations, fishing, and other maritime activities are disturbing marine species. These sound forces changed diving patterns, migration to newer places, and damage to internal organs, and overall panic response. Noises interrupt communication, disrupting migration, communication, hunting, and reproduction patterns for many marine animals. (Iduk et al., 2015)

Land based pollution

The coastline of Karnaphuli River is full of industries. By increasing industrialization more of industrial wastes are released into the river water directly. The south and north side of Karnaphuli, Kalurghat, Patenga, Bhatiary, Sitakunda, Nasirabad, Anwara, and Kaptai are considered industrial hotspots. Most of the land-based source which are polluting Chittagong coastal environment are described below:

Figure 2 : Pollution source in Karnaphuli , Satellite image (Hossain et al., 2005)



Methodology of the study

Methodology is an important part in any study since it gives the procedures through which the study has been implemented. Different research problems imply different research goals, which in turn call for various methods. This study has been carried out to find out the impact of marine pollution in Chittagong coastal area. In order to fulfill this research a questionnaire survey is conducted. This paper is completed by using both primary and secondary data collection method. For this matter, various published thesis, articles, Journals, and leaflets were reviewed, examined and analyzed. Picture are collected by field survey. Telephone interview with some experts in the shipping sector, and with some high ranked personnel is used as primary sources. Simple statistical method is used for data presentation. The statistical data is presented by diagrams, charts, rows, columns, table etc.

Types of research

a) Nature of research: The study adopted applied research employing empirical approach to enable established factual information. The nature of data collected for this study was an integration of qualitative and quantitative data for an informed analysis.

b) Level of research: The level of research boarded in this study was descriptive survey research. The descriptive survey research was implemented as it provided researcher an opportunity to present his perspectives on the subject.

c) Research design: Survey and qualitative research design were used for the study to enable researcher obtain data from the field and existing literatures on the subject for an informed analysis

Source of data

This study obtained data from both primary and secondary sources. Primary data have been collected from the respondent by sending questioner via mail, conducting in-depth interview among the sample population and telephone interview. Sample copy of survey questionnaire and summary of respondents' response are presented in Appendix, and secondary data available on articles, journals, news, internet websites, newspapers, service papers, annual reports and so on.

Methods of data analysis

The analysis of the data collected for the study employed, both qualitative and quantitative methods. Qualitative analysis used logical reasoning to arrive at cogent deductions. Data generated from administered questionnaires were analyzed quantitatively by adopting descriptive analytical tool. The analyses were used to draw conclusions and make recommendations regarding inefficiencies at Chittagong Port and its impact on supply chain and logistics.

Methods of data presentation

Analyzed data were presented in a descriptive analytical form. In some cases, the collected data has been converted into pie charts, tables, bar diagram for clarity.

Major polluting industries

A. Ship breaking industries

The most dangerous pollution source in Chittagong is the ship breaking and recycling industry. This sector contributes to different types of marine pollution. Due to the long heritage of practices, the impact of the shipbreaking activities involves various environmental issues along the coast of Chittagong intertidal zones that are connected to the Bay of Bengal. At present, there are 125+ ship-breaking yards in this area and space extends from over 14 km along Fauzdarhat to Kumira Coast (Hossain et al., 2005). Generally, Tankers, Cargo ships, and Container ships are scrapped in the Chittagong ship breaking yard. The wastes from scrapped ships, including oils and persistent organic pollutants (POPs), Asbestos, Heavy metals , Polyvinyl Chloride (PVC), PCBs,(mainly cables), ODS (mainly polyurethane foam), Paints (metals, tributyltin (TBT), and PCBs, Heavy metals, Waste liquid organic, Miscellaneous (mainly sewage), Waste liquids inorganic (acids), Reusable liquids organics.

Figure 3 : ship breaking activities in shoreline of Bay of Bengal at Bhatiary

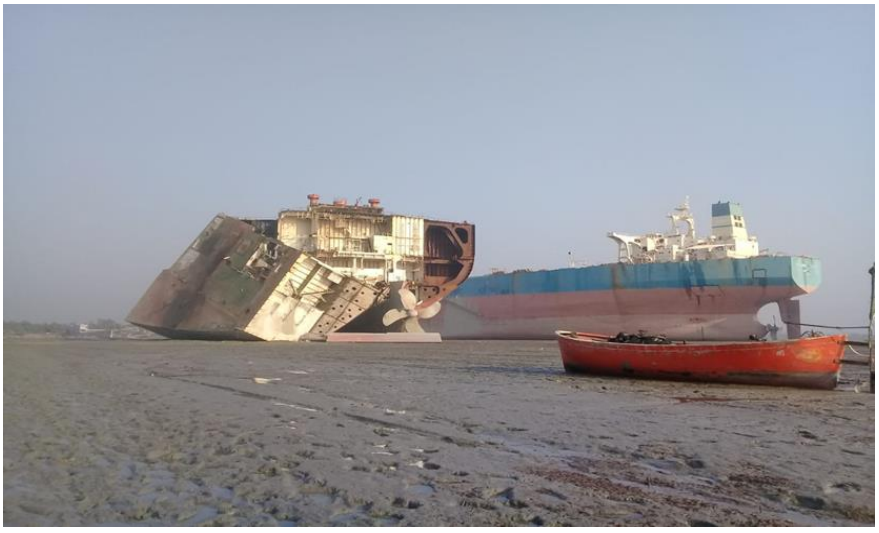


Photo Source: researcher

B. Fertilizer Factory

Triple Super Phosphate Complex (TSPC) located in North of Patenga, Chittagong, on the banks of the Karnaphuli River close to the Bay of Bengal. TSPC produce Triple Super Phosphate (TSP) Fertilizer, Single Super Phosphate (SSP) Fertilizer and Mixed Fertilizer (NPKS), Sulphuric Acid, Phosphoric Acid. This is the most hazardous plant and has been identified by the environmental division of the Bangladesh government as a major issue. The waste is loaded with fluoride and sulfur. Despite the use of a scrubber, there has been significant air emission of sulfur dioxide and trioxide, fluoride, and nitrous oxide. In another case, the water from the scrubber is simply drained into the river(The World Bank, Environmental Economics Division, 2021) Chittagong Urea Fertilizer Limited (CUFL), DAP fertilizer company, and Karnaphuli Fertilizer Company or KAFCO are major fertilizer factories of Chittagong situated adjacent to the Karnaphuli River. All factories discharge waste into the river and also causes air pollution. A large amount of toxic ammonia gas was released from the Di-ammonium Phosphate Factory Limited known as DAP-1 in 2016 due to an overpressure explosion of a 500-ton ammonia tank where ammonia is toxic, corrosive, and can rapidly penetrate the eye even in low concentration. The toxic ammonia gas spread over several kilometers and nearly 250 people fell sick inhaling the toxic ammonia gas.10 ton of fish nearby pond was dead due to this explosion (Chittagong Fertilizer Factory Blast: Gas Disaster Averted, 2016)

Table 2 : Waste generated from fertilizer factories

types	Content
Solid waste	Sludge, Urea dust, Waste catalyst and catalyst dust containing cobalt, zinc, nickel, chromium, copper and iron, Other solid scraps and waste dumped in ship recycling yards.
Liquid waste	Wastewater with high ammonia content, also containing sulfates, phosphates, methanol and hydrogen sulfide, fluorides, urea etc. Chemical
	Effluent from cooling system, boiler, washing, spills and leakage, surface runoff and gypsum sludge in case of TSP complex.
gases	Ammonia, Carbon dioxide, CO, methane, As, etc. Formaldehyde vapor, Urea dust, Sox from TSP production.

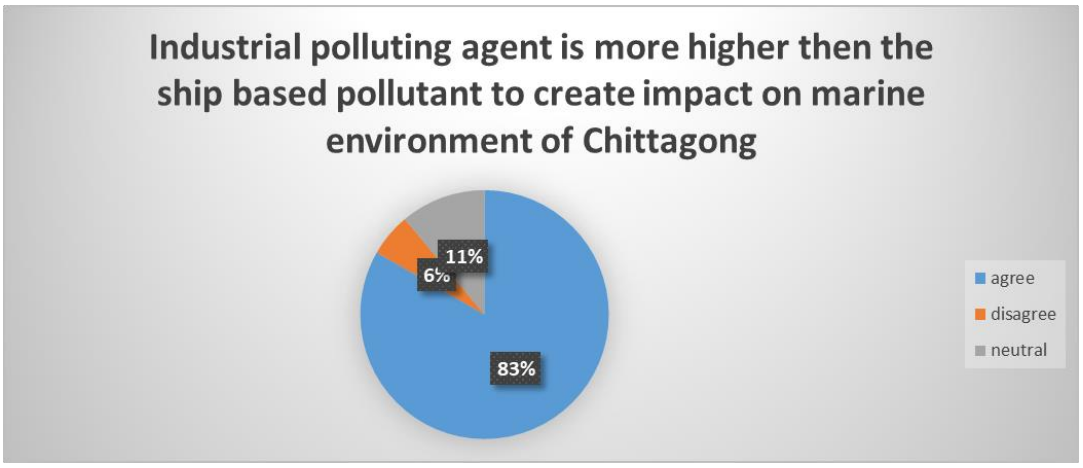
Figure 4 : Effluent discharge from KUFCO

Photo Source: researcher

C. Textile industry

The textile industry is the most significant contributor in our national economy, encompassing both small and large-scale operations worldwide. This industry providing 45% of industrial manpower with employment. More than 4 million people of our country are associated to these industries. Because Chittagong is the heart of countries economy most of the textile industries are situated in Chittagong city and which are also discharging their waste as other industries. About 26 textile mills are located in the coastal zone of Chittagong (Rahman, 2006) Though the industry is a significant contributor The manufacturing process generates a significant amount of waste that is associated with environmental problems like water body pollution by the discharging of untreated effluents, air emission, notably Volatile Organic Compounds (VOC)'s and excessive noise or odor as well as workspace safety. During every stage of production different types of chemicals are used for improving the product quality.

Figure 5 : pie chart showing respondent response on industrial pollution impact in Chittagong



Source: Compiled by the researcher

Pollution from domestic activities

Water is needed for various types of domestic activities. In everyday life, people produce different kinds of wastes. For example, sewage, waste water from cooking and cleaning activities; use of organic materials to inorganic chemicals, plastics, bottles, packages, etc. Usually, people from urban and rural side dump the household wastes in the nearby water sources and all these gradually flows into river that leads to marine pollution. Due to the growth of population and increasing unplanned urbanization, the amount of discharge of wastes from households is high and increasing. Deficient collection system & inadequate disposal practices increasing pollution rate in Chittagong. The port city of six million people produces 2500 tons of waste every day, which is dumped under the open. Generally, the domestic sewages are stored in large septic tanks. After collecting these sewage discharges into the nearby water sources. The Chaktai Khal originates from the Baizid Bostami and Chittagong cantonment area and travels most of the areas of the city and finally falls into the Karnaphuli River. It receives all types of waste materials and effluent from small industries, factories, domestic and municipal users and markets. Public toilet outlets are directly connected with this canal in most of the areas. Wastes from the medical college clinic, hospital, and slaughterhouses discharge into the vicinity of Karnaphuli.

Agriculture and Forestry Pollutants

Agricultural pollutants include fertilizers, wastage of animals, pesticides, insecticides, and sediments. Nitrogenous and phosphoric compounds and organic compounds in chemical pesticides like DDT are the main substances of modern agriculture that contribute to the pollution of the marine environment. Accumulation of agrochemicals in surface water and groundwater is still limited, as their use, apart from urea, is still comparatively low in Bangladesh.

Siltation and sedimentation

The silt load carried by the river systems of Bangladesh is greater than that of any other river system in the world. As the silt-laden waters enter the estuaries, a brackish water interface is formed, slowing the flow of the streams and causing silt to be deposited along channel banks and on mud islands in the estuary. Sometimes deposition is temporary, because of changing river currents. Due to siltation, the carrying capacity of a river decreases as a result there will be an overflow of water or resulting in a flood. Siltation is a blessing for the farmers, but a curse for navigation along the rivers.

Illegal infrastructure

According to a district administration survey, there are a large number of 2181 illegal structures along the Karnaphuli river banks was found by following an earlier order by the Court. Tin-shed houses and concrete structure builds and filling up the banks of Karnaphuli River at Bakolia in Chittagong. People living on this side drastically discharge different waste into the river water. If conscious efforts are not made to stop illegal encroachment on its banks and to do away with the unhealthy practice of treating the river as the dumping ground .Slowly the river will lose its beauty and will become a garbage dump.

This chapter has identified and classified relevant pollution problems and issues. It reveals that the problems and issues faced by Chittagong coastal area due to marine pollution, which are multi-faced and complex in some instances. From a legal point of view, no guidance and frameworks have been provided to control or avoid significant damages. However, competing interests are creating difficulties in cooperation for the common purpose of protecting our coastal valuable resources. Scientific, economic, and legal problems need confronting to control this pollution source.

The possible impact of marine pollution on Chittagong coastal area

The coastal zone of Chittagong contains several ecosystems like wildlife sanctuaries, reserve forest, eco-park, Halda river (natural breading zone of fish and crab), Parki beach (a sanctuary for red crab), mangrove forest, and a lot of beaches that have important conservation values. But marine pollution creates an extensive effect on the esoteric value of beaches, marine flora and fauna, and the entire ecology of the coastal environment. Drastically discharge of hot effluents, untreated sewage, oil spills, plastics, and other forms of debris into our coastal aquatic environment is quite common off the coasts of and major industrialized cities of Chittagong

Effect from fishing net and marine litter

The UN General Assembly resolutions provide a mandate for and indeed require action to reduce ALDFG's (Abandoned, lost, or otherwise discarded fishing gear) and marine debris in general. Causes of fishing gear to be abandoned, lost, or otherwise discarded may be intentional and some unintentional. It has numerous factors like adverse weather; operational fishing factors including the cost of gear retrieval; gear conflicts; illegal, unregulated, and unreported (IUU) fishing, poor grounding, etc. (Macfadyen et al., 2009)Beside Bangladesh became the first country in the world to ban thinner plastic bags in 2002. However, after 18 years, it appears that the ban is not truly came into force. People are using polythene especially single-use plastics and disposing it everywhere. The Government of Bangladesh took the initiative to decrease the use of plastics through enacting the 'Mandatory Jute Packaging Act, 2010'. The unfortunate issue is that since plastic bags are cheaper than jute bags, so using polythene is still running and contributing to marine litter. This litter comes from shoreline and recreational activities, local and smoking-related activities, ocean/waterway activities, waste dumping, and medical or personal hygiene products and the impact of the factors include:

- Continuously catch target and non-target species;
- Interacts with threatened or endangered species;
- Degrade benthic life;
- Micro plastic affects many species, including seabirds, marine mammals and fish through entanglement and ingestion, and humans when the micro plastic enters the food chain causes cancer to human beings.
- Creates navigational hazards
- Disrupts amenity of beaches and other coastal tourist areas, Irritated tourists, swimmers or divers, Money spent for cleaning purposes.

Figure 6 : boys collecting plastics bollte from the shoreline of karnafully for sale

Photo Source: researcher

Habitat Loss

Pollution, subsidence, sea-level rise, infrastructure development that alter sediment flow and contribute to coastal habitat loss. Wetlands and shorelines are becoming more vulnerable due to soil erosion, seawater entering into the freshwater environments, causing floods, water quality is being degraded, human and wildlife lost their habitat and also losing huge mangrove forests. Human disturbances and environmental change like overfishing, coral bleaching are also causes of harm to coral reefs which is the hotspot for aquatic life. The coastal population also face economic and social impact because of coastal erosion. They continuously move their habitation and also change their social behavior with others.

Effect from oil spill and chemical

Most of the time conspicuous effects of oil spills are apparent among larger species of wildlife, like marine mammals, seabirds, crabs, mollusks, and other water organisms. Oil spills are exposed directly to aquatic and coastal wildlife and suffer immediate health problems such as skin irritation, altering of the immune system, reproductive or developmental damage, liver disease, neurological effects (headache, dizziness), etc. through ingestion, absorption, and inhalation. People who had worked in cleaning up the spill had twice as much mercury in their urine than normal levels. Oil spill in Karnaphuli River is also the biggest threat for Ganges river dolphin which use this area as a breading zone. The WWF reports that the essentially blind cetaceans are heavily affected and majority of them are likely to have lost their eyesight due to pollution in their home waters. In the reports of AFP, at least 20 dolphins in the last four years have died of unnatural causes including pollution in the river and in the adjacent Halda River (Eco Watch, 2019).People live in places where the actual oil spill have occurred can be affected by indirect exposure to oil spill by using contaminated water like bathing, swimming, or using household activities and by eating contaminated food. Toxic substances generated by shipbreaking activities pollute the seawater causing harm in the coastal area of Chittagong. 21 species of marine fish in the Bay of Bengal have been depleted from Bangladesh water body Due to this reason. According to several surveys, the marine fishes including Aspisoa Katamach, Nemipscol, Dora Barilla, Foton, Kala Poa, Chapter, Grunti, Kala Taille, Nandi Barilla, Kathu Baillah, Koiputi, Price, Lamba Kukur Jib, Kala, Dosa Chau, Chika, Lohamuri, Bungda, Tiktiki are decreasing day by day. In 2007 a dead blue whale was found at Kattali Sea beach. Another dead Bryde's whale was also found on Kolkata beach in 2018. The marine scientist said due to toxic elements several marine species faced the danger that was released from different ships, scrapping

yards, agriculture, and different industrial sources. Chemical pollutants also contribute to global warming by human activities. Carbon dioxide, methane, nitrous oxide, and fluorinated gases, Methane and nitrous oxide are released mostly through agricultural and industrial activities.

Figure 7 : oil spill in Karnaphuli from ship

Photo Source: researcher

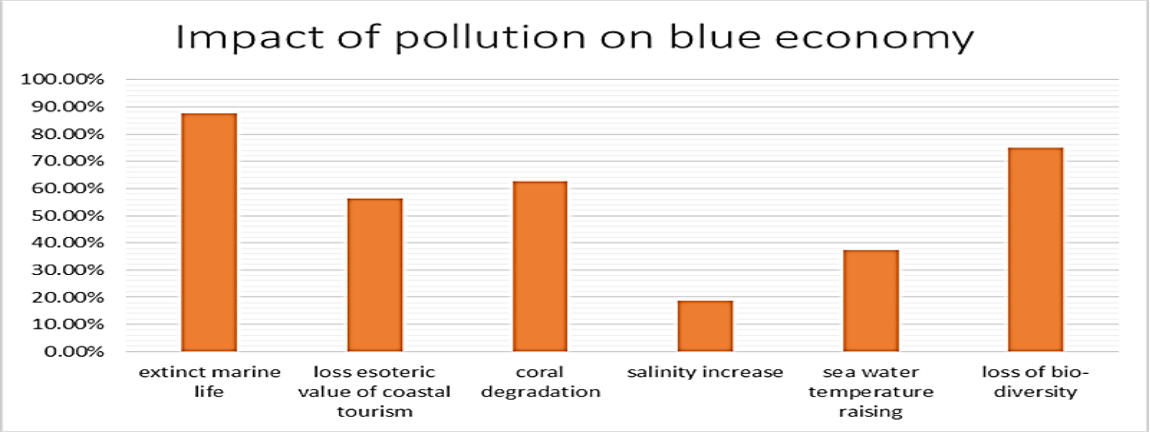
Losing aesthetic value of beaches

Aesthetics values do not deal with a health hazard that directly or indirectly affects wellbeing. World Health Organization (WHO) defines the effect of losing amenity value of marine and riverine environments conclude loss of local, national and international tourist; damage to leisure or tourism center and infrastructure; damage tourism based commercial activities; damage fishery based activities; and damage to the image of a resort. Chittagong is an area of beaches. A lot of beaches are found in the different areas of greater Chittagong. Most of the domestic tourist visit all these beaches every day. Various polluting agents' likes plastic litter, oil, etc. pollute all these beaches continuously. A clean beach is one of the most important characteristics of a waterside resort sought by visitors. The deposition of coastal debris raises a variety of concerns: risks to marine life, potential human health hazards, and also threats for the economy of coastal communities basically in tourist areas. In extreme cases, people may avoid visiting a beach or tourist area if it is full of the litter with hazardous and unaesthetic items such as sanitary and medical waste.

Losing ecosystem service

Marine and coastal ecosystem-wide range of service to human society. These are: Provisioning service, supporting services, regulating service and Socio-cultural service. The country ecosystem is comprised of fisheries, mangroves, beaches, coral ecosystems, plankton, sea grass, and sea-weeds that provide a range of provisioning and cultural services. Coastal and marine fishery species are Commercially Important and also an essential source of animal protein, income, and employment, also deserves credit in foreign ex-change earning. People get important provision services from Mangrove ecosystem that also supplies the fish, shrimp, honey, wax, wood, medicinal plants, fodder. Marine provisioning services can also support blue growth areas of aquaculture and blue biotechnology. Due to environmental pollution, the coast has already lost a lot of marine species including fishes and mangrove forest. Coastal deforestation, degradation, beach pollution, and other pollution source losing ecosystem service which is part of the blue economy. This pollution affects the total economy of the whole country.

Table 3 : Bar chart showing response on impact of marine pollution on blue economy of Bangladesh

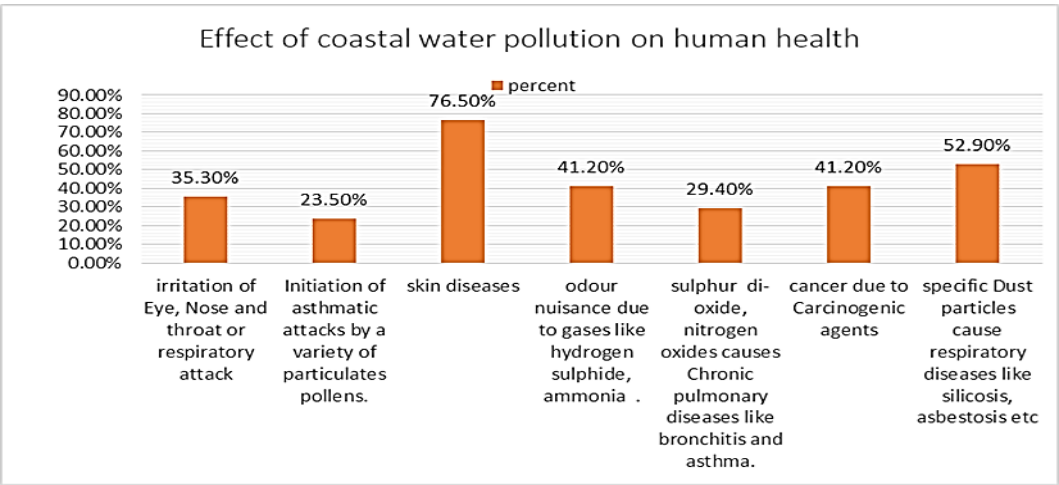


Source: compiled by researcher

Impact on human health

People can directly affected by marine litter in the form of physical damage, for an example injury from broken glass, medical waste or entanglement in floating or submerged debris. Chemicals, toxins or other harmful particles such as viruses or bacteria in the water can causes indirect health impact e.g. Medical waste like as syringes, bandages, etc. and sewage pose a serious health hazard through transmission of infectious diseases. Marine pollution also affected People's livelihoods. For example, polluted water and beaches does not attract tourists. As a result is create impact on the income for coastal communities. Micro Plastic have been found in a wide variety of marine species. That causes risk of chemicals adhered to plastics transferring through the food chain from marine organisms to humans. People lives in coastal area also affected by household activities for an example, taking bath in contaminated water or use water in cleaning purposes.

Table 4 : Bar chart showing response on pollution impact of human health in Chittagong



Source: compiled by researcher

Suggestive Strategies to mitigate marine pollution

Aims to pollution prevention

aims of Pollution prevention is the initial stage at the reduction of pollution from lower to high level of the source to achieve a pollution-free environment. It leads to fostering a safe environment. The previous chapter shows that pollution comes from various source create the harmful effect in the coastal area of Chittagong.it also affected economically benefited areas for example natural breeding zone for fisheries, the tourism sector as well as ecosystem service.

Introducing green tax

Sustainable Green development is a broad approach to maintain a balance in the development of the country and ensure social, economic, and environmental prosperity for the human. It can be able to reduce the impacts of climate change in Bangladesh. The green tax or eco-tax or environmental tax is an initiative to ensure green development which helps to avoid hazardous production systems. It is important to introduce a green tax from the local level. Identifying the main source of pollution, its impact on the environment, and imposing an eco-tax is a good step for the country's economy and environmental safety. Bangladesh government has also emphasized the green development to minimize the negative impacts of climate change and also introduce a new "green tax" in the budget of 2014/2015 against factories that produce high levels of pollution. But it is essential to provide a green tax at every point where the pollution generates. The government can also impose green tax on tourism to protect natural beauty .it is true that a green tax makes our blue economy more sustainable and also help the country to achieve SDGs 14. Moreover, green tax measure ensure green growth in the country and increasing employment opportunities, reduce environmental pollution, sustainable use of resources, correct management of waste, and generate renewable energy.

Increasing safety culture practice onboard ships

To prevent accidents on ships, the international maritime organization has declared that, from 1st July 2002, made the ISM code is mandatory for all commercial ocean-going ships and yachts which has greater than 500 Gross Tonnage, to provide an international standard for the safe management and operation of ships and the prevention of pollution. But several recent incidents suggested that the absence of a fully implemented 'Safety Culture' onboard ships is still a problem. Such a culture is not fully maintained by the ship's crew. They are less willing to inform the company or a captain about their errors and other safety problems because they are afraid of being punished or prosecuted. As a result Managers and captains are not capable to make the proper decisions to improve safety. This problem can be minimized by adopting a just culture that encourages and rewards people even providing a guarantee for confidentiality. It is an important issue that companies should provide training and information to the employee about their approach to adopting a 'just culture'

Installation of new technologies

1. Controlling oil spill

If an oil spill occurs and spreads quickly, it is essential to clean up the spill as quickly as possible to minimize danger and damage to persons, property, and the environment. Oil spill causes evaporation, dissolution, emulsification, and oxidation and also causes bio-degradation. To combat oil spills different types of Containment, equipment is used to restrict the spreading oil based on the quantity, type, and spreading area. In order to effectively maintain and recover the

effect of spilled oil different developing countries have response teams, with a variety of equipment both surface and airborne. Some features are oil Containment boom, Skimmers, Absorbents Dispersant and spraying system, etc. By installing such updated technology country can save the environment from accidental oil pollution.

2. Reducing plastics pollution

The Government of Bangladesh took the initiative to decrease the use of plastics through enacting the 'Mandatory Jute Packaging Act, 2010'. The unfortunate issue is that since plastic bags are cheaper than jute bags, so using polythene is still running and contributing to marine litter. Although people are not maintaining any rules and regulations in our country. In European countries like Norway, they use block chain technology for reducing plastic pollution from the beach area. This technology aims to reduce plastics by recycling stations that provide an incentive to people who deposit plastic waste picked up from the beaches. The financial incentive can be an efficient approach for waste collection in our country.

Increasing environmental knowledge and awareness

Starting education about the dangers of marine pollution is extremely necessary for us. By receiving education people can apply the right attitudes when dealing with the environment. It can be started by the integration of environmental education in the curriculum of all school levels. Educational activities get the people informed and help to protect the environment and this should be encouraged. It helps to enhance critical thinking, problem-solving, and effective decision-making skills and can help in protecting the environment. Awareness-raising activities, the campaign about environmental awareness can help people to know about their activities which contribute to pollution. Another thing is that supporting, appreciating, and rewarding people for not doing any harmful act can help in the awareness generate program. Besides, environmental education and awareness programs can improve an esthetic sense of an individual.

Stakeholder engagement

To achieve a successful marine and coastal resources observing network different stakeholder engagement is necessary. Such as managers, policy-makers, civil society, general scientists and specialists, marine service providers and geo-spatial technology stakeholders. Stakeholder engagement and communication are difficult to achieve sustained funding and actually reap the advantages of integration and joint prioritization in the field of marine and coastal observation. Stakeholders can play a basic role in building, evolving, and sustaining integrated resource management systems. Stakeholders and users should be identified for managing the resources sustainably. Ultimately, by engaging all stakeholders and creating successful partnerships it is possible to improve economic, societal, and environmental benefits from sustained integrated marine and coastal resources observing systems.

Implementing and strict the existing laws

If we go back in 2015, the UN general assembly adopted the 2030 Agenda for Sustainable Development, which aims also include "prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution" by 2025.But the concern is that this goal seems very difficult to achieve in our country, because waste management systems and the relevant legislation are very slack. If this pollution continues, it will certainly destroy the total coastal and marine ecosystem, imbalance, and hinder sustainable development. For the survival of human and sustainable development, it is time to comply with the duty to protect the marine environment and adopt and strict laws and regulations to prevent, reduce, and control pollution. Some of the laws concerning marine pollution were acted a lot of years ago and have not been updated yet. Lack of comprehensive marine environment laws in Bangladesh, there has been limited success in preventing and controlling marine

pollution. The government should give concentrate on existing regulations and think forward to implement new laws against marine pollution.

Adaptive Management

Adaptive management is a systematic approach to learn by doing the process. It a tool which not only used to change a system but also to learn about the system. Because adaptive management is based on a learning process, it allows the identification of new research and information which can improve the next round of Management and give long-run management outcomes. Through adaptive management, Coastal and Ocean management programs should be designed to meet clear goals and help to provide new information to improve them for future management. It helps to identify more effective measures for controlling marine pollution and achieve the planned objective.

Cross boarder coordination

Finally a cross-border approach is too much essential to address common environmental challenges because natural resources, such as the sea, have no boundaries, and pollution reduction cannot fully minimize by a single country to the desired improvements in environmental protection. The crucial step will reduce the risks of marine pollution from hazardous waste, these are joint cross-border strategies that will integrate the law on the use of technologies in the cleaning of water and waste management. Cross-border cooperation allows to exchange of knowledge and best practices between their partnering countries. By using new technologies, cross-border cooperation will help to know another country about the growth of the area's competitiveness, for superior environmental quality.

Conclusion and Recommendation

This study has discussed the possible impact of pollution in coastal areas of Chittagong which create impact on fisheries, habitat destruction, chemical reaction on human body and food chain, losing aesthetic value of beaches and affect tourism activities, as well as entire economy. For this reason, effective solution must be needed which require a substantial financial investment and time. Immediate actions are needed to overcome the situation on an emergency basis. Government bodies, agencies, international organizations and NGO's should give their attention to mitigate the coastal pollution. Establishing measures for reduction of pollution form coastal areas is needed coordination of the many related agencies and programs to effectively target the various laws, programs, funds, training, technical assistance, incentives, and different management tools to address source pollution of coastal waters. Ongoing monitoring assessment is vital to assess the health of marine and coastal ecosystems and detect changes over time. This study will, therefore, seek to analyze the vulnerabilities and risk of the coastal area and suggest adopting appropriate measures for mitigation and management of coastal environmental pollution by the extent of creating awareness among the public and authorities about the threat of marine pollution.

The areas of recommendation may be summarized as follows:

1. The government should immediately start to charge fines for damaging ecosystem and also the "polluter pays" principle for the defaulter to pay for all the cleanup and compensation to all affected people.
2. The Chittagong Port Authority must assess the economic and environmental impact of marine pollution and establish an effective monitoring system. It should be better understood to prioritize and inform changes in pollution control policies.

3. Picking up plastics or marine litter is an easy solution to reduce pollution on our beaches. The Chittagong City Corporation should adopt a liter control policy and give the responsibility to the private agency for the weekly marine litter cleanup campaign.

4. Rising public awareness through television, radio, social media, and website can help to introduce the public to the impact of pollution, reduce the improper disposal of waste, and develop innovative approaches to reduce marine pollution. The Ministry of Shipping can carry out workshops with the participation of scientists, environmental specialists and professionals in marine sector to define the potential solutions of marine pollution.

5. All ports should have waste reception facilities for the disposal of ship borne waste and enhance ship monitoring system aid for surveillance. The Port authorities of Chittagong, Mongla and Payra should establish such facilities immediately.

6. The Government should obtain International support for the installation of new technology and increase cross border cooperation in the context of marine pollution.

7. The Ministry of Shipping should give urgent emphasis to review the legal and regulatory instruments and standards in place for dealing with ship source and land-based pollution.

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Regional variability of precipitation over the Bay of Bengal and its response to the climatic indices

Abstract

Very often the Bay of Bengal (BoB) and its surrounding countries experience heavy precipitation that causes enormous loss of property and results in coastal flooding. Phenomena like the El-Niño-Southern Oscillation (ENSO), Land-Ocean Temperature Index (LOTI), and Indian Ocean Dipole (IOD) regulate the climate of the Indian Ocean (IO) rim and the entire globe. The basin-scale strong warming (1–2°C) is normally amplified by the locally supplied wind-driven moisture causing rainfall from the westward extension of the Indian Ocean warm-pool region while salinity does not influence the rainfall directly. The study focused on the correlation patterns of precipitation over the BoB showing the impact of El Niño, LOTI, and IOD events between 1993-2018. The present study also contradicts the findings of increasing trends of precipitation due to climate change. A good association of El-Niño with positive IOD events and negative precipitation anomalies was noticed. Besides, negative precipitation anomalies during positive El-Niño phases can be explained with the positive latent heat flux, driven by atmospheric forcing. Eventually, the atmospheric circulations are supposed to be strongly connected to the incidence of rainfall.

Keywords: Precipitation, temperature, climatic indices, Indian Ocean Dipole, Bay of Bengal

1. Introduction

The Bay of Bengal (BoB) is situated within the northern Indian Ocean (NIO), a semi-enclosed basin at the north of 5-23° N latitude; its maximum zonal length is about 1200 km, where the eastern boundary touches the equator (Shetye et al., 1996). The BoB is an interesting and dynamic area as wind patterns changed with the Indian Monsoon (Potemra et al., 1991), which is a semi-annually reversing wind system (Narvekar & Prasanna Kumar, 2006). The winter monsoon (November to February) is characterized by the weak (~5 m/s) and north-easterlies wind system. These winds bring dry and cool continental air to the present semi-enclosed tropical basin. From June to September the winds become strong (~10 m/s) and from the southwest which brings humid air into this basin (Narvekar & Prasanna Kumar, 2006). The northern part of the bay maintains a warm sea surface temperature (SST) >28 ºC, throughout the summer or southwest monsoon (SWM). Vinayachandran and Shetye (1991) reported favourable conditions for the development of several low-pressure systems in this area. The maintenance of this warmer SST in the BoB has been assigned to the low salinity cap (Shenoi 2002). Behara and Vinayachandran (2016) showed that runoff leads to a large (>3 PSU) decrease in salinity in the northern bay during summer and along the western boundary during winter due to weaker contribution from rainfall. The sea surface temperature response to freshwater forcing shows large spatial variations with the eastern bay showing higher differences. The north-western bay warms by ~1.5º Celsius in the presence of fresh water during summer because of greater heat absorption within a shallow mixed layer (ML).

The BoB is especially distinguished from the rest of the IO because it receives a large quantity of freshwater from rainfall and huge river discharge. The salinity of the upper layer of the bay is remarkably low because of the enormous freshwater input, which results in strong vertical stratification (Masud-Ul-Alam, et al. 2020). At summer southwest monsoon (SWM), river runoff doubles the surface freshwater input (SWM), into the bay to nearly 183×10^{11} m^3 (Varkey, Murty, and Suryanarayana 1996). Due to the large seasonal freshwater pulse upper layer of this bay is a smaller amount of saline and stratified (Masud-Ul-Alam, Khan, Islam, et al. 2020). A powerful humidity horizontal convergence causes much more precipitation over the bay and nearby land (Yamanaka, 2014). That makes the north and north-eastern side

fresher (Benshila et al., 2014), about less than 33 practical salinity unit (PSU), while the subsurface water is much saltier (33 to 34.5 PSU) (Yamanaka, 2014).

The inter-tropical convergence zone (ITCZ) is a semi-permanent feature over the IO during moderate to active monsoon conditions. In the pre-monsoon season, i.e., March–April–May, there is a shift of ITCZ to the north from the equator. The Indian summer monsoon trough can be considered as a large-scale cyclonic vorticity pattern which is extending from the northern BoB to the western part of India (Rao 1976). This monsoon trough expands in May over the BoB. The associated rainfall in the course of the monsoon season depends on the strength of the monsoon trough. Generally, March–April–May is the climatological hottest period in the South Asian region (Choudhury, Nath, and Chen 2019). Choudhury, Nath, and Chen (2019) found that a significant increase in rainfall over the BoB, and it is linked to the strengthening of local Hadley circulation. Besides, these atmospheric circulations which are strongly corresponding with the occurrence of rainfall in the tropical and subtropical regions. Over the Indian subcontinent, a transition from hot and dry pre-monsoon season to wet monsoon season occurs because of the changes in large-scale circulations. Apart from this, the strengthening of the westerly enhances the wind speed and transports more moisture to the NIO. In consequence, recent year's El Niño effects on lower rainfall, warmer temperature drier climate and higher cyclone activities have been observed. Goswami et al. (2006) revealed that, though seasonal mean monsoon rainfall remains stable, the frequency of extreme rainfall events has increased, meanwhile, the frequency of moderate rainfall events has decreased in the latter half of the twentieth century. Sathiyamoorthy, Shukla, and Pal (2010) found that rainfall has increased over the pre-monsoon rainfall belts of the BoB and Southeast Arabian Sea (SEA) during May. It has possibly caused more rain by enhancing the meridional pressure gradient. Rainfall has a much larger spread, but causes a smaller decrease in salinity.

The BoB faces various impacts by El Niño and La Niña events and already has affected Bangladesh in that context. As a result, precarious drought, acute rainfall, unusually warm, sea surface temperature increase, cyclones, and other notorious natural disasters, land erosion, salinity intrusion, and loss in biodiversity are occurring frequently (Islam and Parvez 2020). Lack of in-situ dataset and infrequency of research cruises make the BoB a data deficit region, which urges researchers to utilize satellite or remotely sensed datasets to interpret the existing oceanic and atmospheric phenomena in this region (Mili et al. 2021; Masud-Ul-Alam, Khan, Sunny, et al. 2020). A basic aim of this paper is to propose the indices that provide simple measures of the climate variation in the BoB. Because of the large correlation between tropical oceanic and atmospheric circulations, our indices are based upon SST and precipitation analyses. Therefore, this study also aims at the spatial and temporal variability of the aforementioned parameters in the regional aspects. Thus, this research will be helpful to study the regional climate dynamics influencing droughts, floods, extreme rainfall events, etc. experienced by the land masses, especially situated in the periphery of the BoB.

2. Data and Methods

2.1 Data Sources

Satellite-derived precipitation, which was obtained from Climate Prediction Center (CPC) Merged Analysis of Precipitation data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA through the website: [https://psl.noaa.gov/data/gridded/data.cmap.html]. The enhanced file also includes blended NCEP/NCAR Reanalysis Precipitation values (Xie, P., 1997). Level 4 global ocean Operational SST and Ice Analysis (OSTIA) datasets were obtained from Hall et al. (2021) and through Copernicus Marine Environment Monitoring Service (CMEMS) site (https://resources.marine.copernicus.eu/). CMEMS SST reprocessed (level 4) product over the global ocean, which was processed at the Met Office (UK). The OSTIA (Good et al. 2020) reprocessed analysis product is a satellite and in-situ foundation SST analysis

(free from diurnal variability) created by the OSTIA system using re-processed ESA SST CCI, C3S (Merchant et al. 2019). EUMETSAT and REMSS satellite data and in situ data from the HadIOD dataset (Atkinson et al. 2014). The product is available from October 1981 on a global regular grid at 0.05° resolution. It is extended twice-yearly in January and July to the previous June and December respectively. Additionally, multi-observation 0.25°, level 4 SSS data were downloaded similarly through CMEMS the website. The dataset incorporated multi-year reprocessing with global ocean ARMOR3D L4 analysis, developed by CLS Production Unit (Guinehut et al. 2012; Mulet et al. 2012). Daily zonal (u) and Meridional (v) wind speed, within the NCEP Reanalysis data has been retrieved from NOAA National Centre for Environmental Prediction, USA [https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.pressure.html]. Temporal coverage of data encompasses long-term monthly means, derived from the dataset between 1948 to present. Spatial coverage of original data has a global grid of 2.5° from 0.0°E to 357.5°E, 90.0°N to 90.0°S, here we extracted dataset for 80-100°E and 5-25°N only (Kalnay et al. 1996).

Monthly Niño 3.4 indices were retrieved from NOAA Physical Sciences Laboratory (PSL) [https://psl.noaa.gov/gcos_wgsp/Timeseries/Nino34/] which was calculated from the HadISST1 (Rayner et al. 2003). The intensity of the IOD is presented by an anomalous SST gradient between the western and the south-eastern equatorial IO. This gradient is known as Dipole Mode Index (DMI). This was also collected from PSL [https://psl.noaa.gov/gcos_wgsp/Timeseries/DMI/] and calculated using the HadISST1.1 (Saji and Yamagata 2003). Spatial plots are used for spatial analyses. In addition, temporal plots indicate time series and long-term analysis. For correlating some climatic events we showed some cross-wavelet plots. They are derived from simple calculations.

2.2 Calculation

SST data were primarily daily (°F); these were converted to monthly (°C). Monthly climatology data were averaged from 1979-2021 for precipitation and temperature, salinity datasets were averaged from 1993-2018 using Climate Data Operators (CDO). CDO is a collection of command-line Operators to manipulate and analyses Climate and model Data. By using the Hovmoller diagram seasonality can be explained with latitude and longitude, inferring seasonal variations in the given time and space which disclose a heavy pattern, using Pyferret (7.5), "an Ubuntu-based Python-Ferret module developed jointly by the National Oceanic and Atmospheric Administration (NOAA) and the Pacific Marine Environmental Laboratory (PMEL)". Time series plots of anomalies and indices calculated from atmospheric or oceanic data can provide a useful technique for describing climatic variability. Servain (1991) claimed a well-known example is a difference between the sea level pressures at Tahiti and Darwin, which is widely used as an index of the Southern Oscillation (SO). The paper is discussed about SST (Sea Surface Temperature) anomalies in the BoB and compares them with precipitation events over LOTI and E1 Niño occurrences. We also used R, a programming environment for statistical computing (R Core Team, 2019), for Wavelet analysis. Following Torrence, Christopher, (1998) methods, cross wavelet power of the two time-series which contains background power spectra P_K^X, P_K^Y was calculated from this equation (1):

$$D = \frac{Zv(P)}{v}\sqrt{P_K^X P_K^Y} \quad (1)$$

where the probability (p) coupled confidence, the level is $Zv(p)$, which is 95% for the square-root of the product-defined probability density function (pdf) of two distributions. Wavelet coherence (WC) in a time-frequency was computed with S which is being the smoothing operator (equation 2):

$$R_n^2(s) = \frac{|S\left(s^{-1}W_n^{XY}(s)\right)|^2}{S\left(s^{-1}W_n^X(s)\right).S\left(s^{-1}W_n^Y(s)\right)} \quad (2)$$

All calculations for the wavelet analysis between time series of precipitation and climatic events were carried out through a bi-wavelet package (Tarik C, Grinsted A 2019) in R programming.

3. Results

3.1 Spatial Distribution of Seasonal Precipitation

The most precipitation occurring north of 12°N at the central and eastern part during the summer monsoon in the BoB up to 14 mm/day (Fig 1). The seasonal maximum in precipitation at the end of the spring monsoon coincides with the noted that in summer freshening the northern BoB. Less precipitation occurred in the spring monsoon, whereas moderate rainfall in winter and fall monsoon, which are 10-11 mm/day. Although there have been studies to examine the long-term pattern of precipitation over the years

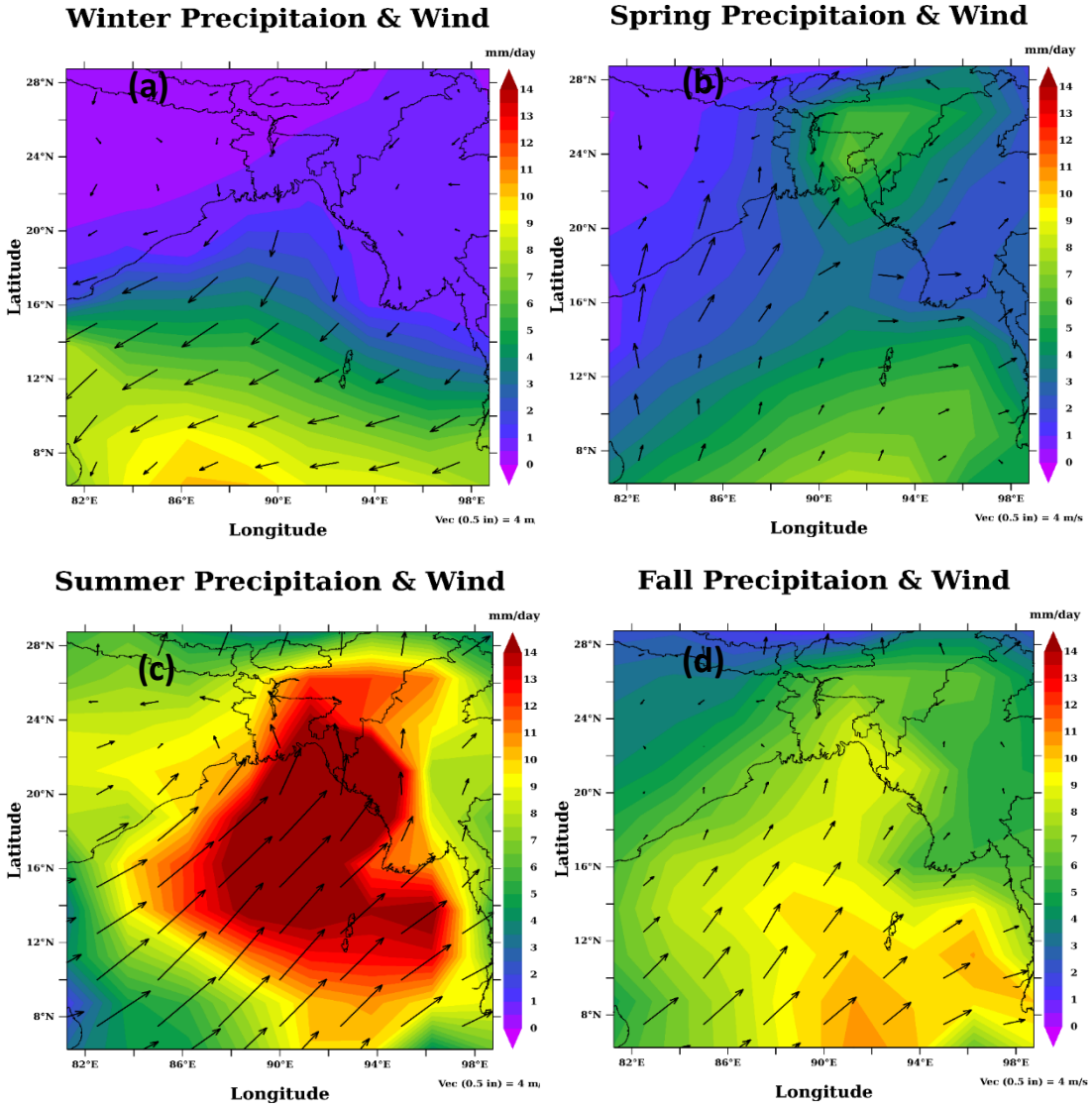


Figure 1: Seasonal climatology (1979–2021) of precipitation (mm/day) and wind (m/s) in Winter (a), Spring (b), Fall (c), and Summer (d), illustrating changes in the concentration throughout the four seasons. Red color indicates the higher concentrations,& the lower concentrations denoted by purple.

in the BoB, we found there was a slight increase in recent years.

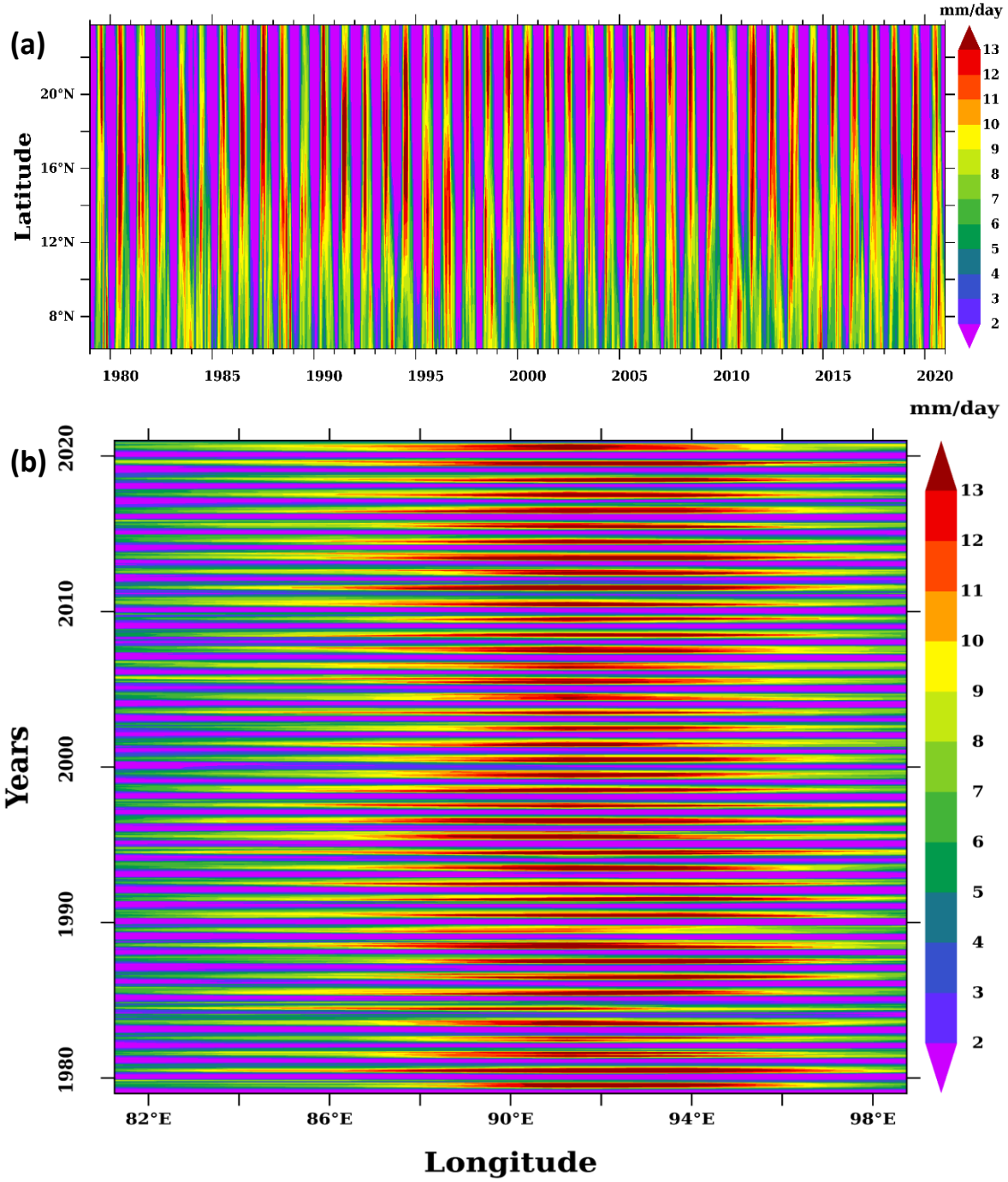


Figure 2: Hovmöller plot of precipitation showing latitudinal (a) and longitudinal (b) variation in the Bay of Bengal over the study year (1979-2021).

Latitude versus years and longitude versus years' diagram, also known as Hovmöller diagram were plotted to depict the spatial variations of precipitation throughout the years. The latitudinal plot revealed that areas from 12°N to 20°N faced more than 12 mm/day rainfall until 1996. Heavy precipitation regions reduced between 18°N to 26°N. This rainfall deficit persisted from 1997 to 2005. However, an extended spatial pattern with higher rainfall is noticed once again from 2006 to the present. On the contrary, the longitude versus years' precipitation plot did not contain as much variation as its latitudinal counterpart since most of the high rainfall zones ranged between 89°E to 96°E. Nevertheless, the only exception was noticed

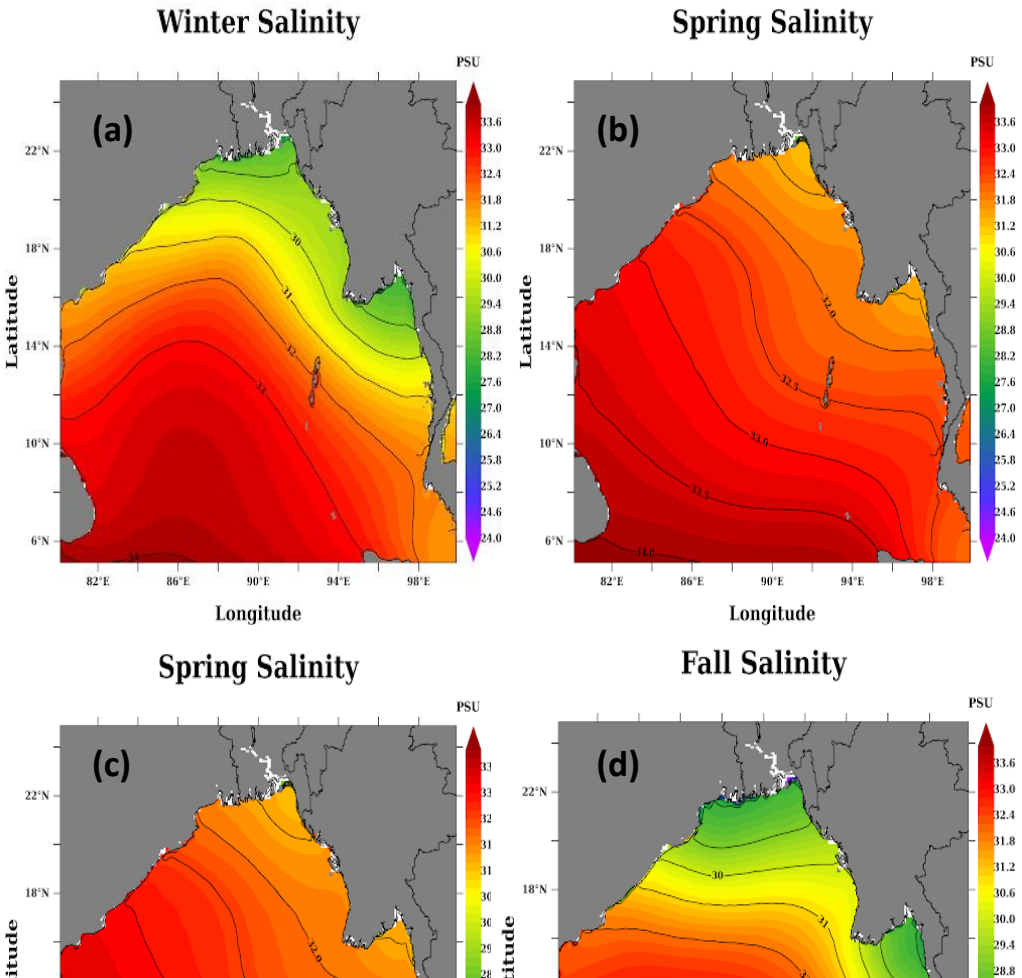
between 1983 and 2011. These two displayed a very insignificant extent of precipitation (13 mm/day), compared to other years.

3.2 Seasonal Wind Pattern

This research suggested that the southward flowing EICC in November–December–January could help transport the freshwater plume southward along India's western coast. Over the summer monsoon, abundant rainfall, except for the western portion, refreshes the upper layers of the Bay, surface layer becomes highly stratified. The BoB weaker winds are unable to erode the highly stratified surface layer, limiting turbulent wind-driven vertical mixing. Wind-driven circulation is critical in deciding the path of fresh water in the BoB. During the monsoon, lateral advection of low salinity waters from the northern BoB. Annually reversing winds blow from the southwest during the summer monsoon (May–September) and from the northeast during the winter monsoon (November–March), forcing the northern Indian Ocean to change direction.

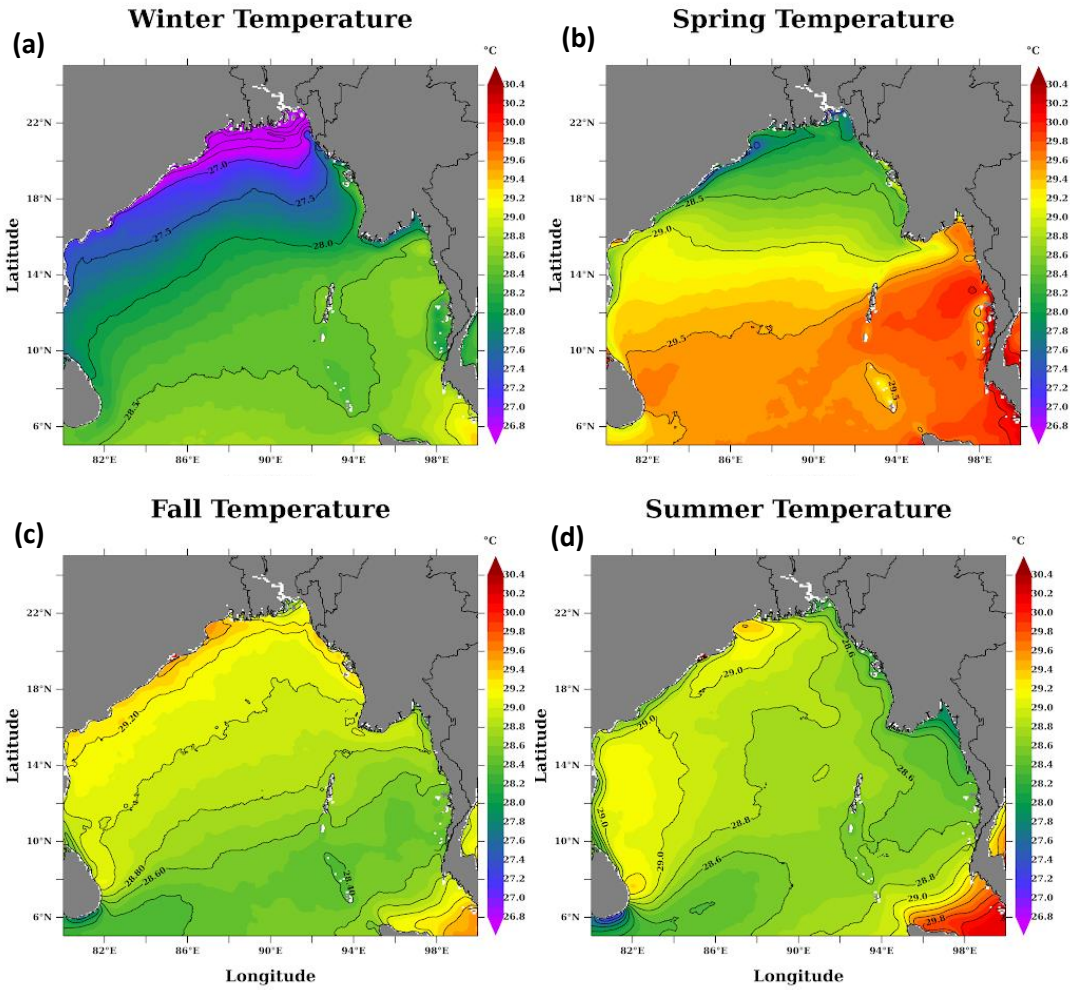
3.3 Salinity Distribution Throughout the Seasons

In the BoB, the SSS displayed a dramatic decline north of 14°N. The distribution of sea surface salinity (SSS) interprets low saline water near the north-eastern bay with an increase towards the south. The lowest salinity was 28 PSU while the highest value was about 34 PSU. Along the eastern and western boundary also the salinity was low (~29-32.5 PSU). The spatial variation of SSS from north to south was about 4 PSU. In the Fall the spatial distribution was similar to that of winter with the lowest salinity of 28 PSU (Fig 4) in the north and the highest salinity of 34 PSU in the south. However, the region of 29 PSU salinity reduced in its spatial extent considerably, compared to winter, and was confined very close to head Bay. The SSS distribution in the summer showed an increase of 1 PSU in the northern bay with the lowest salinity being 30 PSU. In the south, south of 14°N the spatial distribution of SSS was like that of winter. The spatial variation was 4 PSU. In spring the highest salinity occurred, while the northern bay salinity was showed 31 PSU salinity and south part not so changed that of another monsoon.



3.4 Spatial Pattern of Surface Temperature

The spatial distribution of sea surface temperature in the BoB during spring and winter showed a decrease from south to north. Fig. 3 illustrated the lowest SST of 26.8°C was in the north in winter, low salinity remains all over the basin. The highest temperature occurred in the spring monsoon, while the highest sea surface temperature of 30°C was near the 9 to 6°N latitude, due to Indo-pacific warm water pool intrusion. The spatial distribution, thus, showed a 1.5°C cooling from south to north over the years. In the Summer and Fall seasons, the temperature pattern was the same. Cold-water intrusion from towards the eastern boundary through the central bay. The spatial distribution of temperature was less, about 1 PSU.



The area with relatively freshwater and high SST appeared to be an excellent breeding ground for the development of monsoon depressions. Monsoon depressions made rainfall to the northern BoB. Sea surface temperature response

Figure 4: Seasonal climatology (1979–2021) of Temperature (°C) in Winter (a), Spring (b), Fall (c), and Summer (d), illustrating changes in the concentration throughout the four seasons. Red indicates the higher concentrations, & the lower concentrations denoted by purple color.

to freshwater forcing varied greatly across the bay, with the eastern bay having the most variation. The rain fell over a wider region but was limited to the surface because of a significant amount of fresh water on a seasonal time scale in the BoB.

3.5 Time Series Anomalies

The monthly time-series of precipitation showed that there was no significant increase in the average rainfall from 1979 to 2021. Nevertheless, some decadal variation in the intensity of the precipitation was observed from the same data. The least rainfall (< 9 mm/day) was evident from 1998 to 2008. Whereas, significantly higher precipitation (13 mm/day) was evident from 1981 to 1991. Anomalies from the precipitation time-series were linked to several climatic indices to explain the variations. In the combined time series of

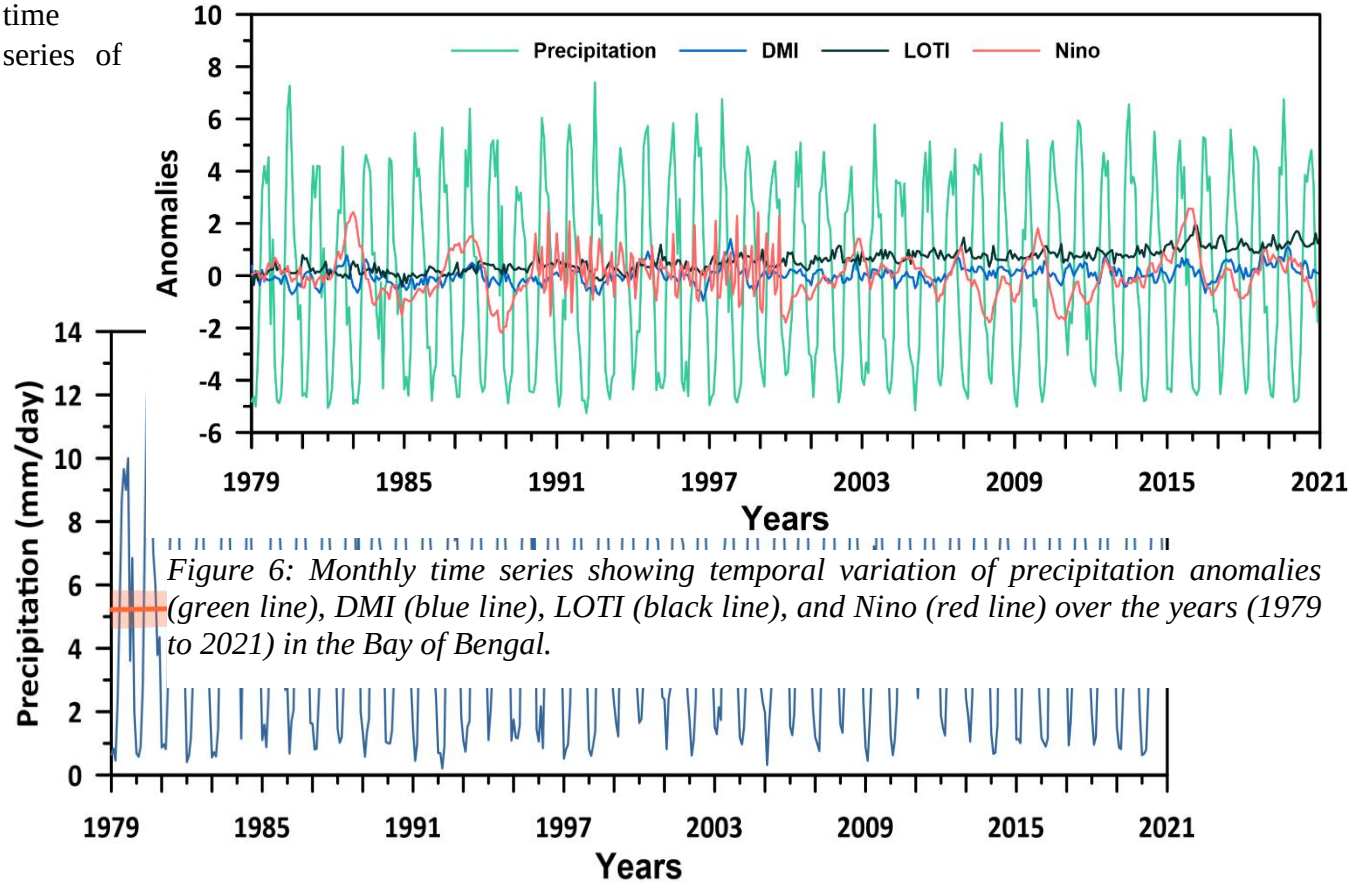


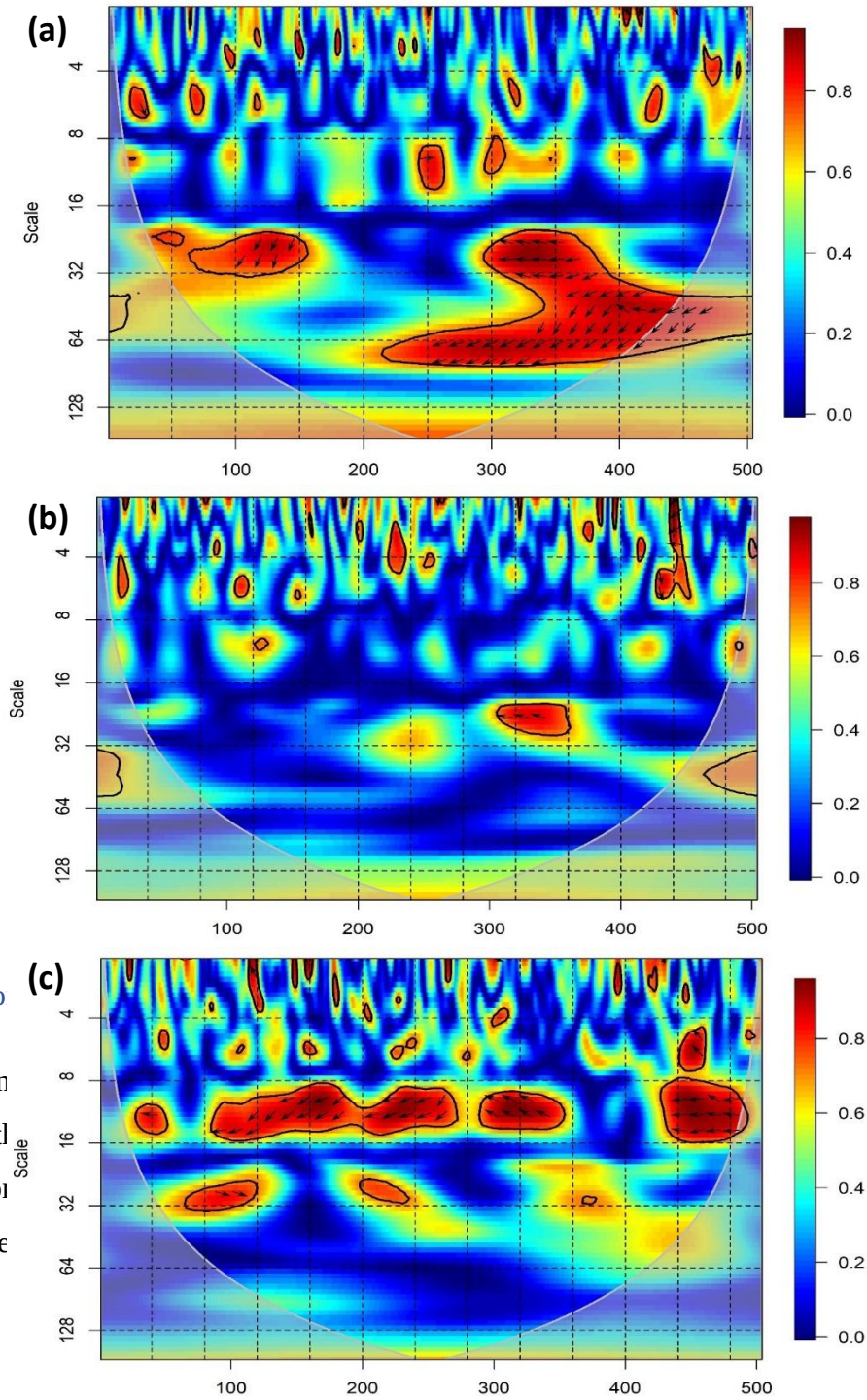
Figure 6: Monthly time series showing temporal variation of precipitation anomalies (green line), DMI (blue line), LOTI (black line), and Nino (red line) over the years (1979 to 2021) in the Bay of Bengal.

Figure 5: Monthly time-series, averaged from 81° E to 99° E and 5° N to 23° N, showing temporal changes in Precipitation over the years. Corresponding p values and equations are illustrated in the monthly time series. Linear method (orange) was used, with 95% confidence level (transparent orange), to draw trend line.

precipitation, DMI, LOTI, Niño, we noticed that precipitation followed the seasonality and had a strong correlation with DMI, Niño, LOTI. There were maximum negative anomalies throughout the years except 1989, and 2021. Most of the El Niño and DMI phases were accompanied by the positive and negative anomaly with negative and positive precipitation anomaly accordingly except the years, which are 2000, 2008, and 2011. LOTI was slightly increased trends in recent years and there were all positive anomalies throughout the years and have a strong correlation with precipitation.

3.6 Wavelet Coherence Between Precipitation and Climatic Indices

Wavelet coherence plot depicted that El Niño led to increased precipitation across the BoB on a decadal scale and they have a strong correlation between them. Annual phase events were found and some monthly events had Niño dominated events were noticed (Fig. 7) in the wavelet coherence analysis. They were survived for 1 year to 2 years. Most events in DMI indices were moderately correlated with precipitation and leads to rainfall for the annual scale. Some events were strongly correlated and existed for 3-4 months. Mostly, LOTI led to precipitation on a seasonal scale, besides, precipitation-controlled consequences on LOTI and anti-phase strong correlation were also well visible. They showed a moderately decadal correlation between them. Most of the events were seen for 4-6 months which indicated the seasonal to sub-seasonal scales. Only one event remained for 20 months' scale which was strongly supported by the inter-annual variability of the signals.



4. Discussio

This study an BoB and its affiliated countries witl he southwest and the northeast mo rrounding landmasses (Salahuddin e ıe BoB, up to 75% of

Figure 7: Wavelet coherence showing correlation between precipitation & Nino3.4 (a),

total annual rainfall (Chanda et al. 2018). While the lesser in magnitude, some parts of the Indian Ocean faces insignificant precipitation from December to February, which is driven by winter or retreating monsoon (Rao 1976). The seasonal pattern obtained from this study agrees with these findings, as the current analysis presented that summer incorporates the heaviest rainfall at the central and the northern BoB. On the contrary, a weaker trend is also perceived. A few of the major controllers of precipitation over the BoB are SST (Caesar et al. 2011), local Hadley circulation over the BoB, land-sea thermal contrast (Choudhury, Nath, and Chen 2019), and linkage with El Niño, La Niña, extreme IOD events (Chanda et al. 2018). Despite several previous types of research indicated global (Dore 2005) and regional (Kayano and Sanságolo 2009) changes in rainfall, results from the current study suggested otherwise as the time series plot revealed that there are no significant changes in precipitation in the BoB region, from 1979 to 2021. The present study also contradicts the findings of increasing trends of precipitation due to climate change in Parry et al. (2007), since a steady increase is yet to be seen in this region. Nevertheless, this article's outcome is in accordance with Goswami et al. (2006) as he mentioned the stability of monsoon rainfall over the latter half of the twentieth century, however, they also added that extreme rainfalls are more frequent than moderate ones.

The seasonal surface plot of SST revealed that summer and spring had a considerable warming, whereas fall and winter contained cooler SST. Patterns that emerged from this study are coerced with the findings of Behara and Vinayachandran (2016). They mentioned a ''plateau-like'' seasonal structure (Vinayachandran and Shetye 1991) where heating took place from February to May and cooling began with the advent of summer then intensified in fall; finally, dropping abruptly in winter. Large-scale fluctuations in surface winds and convection were held responsible, by Vecchi and Harrison (2002), for regulating sub-seasonal SST variability's structure in the BoB. They further reported a basin-scale strong (1–2 °C) warming, amplified by the locally supplied wind-driven moisture from the westward extension of the IO warm pool region. While salinity does not influence the rainfall directly, fresh water added to the ocean surface from the precipitation can fluctuate the SSS pattern. The current study indicated that SSS in the BoB encompassed a southwest-northeast orientation with a smaller extent toward the southwest. Additionally, fall and winter were characterized by the lower salinity especially near the river mouth, whereas spring and summer depicted high saline regions throughout the bay. Such seasonal variation is due to freshwater input by both precipitation and river water influx. Freshening of the eastern portion of the bay is caused by rainfall, which starts in late summer and persists throughout the winter; some impact of this freshening extends to western bay. Nevertheless, withdrawal of summer monsoon is followed by the equatorward flow of the East Indian Coastal Current (EICC) which freshens the BoB. Another reason for freshwater abundance during winter could be a presence of a low salinity plume (made

from the combined effect of rainfall and river discharge) that advected southward (Behara and Vinayachandran 2016).

Table 1. List of the years that incorporated noteworthy variations between precipitation anomalies and their corresponding Niño 3.4, DMI, and LOTI

Year	Precipitation	Niño 3.4	DMI	LOTI
1983	-4.8	+2.6	-0.6	+0.4
1989	+2.2	-2.2	+0.3	+0.3
1991	-5	+2.4	+0.2	+0.4
2000	-3.5	-2	-0.1	+1.1
2003	-4.2	+1	+0.2	+0.8
2008	-4	-2.1	-0.1	+1.3
2010	-4.9	+1.7	+0.3	+1.1
2011	-3	-2	-0.2	+1
2016	-4.8	+2.7	+0.8	+1.8
2021	+4.2	-1.2	-0.2	+1.9

An increase in SST across the tropical Indian Ocean could also be led by El Niño, especially within one season's time gap (Lau and Nath 2003). A propensity of amplified incidence of monsoon depressions is imposed by warm El Niño Southern Oscillation (ENSO), during July–September, in the BoB (Singh, Khan, and Rahman 2001). ENSO is also expected to have links with the Asian summer monsoon's components of inter-annual variations (Singh and Khan 1999). Precipitation El-Niño and DMI time series plotted in this study, concurs with the findings of Caesar et al. (2011) as both of the studies suggest a good association of El-Niño with positive DMI events and negative precipitation anomalies. However, some exceptions were noticed in 2000, 2008, 2011, and to some extent in early 2021. Negative precipitation anomalies during positive El-Niño phases can be explained with the positive latent heat flux, driven by atmospheric forcing. The spreading of north-easterly anomalies during El Niño events introduces an intense heating impact throughout the NIO, which decreases precipitation (Du et al. 2009). A prolonged rainfall deficit is noticeable in the years where El-Niño events were longer, especially in 1983, 1989, 2010, and 2016. Fluctuations in El-Niño and La-Nina events were much frequent from 1990 to 2000, such disturbances require further decade-specific studies. DMI contained an opposite relationship with precipitation anomalies, which is positive DMI begets negative rainfall anomaly and vice versa. But, 2000 and 2011 were an exception to this rule. The same two years had coinciding La-Nina events, thus suggesting the fact this event had something to do in alternative the association between DMI and precipitation. A possible reason for the opposite connection between these two parameters is due to the creation of a near-surface salinity stratified barrier because of the massive river discharge, which insulates the circulation from the rest of the Indian Ocean (Thadathil et al. 2007).

Additionally, atmospheric circulations are strongly related to the incidence of rainfall in tropical and subtropical areas. A transition from hot and dry pre-monsoon season to wet monsoon season occurs over the Indian subcontinent, due to the deviations in large-scale circulations. It is mainly motivated by strong land-sea thermal dissimilarity and transports significant moisture to the Indian landmasses. While land-sea thermal interactions are not as extensively studied as El-Niño or DMI, some studies still exist. One of these studies depicted that LOTI contains a strong positive trend over the BoB regions (Choudhury, Nath, and Chen 2019). This study shares a similar outcome since all of the focused year returned with positive LOTI values thus reconfirming the results.

5. Conclusion

Scientists are consistently trying to identify the spatio-temporal patterns of the monsoon and precipitations over the Indian sub-continents and the northern Indian Ocean (NIO) for decades. Our study is a part of the research on rainfall variability and its teleconnection to different climatic conditions. This paper addressed

the parameters that actively influence the variability and intensity of the seasonal and decadal precipitation throughout the BoB. The corresponding seasons' SSS and SST patterns were in good agreement with the previous finding and were seasonally influenced by precipitation on a basin-wide scale. Moreover, El-Niño and DMI were found to be well associated with the precipitation, whereas LOTI did not reveal any specific relation with it (with some exceptions). Decreased precipitation was evident in the case of strong El-Niño and DMI events. The year 2000, 2008, and 2011 were the exception to this general outcome. In contrast to the previous researches and recent concerns about climate change, this study did not find any steady increase in precipitations for the past 40 years. Nevertheless, further region and season-specific studies should be performed to detect whether there is an increase in specific seasons over a long time.

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Modeling the Impact of Salinity on Growth and Survival of Mangrove Seedlings in Bangladesh

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Abstract:

Mangrove is the most dominant tropical and subtropical forest and estuarine ecosystem having unique ability to complete their life cycle in the highly fluctuating saline environment. The largest mangrove forest, Sundarbans is the only, relatively, intact natural ecosystem in Bangladesh and is providing its full share of ecosystem services to the country in the form of livelihoods and protection against cyclones and storms. Reviewing number of recent articles on impact of salinity on growth and survival strength of mangrove plants, the major understanding is, salinity is the controlling factor of mangrove seedling and germination. The most of the planted species, especially *S. apetala*, shows good germination and growth rate at low salinity, high fresh water flux, low osmotic (stress) presser, low siltation and higher nutrient rich condition. Since 1990, the mangrove afforestation program cannot make any success due to the lack of scientific research, practical experiences, and wrong site selection. Depending on the physical parameter, coastal morphology, seasonal variability, mangrove seedling should have different approach as all species does not require same biotic and abiotic factors. Following the developed model, an integrated approach for mangrove afforestation program may make a story of success.

Introduction:

Mangroves are the dominant woody vegetation and a group of trees and shrubs that grow in the intertidal, subtropical and warm temperate zones (M. Hossain et al., 2008) and they also characterized with structural and physiological adaptation that is influenced by saline and tidal inundation(M. Hossain et al., 2014; Saenger & Davie, 1983). In respect of economics and ecological purpose, mangrove is important sources of renewable resources (Aheto et al., 2016; Field, 1995). And mainly a mangrove forest can produce three kinds of benefit (forest product, fisheries, and ecotourism) to the territory (Paul et al., 2017) as well as it protect from natural calamities, coastal protection, species conservation (Mukhtar & Hannan, 2012).

South and South-East Asia is the home of mangrove (41% of the total)(S. M. D.-U. Islam & Bhuiyan, 2018) among them Sundarbans is the single largest mangrove forest in the world, on the other hand, Indonesia occupies 23% (Malik et al., 2017), Australia, Brazil and Nigeria combinedly hold 20% (Gopal & Chauhan, 2006). Ganges–Brahmaputra–Meghna (GBM) delta possess 6017 km^2 of Sundarbans, a unique ecosystem that hold 334 plant and 693 species of wildlife, shared between Bangladesh and India (Iftekhar & Saenger, 2008). Sundarbans provide about 41% of forest revenue of Bangladesh and it plays a significant role on marginal people's income (N. Islam & Islam, 2011). Recently the forest is threatened due to different anthropogenic and natural causes i.e., industrial discharge, agricultural wastes, aquaculture ponds, oil spillage (Chowdhury & Maiti, 2016; Didar-Ul Islam & Bhuiyan, 2016; MacFarlane et al., 2007) and decreasing its land coverage day by day at a significant rate. The existing area was around double in the past (Das & Mandal, 2016).

In addition, global warming, Sea Level Rising (SLR), decreasing freshwater flow, frequently occurring of cyclone and insufficient regeneration are highly responsible for declining of Sundarbans (M. S. Hossain et al., 2016). Recently the degradation process is accelerated by the development activities in the Sundarbans region like, Mongla export processing zone (EPZ) and sea ports in Khulna, for exports and imports (M. S. Hossain et al., 2016). Frequently occurring devastating cyclone become one of the major driving factors for the destruction of the Sundarbans. As a result, the shortage of animal resources, fisheries and forest resources in the Sundarbans has been noticeable for several years.

Mangrove forests have been extensively using wood products such as nuts, poles, posts, fuel wood and charcoal for coastal livelihoods (Bosire et al., 2008). As mangrove is the most diversified ecosystem with a source of livelihood for marginal people, breeding & nursing ground for juvenile and migratory marine fish species (Aheto et al., 2016) sources of aquaculture, agriculture, forestry, building material, alcohol, medicines, fodder and other local subsistence (Alongi, 2002; Peter J. Hogarth, 2002); the concept of conservation, regeneration and restoration of mangrove habitat, in a sustainable manger, is become important in recent decade. Information gaps and limitations need to be identified in order to sustainably manage mangrove ecosystems within an integrated approach (S. M. D.-U. Islam & Bhuiyan, 2018).

Global mangrove forests have been declining at a rate of 2% per annum from 1980 to 1990 and at a rate of 1 to 2% per annum since 1990 (Valiela et al., 2001). In the 1980s, the world's mangrove forests were about 19.7 million hectares, up from 15.9 million hectares in 1990 and 14.7 million hectares in 2010 (Kauffman & Donato, 2012). There is no other way to compensate for the rate at which all mangrove forests in South Asia, including the Sundarbans, have been declining over the past few decades, other than artificial planting. Other countries including India, Sri Lanka, Myanmar, Ghana, Australia and Indonesia have been trying to protect and grow mangrove forests by reforestation, seedling (Field, 1999).

To manage Sundarbans mangrove, detailed work plan was first prepared in the year 1893–1894 (Chowdhury RA, 1994) and then an executive plan for forest management was prepared on the basis of the inventory of the Sundarbans during 1960-1980 (Biswas & Choudhury, 2007). Bangladesh had high-priority initiatives in afforestation program in coastal tidal belt restoring mangrove by planting 4000ha in 1990 and targeted to plant 100,000ha by 1995 with a master plan (Ahmed M., 1981; Karim A & Khan, 1980). Ionic factors of soil, water, tidal wave and geological structure are related to the growth of mangrove forest trees. Studies have shown that the distribution of species is closely related to the salinity of the soil produced by the interaction of geophysical processes and tidal waves(Karim & Karim, 1993). The Food and Agriculture Organization (FAO) is preparing a management plan for the protection of the Sundarbans. The goal of this project is to achieve sustainable management of mangroves to utilize forest resources. In recent times the activities of forests, species diversity and ecosystems have declined rapidly, although a number of guidelines exist to protect forest resources(Choudhury, 1997). But all the initiative could not get the final success.

In this review, we will try to find out the drawback of the mangrove seedling and afforestation in the Sundarbans, Bangladesh region. The study will focus on the impact of different environmental factors on the growth of different mangrove trees, a knowledge that is expected to provide a better idea of the distribution relations of plants and the selection of suitable species for our coastal afforestation program.

Materials & Methods:

The modeling approach is conducted based on the reviewing the published research papers related with the salinity resistance ability of mangrove species and their mechanism. I have found may papers relevant on salt resistance mangrove planting but I hardly found any paper having model on the impact of the salinity on the growth and survival of mangrove species.

In this regard, I have to read and learn salt resistance mechanism of mangrove plant as well as I have read number of papers about non mangrove (paddy and crops) plants salt resistance model and how the life cycle is being modified due to salt condition.

In the model section, we have followed three mangrove and non-mangrove plant saline conditions model and I have developed the model in a new dimension and concept having modified of them.

Exploitation of mangroves:

So, due to extensive human activity and development work, Sundarbans is now under great threat of biodiversity that is beyond the level of natural recovery. The existing authority permit aquaculture, farmland, transportation and other activity without considering its effects and finding out the way of minimization and now pollution is taking its toll (Kumar & Bhavanath, 2010). The mangrove ecosystem is in the front line to be affected by the global changes due to their position at the interface between land and sea. Scientist predict that the mangrove are trend to retreat land ward in the context of global changes and sea level rises (Field, 1995).

Mangroves and salt tolerance:

As mangroves grow in both high and low (fluctuating) saline habitats they maintain processes and adaptations to cope with this harsh environmental conditions(Tomlinson, 1986). The ability of ion compartmentalization, osmoregulation, selective transport, and the excitation of ions and the ability to adjust the flow of salts are some of the major adaptations that plants develop to combat saline conditions (Asish Kumar Parida & Jha, 2010). These adaptations of seedlings and mature trees to tolerate saline conditions in most of the true mangroves have been widely studied (Hogarth, 2015). However, the adaptation of mangrove seeds and their germination behavior has rarely been investigated (Willis et al., 2014). Furthermore, even the seed germination physiology of other halophytes is still mostly unknown (M. Khan et al., 2006).

Germination time is an important life-history feature that determines germination survival as well as phenotypic expression of post-germination characters (Donohue et al., 2005). Germination behavior (dormancy, dormancy-break requirement and germination requirement) determines germination time (Baskin & Baskin, 2014). The seed layer is the first line of adaptation to withstand harsh environmental conditions, therefore, the seeds should adapt to the conditions of their germinated environment (Donohue et al., 2005). Mangroves need to further study the germination process to uncover the strategies they have developed to combat the harsh environmental conditions they face. In addition, knowledge about seed germination behavior can be used in meaningful conservation of mangroves as well as in mangrove ecosystems, which are greatly threatened by development (Spalding, M. D., Blasco, F and Field, 2007).

Mechanisms of salt tolerance in mangroves:

The ability of plants to grow and complete the life cycle in an environment that contains high salinity is known as salt tolerance. The salt tolerant plants are called halophytes. Halophytes are either obligate (less

morphological and taxonomical diversity) or facultative. Mangroves are facultative halophytes tolerant to both high and fluctuation salinity (Parida & Jha, 2010). Some authors have also categorized mangroves under obligate halophytes. There is an intensive study have done on the effect of salinity on seed germination of halophyte (AM et al., 2000); but only a few studies that have included mangroves Salinity affects germination by an osmotic effect or by specific ion toxicity. (Kaymakanova, 2009) has shown that the effect of NaCl on germination is mainly an osmotic result. Although there are several other salts in mangrove water, 85% of the salt content is represented by NaCl.

Physiological and biochemical mechanisms:

Most salt-tolerant mangrove species grow in environments where tidal effects are reduced but water evaporation from the soil surface is high. The salt concentration in the soil of this region increases so much that it turns into hypersaline (Lovelock & Feller, 2003). Seawater contain 35 g/l of salt (3.5%), 483 mM Na^+ and 558 mM Cl^- with an osmotic potential of -2.5 MPa (P. Scholander, 2006). Mangroves need to maintain a constant water enjoyment and ion uptake and compartmentation control with a strong external salt (Ball, 1996). To maintain water intake, mangroves need not only through conservative morphological and physiological adaptations to prevent waterlogging of the leaves, but also to maintain adequate water potential (Ball, 1996)(Lovelock & Feller, 2003). However, as the osmotic potential of seawater is approximately -2.5 MPa (Sperry et al., 1988), mangrove leaf water potentials have to range between -2.5 and -6.0 MPa (M. A. Khan & Aziz, 2001; P. F. Scholander et al., 1966; Sobrado & Ewe, 2006). Salinity stress causes low stomatal conductance, which decreases the rate of CO2 accumulation and uptake, rate of transpiration and increase in xylem tension (Ball & Farquhar, 1984; M. A. Khan & Aziz, 2001; A K Parida et al., 2004).

Mangrove Seedling in Bangladesh:

Mangrove afforestation program was started from 1966 and up to 1996 the program was funded by the World Bank and the Government of Bangladesh. During that time, about 765 km2 of coastal area was under the program and planted (Revilla, J.A.V. & Ahmad, 1998). After 1996, the program was extended in a large scale, though it was single funded program by government of people's republic of Bangladesh. Major planted species are *Avicenna officinalis* and *Sonneratia apetala*. Others are *Excoecaria agallocha*, *Bruguiera gymnorhiza*) and *Nypa fruticans* (Serajuddoula et al., 1995).

The main objective of mangrove plantation was to mitigate disastrous effects of cyclones and storm surges, with which some other objectives were added later:

- Conservation and stabilization of newly accreted land, and acceleration of further accretion with the ultimate aim of transferring a large part of this land to agriculture;
- Production of timber for fuel wood and industrial uses;
- Supply of urgently needed resources into national economy (i.e. timber and new land);
- Creation of employment opportunities for remote rural communities;
- Development of suitable environment for wildlife, fish and other estuarine and marine fauna (Siddiqi, 2001)

Coastal afforestation programs in Bangladesh

Since 1960-61 coastal afforestation program was initiated by Bangladesh Forest Department (BFD). Afterward various development project and massive afforestation programs were implemented along the coastal belt of Chittagong, Feni and Cox's Bazar Forest Division.

Table 2: List of coastal afforestation project projects implemented by the Bangladesh Forest department

Name of Project	Starting Year	Completion Year
1. Afforestation in the coastal belt and offshore islands	1960-61 1965-66	1964-65 1969-70
2. Afforestation Project in the coastal regions of Chittagong, Noakhali, Barishal and Potuakhali	1974-75	1979-80
3. Mangrove Afforestation Project	1980-81	1984-85
4. Second Forestry Project	1985-86	1991-92
5. Forest Resources Management Project-FRMP	1992-93	2001-02
6. Extended Forest Resources Management Project	2002-03	2003-04
7. Coastal Embankment Rehabilitation Project (CERP)	1997	2003
8. Coastal Green Belt Project-CGP	1995-96	2001-02
9. Forestry Sector Project	1997-98	2005-06
10. Sundarbans Biodiversity Conservation Project (SBCP)	1999-2000	2004-05
11. Char Development and Settlement Project (CDSP)	2000-05	2005-10
12. Coastal Char Land Afforestation Project	2005-06	2009-10
13. Management Support Project for Sundarban Reserve Forest	2005-06	2009-10
14. Plantation of BWDB's Embankment in the Coastal Belt and its adjacent Char Areas	2009-10	2011-12
15. Afforestation in the Coastal Areas to Mitigate Adverse Effect of Climate Change Project	Nov.2010	June 2013
16. Community Based Adaptation to Climate Change Through Coastal Afforestation Project in Bangladesh	July 2009	June 2014

Total of 1,92, 395 ha mangrove was planted in the southern coast of Bangladesh till 2013 (Hasan, 2013). Among the mentioned plated area, *S. apetala* occupies about 80%, A. officinalis occupies about 15%, and rest of the area was plated by *Bruguiera sexangula* (kankra), *E. agallocha*, *H. forms*, *Ceriops dacandra* (goran), and *X. mekongensis*. Among the all plated species of mangrove plant, *S. apetala* was the most

successful species in terms of showing best survival and growth performance and A. officinalis was the second most successful species in the eastern coastal belt. Basically, these two species dominate the entire coastal belt mangrove plantation and increase the success rate. On the other hand, *X. mekongensis* is one of the best timber, fuel wood and paper pule producing species (S. A. Islam & Rahman, 2015).

Other than *S. apetala* and *A. officinalis* did not survive at an expected scale probably due to the lack of proper scientific knowledge and practical experiences. However, there were some species which did grow sporadically with *S. apetala* and *A. officinalis*. And because of these reasons, in the most of the development project there was a massive plantation of *S. apetala* along the coastal belt. But the fact is that there is hardly regeneration of *S. apetala* due to salinity fluctuation, continuous siltation, lack of seed sources, grazing by cows and buffalos.

Mangrove trial plantations

Sustainable mangrove afforestation program is threatened due to rapid sedimentation, species succession as well as traditional practices of insect management (Siddiqi et al., 1992). The mortality rate of planted species is very high in the coastal area and as a result, *S. apetala* and *A. officinalis* failed to have optimal growth. Moreover, researchers observed rising the forest floor and hardly find any regeneration of the planted species. Therefore, it become very difficult to have enhanced production of coastal forest coverage from the underplanting valuable mangrove carried out by Bangladesh Forest Research Institute (BFRI) since 1990 in the coastal belt of Bangladesh.

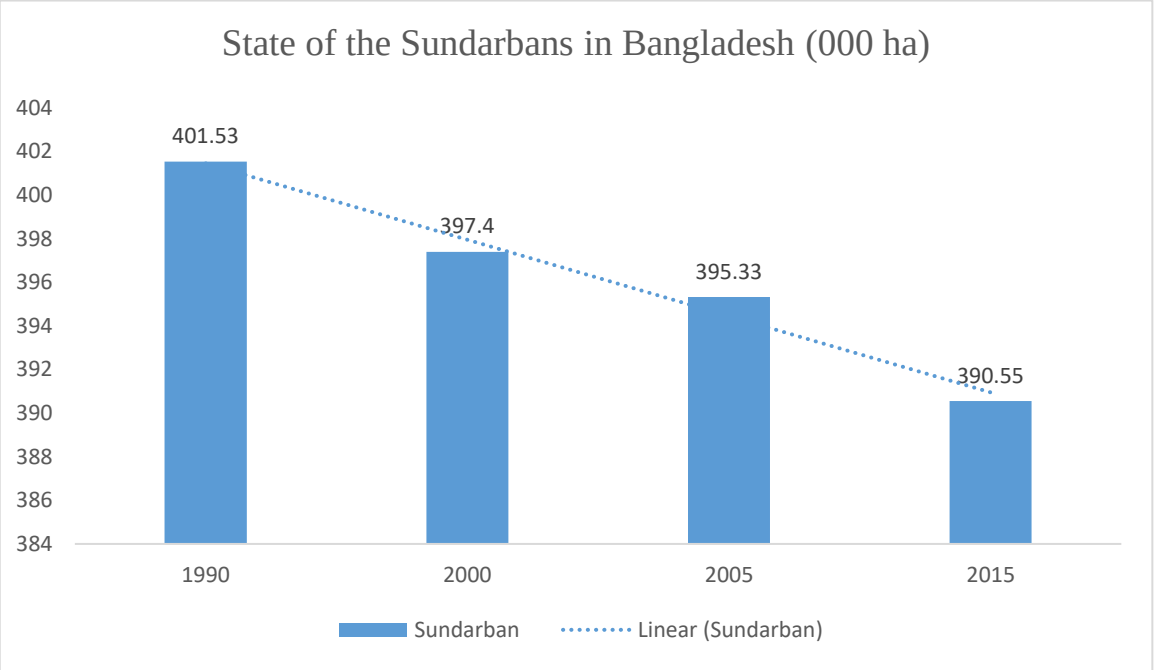
Eleven commercially important mangrove species were planted on experimental basis. The trial plots were laid out in several sites under Rangabali island of Patuakhali district; and Char Kukri-Mukri island of Bhola district. Seedlings of all mangrove species (Table 2) were raised in polybags except N. frutican which sown in muddy soil. The trial plots were raised under 9-12 years old S. apetala plantations at a spacing of 1.5m x 1.5m. Ten-month-old seedlings were planted in the selected sites, except for N. fruiticans seedlings, which were planted when three months old.

Table 3: Growth performance of mangrove species from 16-21 years old experimental stands at Rangabali and Char Kukri-Mukri islands of Bangladesh

Common name	**Scientific name**	**Rangabali Island**			**Char Kukri-Mukri Island**		
		Mean Survibal (%)	Mean Hight (m)	Mean DBM (cM)	Mean Surviba l (%)	Mean Hight (m)	Mean DBM (cM)
Sundri	*Heritiera fomes*	51.34	6.19	5.87	39.21	5.65	5.34
Gewa	*Excoecaria agallocha*	61.76	9.31	9.83	58.64	9.29	9.49
Passur	*Xylocarpus mekongensis*	47.87	6.84	7.97	26.18	6.84	7.34
Dhundul	*Xylocarpus granatum*	30.32	4.70	5.24	-	-	-
Kankra	*Bruguiera sexanula*	13.90	5.04	5.46	-	-	-
Khalshi	*Aegiceras corniculatum*	62.84	5.90	6.13	46.02	6.61	7.96
Shingra	*Cynometra ramiflora*	35.85	6.54	5.24	18.38	4.96	4.27

Goran	*Ceriops decandra*	23.38	4.98	5.04	-	-	-
Kirpa	*Lumnitzera racemosa*	43.95	5.24	6.31	11.66	5.30	7.51
Hantal	*Phoenix paludosa*	58.28	6.39	6.03	71.29	5.25	6.11

Table 4: Status of other mangrove forests



Climate Change Projections for Sundarban

Coastal regions such as the Sundarban, which include the vast mangrove forest, will face the adverse effect of temperature increase and rising sea-level in the near future. Based on the RCM RCP8.5 projection, it is evident that this area will face a 3°C rise in temperature by 2050s. Projected SLR is 0.5 Meter by the 2050s, which would inundate approximately 491 Km^2, about 8% of Bangladesh part of the Sundarban. By the end of the century, the projected 1 to 1.5 Meter rise, would inundate approximately 43 to 61% of the Sundarban. In addition, the El Niño event will cause more forest fires and a La Niña event will cause more inundation due to higher sea level. The species composition will also change. The proportion of the species such as Gewa and Goran will increase.

Freshwater flow either from rainwater or from upstream rivers is critical to the stability mangrove forests. The freshwater flows from the rivers and the tidal ingress result in a gradient of three salinity zones namely (1) less saline (salinity <2dS m-1), (2) moderately saline (2 – 4 dS m-1) and (3) strongly saline (>4dS m-1). Salinity decreases from west to east and these three zones correspond to technical classification of oligohaline, mesohaline and polyhaline zones respectively (Siddiqi, 2001). Variations in salinity along with physical factors such as topography, soil condition, tidal variation, etc. causes implications on the floristic composition, forest type, growth habits, etc. At present considering geomorphology there are roughly 6 ecological niches where species find their habitat, which are (1) mudflats, (2) ridges or levees, (3) back swamps or basins, (4) river channels, (5) tidal creeks and (6) bay or sandy shore. Sundari (Heritiera fomes) dominates the less saline and elevated back swamp or basins. The combined impact of reduced fresh water flow due to loss of connection with the Ganges due to Farakka barrage, Halifax cut and the Mangla– Gashiakhali cut and the projected rise in sea level will alter the salinity regime and may reduce habitat for Sundari species (IUCN, 2014).

Result and Discussion:

Due to its geographical location, dense population and socio-economic conditions, Bangladesh is extremely vulnerable to climate change. Implementing some strategic copying e.g.: mangrove afforestation, can mitigate the climate change impact. Bangladesh Forest Department and BFRI has already started large scale mangrove planting program over the coastal belt of Bangladesh. Being prograding deltaic country, there is no alternatives of coastal plantation to protect the shoreline as well as trapping sediment.

Since the beginning, there are some draw back in the field of research, physical condition and practical knowledge of on field working. Among the planted species, *S. apetala* is most intensively planted species, for which rainy season is the most favorable time. As well as, during site selection, we need to consider some parameter, e.g.: salinity, fresh water flux, siltation rate, temperature, nutrient abundance and osmotic pressure. If these parameters remain in the favorable conditions, our afforestation program may see the success.

By this research, we have found some unique phenomena about mangrove plantation in Bangladesh. The most influencing factor of mangrove seedling is Salinity variation. As, various research suggest, low salinity is favorable parameter for germination and high growth rate, so rainy reason is the best time for seedling. Another reason behind choosing of it, the reason is intensive freshwater flux. The only unfavorable fact is high sedimentation rate in spite of nutrient availability and low osmotic pressure.

Model:

The model is developed for the mangrove species, especially for *S. apetala, Avicenna officinalis* and *Sonneratia apetala* of Sundarbans. This model is valid only for the Sundarbans or Sundarbans like mangrove forest where most of the physical parameter will be matched.

The concept of the model has been developed from different research papers. I have get idea from Conceptual Model of Mangrove Rehabilitation Process in Salt works Areas, Including Edaphic Constrains and Forcing Functions (DOS REIS-NETO et al., 2014). The concept have been modified from “The proposed regulatory networks of H2S on salt tolerance of K. obovata seedling leaves” (Liu et al., 2019), “biological and physical processes that influence soil building” (Krauss et al., 2014).

Previously reported models were about the physical, chemical, biological processes carried in the mangrove wetland. Most of them tried to focus on their natural process and how they act. I tried to show the entire process step by step about mangrove afforestation in the deltaic coastal area where physiochemical process is very dynamic especially similar to Sundarbans Mangrove forest. As Sundarbans is very dynamic (seasonal, environmental, spatial variation) with respect to global mangrove forest, coastal afforestation process considering its geo-location, fresh water flask, etc for this area requires unique and suitable model.

Here we tried to identify the impacting and controlling factors behinds the survivability and growth of mangrove species in the coastal area.

Model In-brief:

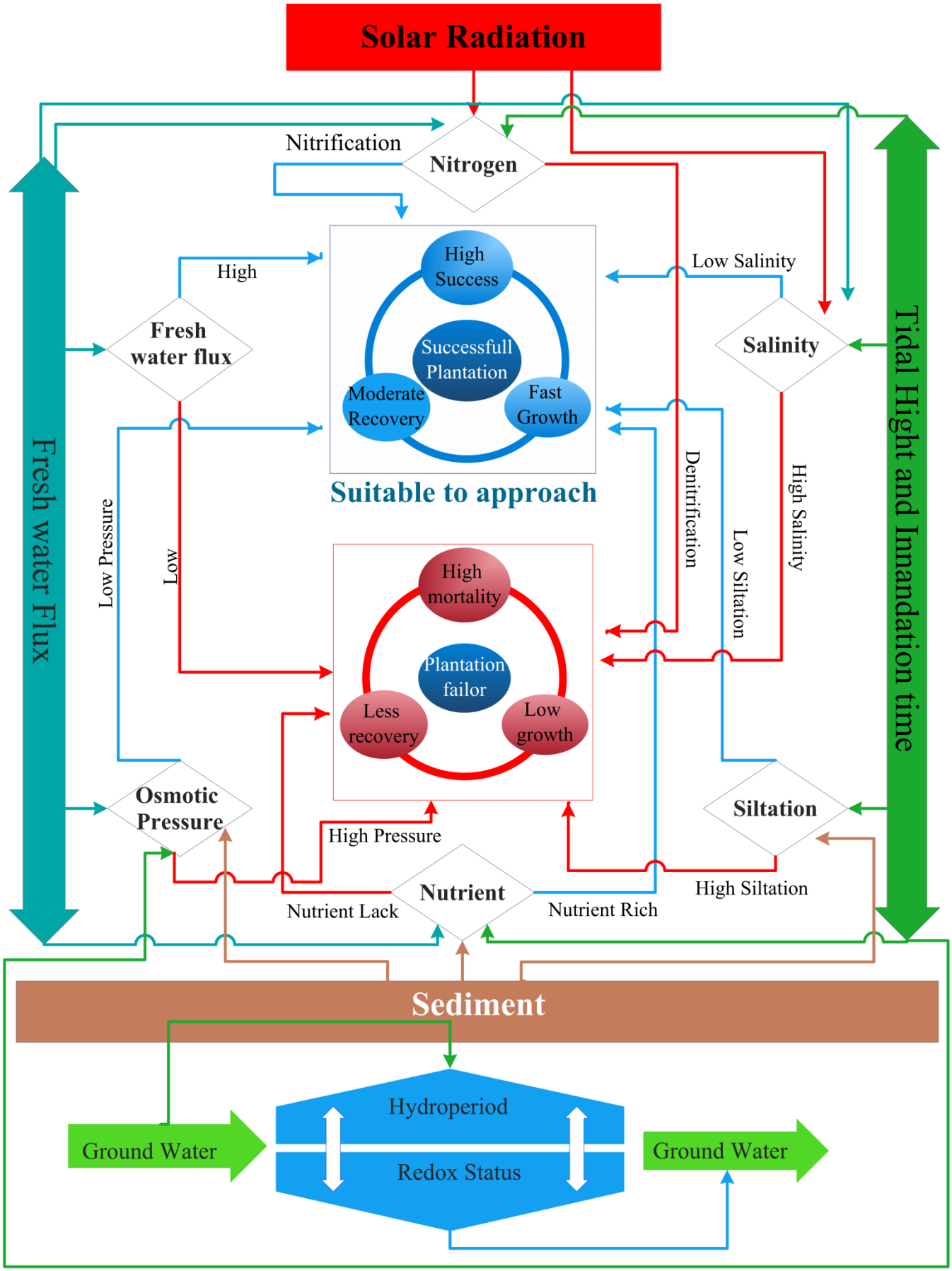


Figure 1: Modeling the Impact of Salinity on Growth and Survival of Mangrove Seedlings

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ASSESSMENT ON RESTORATION OF SHUVADYA CANAL

Taspiya Hamid[1] Md. Shahadat Hossain[2] Maria Abdullah Tarin[3]

ABSTRACT

Having lost connection with Buriganga and Dhaleshwari rivers, shuvadya canal is filled up now partially due to continuous encroachment and dumping of solid wastes. As per our study every person produces 0.5 kg solid waste per day and in Keraniganj around 400 metric tons of solid waste is produced per year and unfortunately they are not collected and systematically disposed. Many of those get dumped into the canals of keraniganj and deteriorate the ecosystem around it. Being exposed to this catastrophic impact, shuvadya canal needs to be restored and turned back to its previous link with major rivers. By doing this with a proposed measure, the quality of aquatic life can be improved as well as the aesthetic beauty of the surrounding. The Government of Bangladesh possess a plan to include the keraniganj upazilla to Dhaka city later and the route alongside the canal can be an important hub then. Land acquisition and requisition, optimizing use of geotextiles, refueling of barges and boats etc. have been recommended as measures. Moreover, being the bed of Shuvadya canal is up from the riverbed of Buriganga during the dry season, it was needed to excavate one meter more. Following the WHO guideline and ECR 1997, other relevant measures have been proposed to conserve the biodiversity, ecosystem and environmental quality.

Keywords: *ecosystem, geotextile, biodiversity*

1. INTRODUCTION

The town of Keraniganj stands on the southwest side of Dhaka City on the bank of the Buriganga Shuvaddya Canal. Keraniganj Upazila with an area of 166.87 km^2, is bounded by Savar Upazila and Mohammadpur, Hazaribagh, Kamrangir Char, Lalbagh, Kotwali and Sutrapur Thanas to the northeast, Shyampur Thana and Narayanganj and Sadar Upazilas to the east, Serajdikhan Upazila to the south, and by Nawabganj and Singair Upazilas to the west. The main Shuvaddya Canals are the Buriganga and Dhaleshwari. Keraniganj is connected to Dhaka Metropolitan through two modern canal restoration (Buriganga Canal restoration-2 and Bangladesh China Friendship Canal restoration which is also known as Burignaga Canal restoration-1) over Buriganga Shuvaddya Canal. With rapid industrial development and urbanization, cities in Bangladesh are facing unprecedented challenges with regard to solid waste management. Currently, our cities have not waste treatment and recycling plant. Informal sector exists in resource recovery and recycling of solid waste. The poor and socially disadvantaged people working in the street, waste bins, dumpsite. Due the lack of proper waste management system and lack of formal public agency, waste management has reached in its worst situation. These wastes are degrading environmental condition of Shuvaddya Canals and the water bodies also are encroached with solid waste. Environmental pollution, especially water pollution, has gone at acute level.

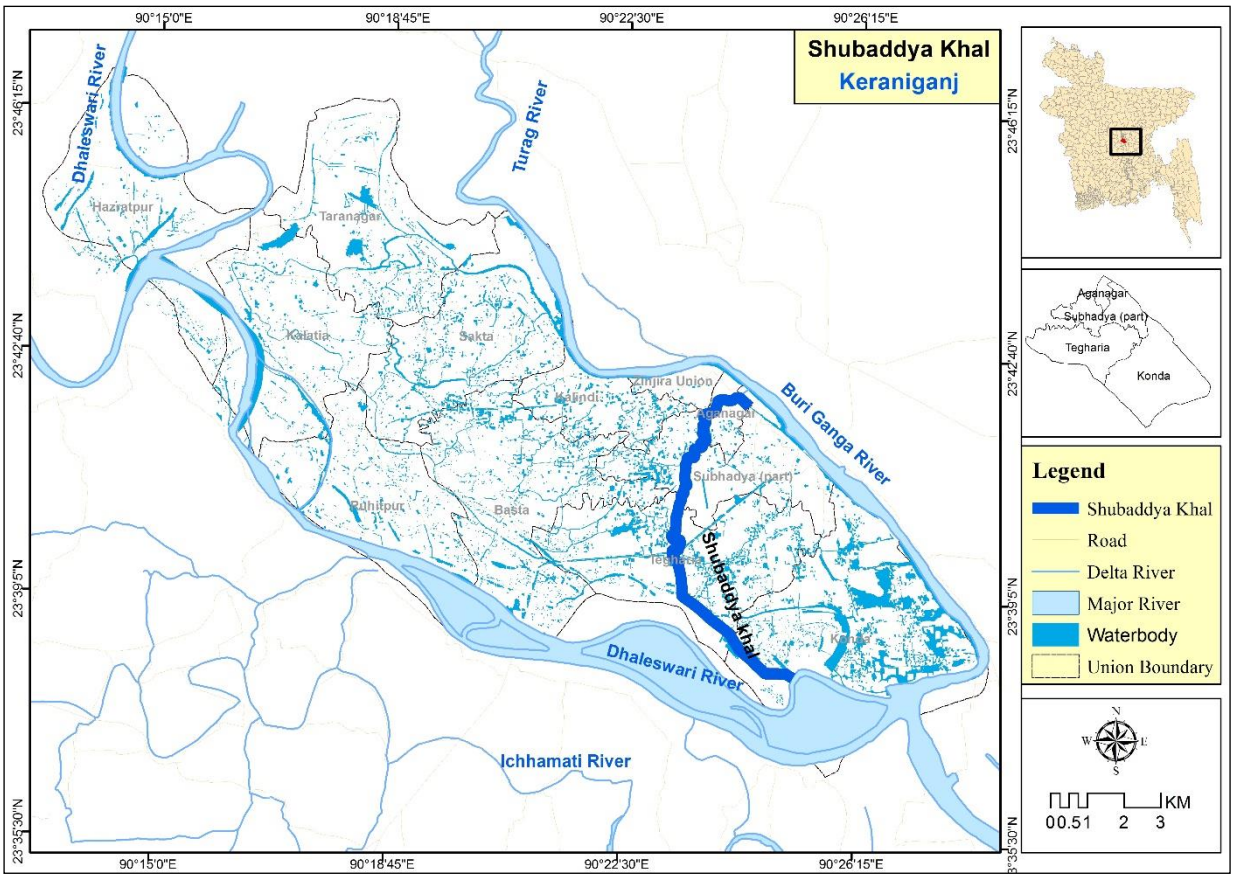

Figure 1: Study area with water bodies and urbanizations.

2. METHODOLOGY

2.1 *Survey Area*

Keraniganj Upazilla is very close to study area but out of its jurisdiction area. Naturally, this upazilla doesn't have formal process of solid waste management system though it is very densely populated area and economic activities are enormously concentrated in this upazilla. On an average people produce 0.5 kg solid waste per day and in Keraniganj around 400 metric tons of solid waste produced and unfortunately they are not collected and systematically disposed. Due the lack of proper waste management system and lack of formal public agency, waste management has reached in its worst situation, environmental degradation at the bottom of its state, Shuvaddya Canals, canals and the water bodies are encroached with solid waste. Environmental pollution, especially water pollution, has gone at acute level.

2.2 Survey Steps

The survey covered Initial Environmental Examination (IEE) and Environmental Impact Assessment (EIA) during the study. In addition, field observations and literature surveys conducted. During the EIA, environmental and social impacts to be caused by the proposed canal restoration construction have been identified. The identified environmental and social impacts cover physical, ecological and socioeconomic environment by phases of pre-construction, construction, and post-construction or operation and maintenance (O&M). The pre-construction activities include land acquisition and resettlement, if needed, among others. The construction activities include construction of the main canal restoration and related facilities including approach roads, and Shuvaddya Canal

training works (if needed). The O&M activities involve the maintenance of the canal restoration and approach roads.

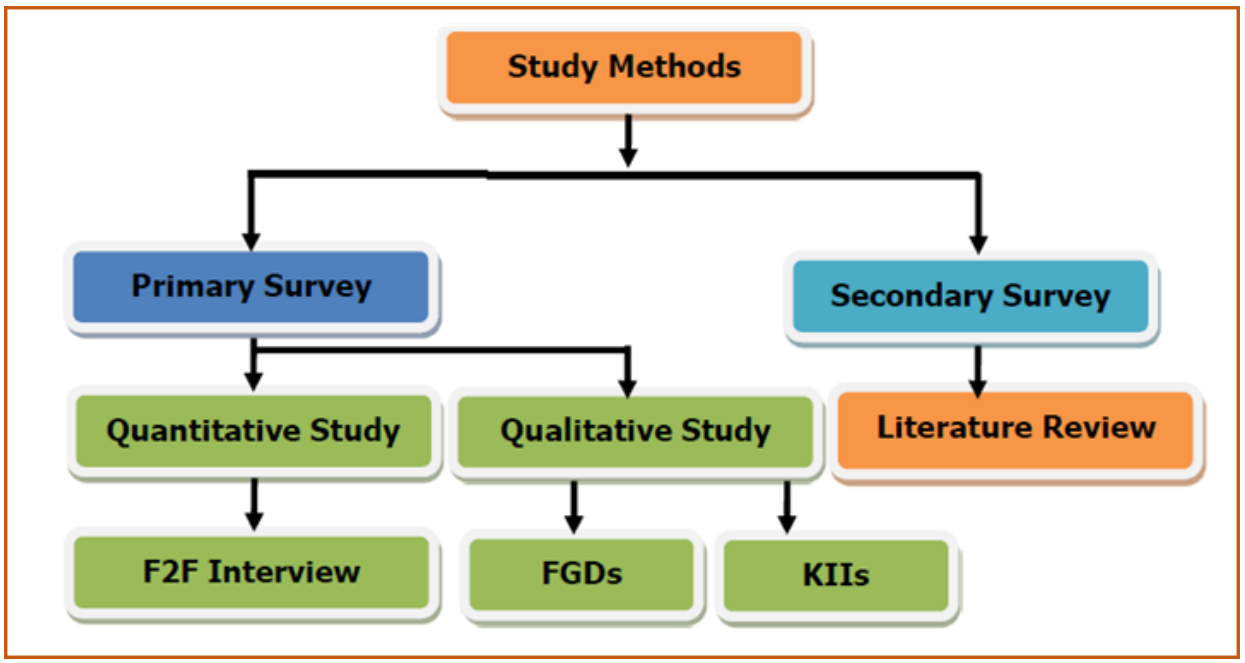

Figure 2 Flow diagram of data collection process

3. THE PRESENT SCENARIO

There are various khals around the Keraniganj Upazila. Normally the quality of Shubhaddya Khal surface water does not meet usable water quality standard due to presence of inferior substances, pollutants and treatment is needed to keep the canal alive. Agricultural operations can be the source of non-point pollution in surface water with major causes of surface water pollution associated with farming and ranching being sediment and nutrients. Soil erosion and resulting suspension of sediment is the leading cause of surface water pollution. Silt is the leading cause of water quality problems in canal. Although soil erosion is a natural process, it can be greatly accelerated and contents of polluting elements been increased by human activities such as farming, industries and urban runoff. Major sources of sediment include runoff from cropland, plantations and urban/suburban developments and are the key points for surface water pollution.

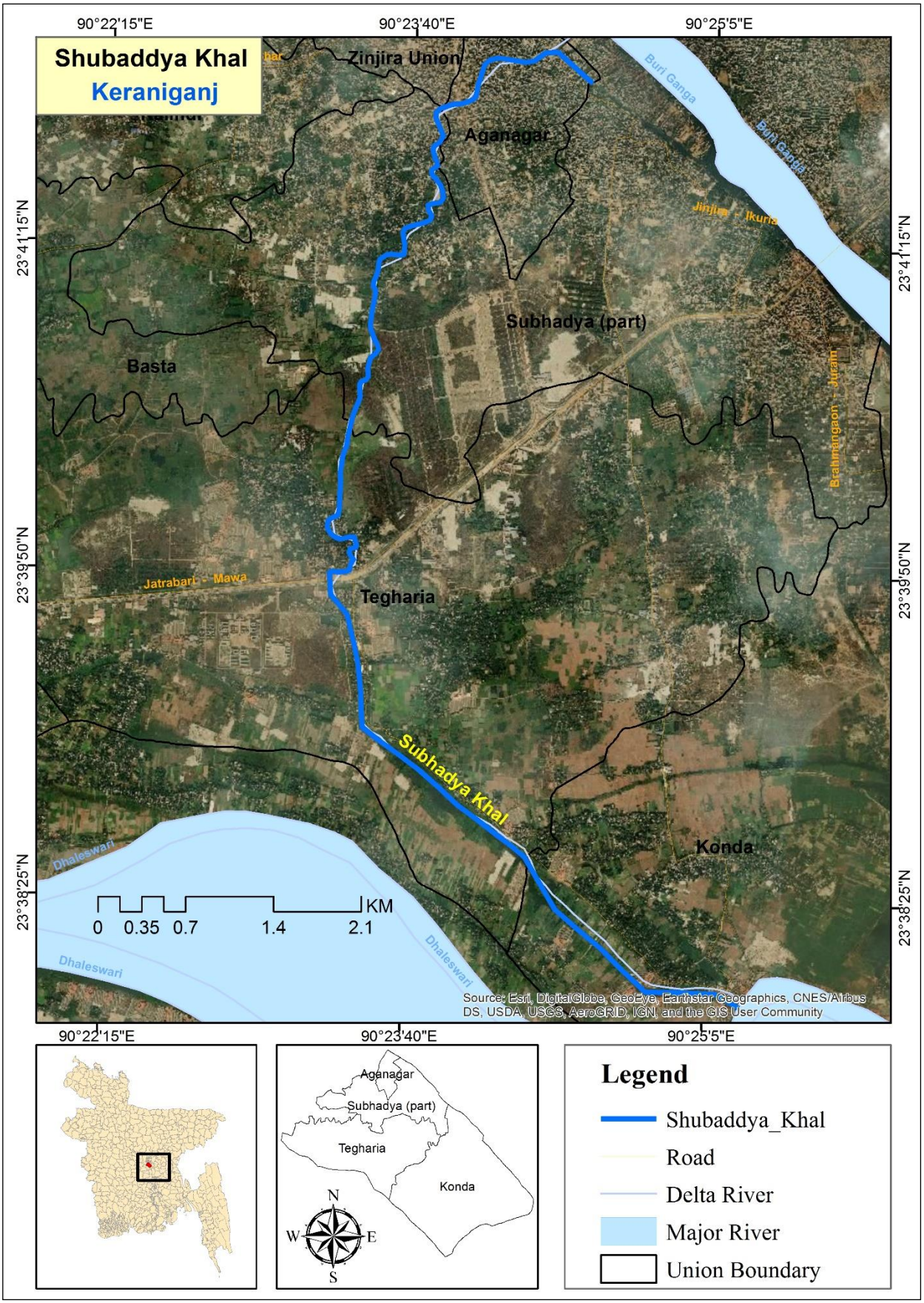

Figure 3: Proposed Alignment of Shubaddhya Canal

4.1 CANAL MORPHOLOGICAL CONDITIONS AND ENGINEERING DESIGN

The morphological survey, based on field measurements of different points, and changes in cross section at or nearby the proposed canal restoration point, revealed that the proposed canal restoration construction site is not an erosion prone area. The interviews with local people, in particular the elderly and teachers, also revealed that the streamline of the Shuvaddya Canal has been relatively stable at the proposed canal restoration site. Initial site observation by the consultants also confirmed that the proposed site is the feasible location for the canal restoration construction. It is, therefore, concluded that from the engineering perspectives, the proposed canal restoration site will be appropriate.

Figure 4: Shubaddya Canal is filled with solid wastes

The Nundaha Shuvaddya Canal ghat is the only crossing ghat on the Korotoa Shuvaddya Canal connecting the two Upazilas. From both sides of the ghat, the Upazila Roads (UZRs) will go to nearby Upazila centers Keraniganj in one side and Ghoraghat in other side), Dhaka town, and other economic centers, namely the Hili land port. Local people stated during FGDs and interviews that the proposed canal restoration site is the most suitable one, and the sole site for canal restoration construction for connecting the two Upazilas as well as districts (Dhaka and Dinajpur).

Figure 5: Shuvaddya Canal which needs to restoration

4. RESULTS

Surface water hydrology

Long-term (1982 to 2012) simulated flows of Buriganga and Dhaleswari Shuvaddya Canals in the Upazila have been assessed. It was found that on average the lowest flow months are Feb and Jan. When compared to the Base year crop water demands, there is sufficient 80% dependable Shuvaddya Canal water resources in all dry season months. However, it should be noted that due to topography and other physical constraints as well as downstream requirements, it may not be possible to utilize all the available Shuvaddya Canal water resources.

The static water volume in the floodplains of the Upazila have been estimated for the dry season months of Nov to May. The underlying assumption is that as the floodplains are generally connected to the Shuvaddya Canal, the static water volume varies from month to month based on the Shuvaddya Canal water level. Therefore, the average (and 80% dependable) end of month water level (from the long-run simulation, 1983-2012) was compared to the elevation-storage curve presented earlier in the report. In this approach, static water stored in ponds and other local depressions disconnected from the Shuvaddya Canal are not included in the estimate.

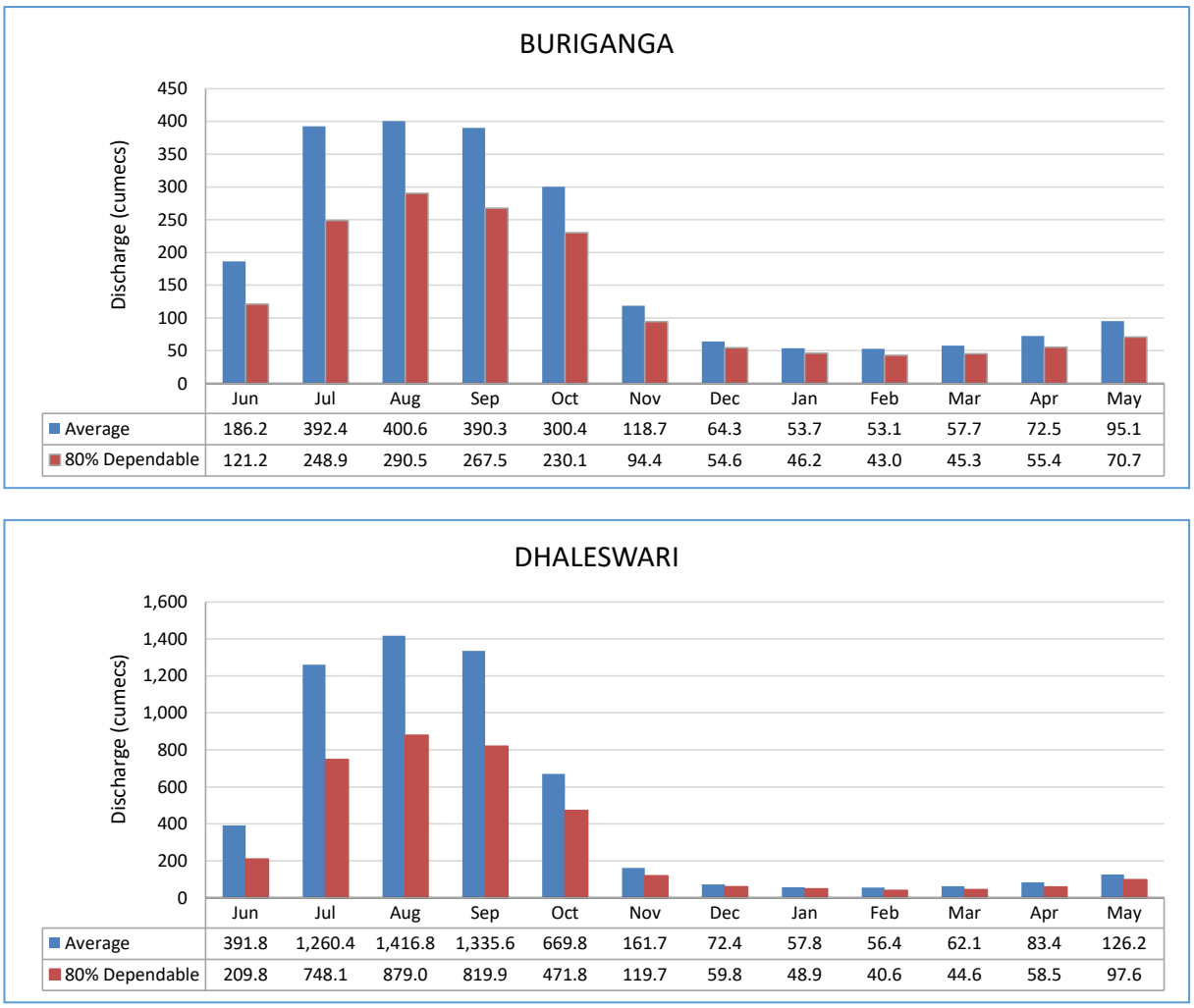

Figure 6: Simulated Shuvaddya Canal Flows

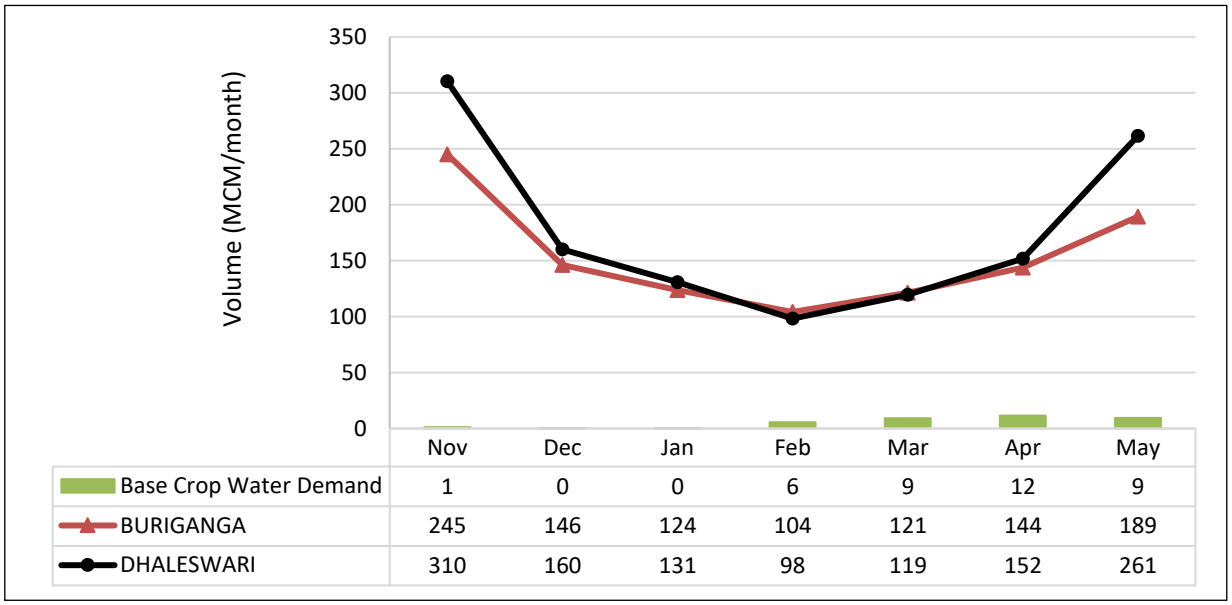

Figure 7: Dry Season Crop Water Demand with Shuvaddya Canal Resources

GROUND WATER

Detailed assessment of the groundwater resources has been undertaken. Available borelog data have been analysed to understand the aquifer system of the upazila and surrounding area. Due to data unavailability and quality issues, probability borelog was not produced for the Upazila. Seasonal variations of water levels are prominent within the hydrographs due to different sources of recharge, i.e. rainfall and flood water. For this period, the average potential recharge varies from 952 to 1405 mm/yr.

Bottom sediment quality

Shuvaddya Canal bed materials will be re-excavated to some extent during construction of the proposed canal restoration that would be used for the filling of the approach roads, and Shuvaddya Canal training works, depending on the plan of construction works. The soil is sandy loam type in the vicinity of the canal restoration site. As the Shuvaddya Canal flow level is the minimum during winter season and maximum during monsoon period, the siltation is the maximum during winter season, and similar siltation with sandy loam soil in the Shuvaddya Canal bed observed. Sediment quality may change after the construction of the canal restoration. No standard for Shuvaddya Canal bed sediment has been set in the ECR, 1997 and other regulations in Bangladesh. Therefore, the standard limit set by the United States Environmental Protection Agency (USEPA) is quoted for this EIA, which is widely followed in Bangladesh. The Zinc, Mercury and Cadmium levels should be observed during construction works.

Water quality

The quality of surface water may be affected during and after construction of the proposed restoration works. There is also a slight possibility that the construction work may change the quality of groundwater. Considering such risks, tests of existing surface water and groundwater have been conducted on important parameters to verify their present qualities. A total of two water samples were tested during the study. These test data will be the baseline information which can be referred to in the post-construction monitoring at the proposed restoration site. The results are indicated for comparison in future and their results are indicated in Table 3.19.

Table 1: Standard for surface water quality set by the ECR, 1997

Parameters	Unit	Drinking water	Recreation purpose	Fishery purpose	Industrial use	Irrigation purpose	For animals and birds	Coastal water quality
DO	mg/l	6	4-5	4-6	5	5	4-6	6
BOD	mg/l	< 0.2	3	6	10	10	NYS	NYS
COD	mg/l	4	4	NYS	3-10	NYS	1000	NYS
pH	--	6.5-8.5	6-9.5	6.5-8.5	6.0 -9.5	6.0-8.5	5.5-9.0	6.0-9.0
EC	ms/cm	0	500	800-1000	NYS	750	NYS	NYS
TSS	mg/l	10	20	25	75	NYS	NYS	75

TDS	mg/l	1000	NYS	NYS	1500	2000	5000	NYS
Turbidity	JTU	5	NYS	10	NYS	5	NYS	NYS

BOD: biochemical oxygen demand; COD: chemical oxygen demand; DO: dissolved oxygen; EC: electrical conductivity; JTU: Jackson Turbidity Unit; NYS: not yet set; TDS: total dissolved solids; TSS: total suspended solids

The drinking water sample collected from HTW (hand tube well) was tested. According to the test results, it is found that the Manganese and Turbidity values exceed slightly than the Bangladesh standard. The result of deep tube well (DTW) water reveals that the Iron, Manganese and Arsenic values are greater than the Bangladesh standard. The surface water (Shuvaddya Canal water) test result reveals that only COD value exceeds the Bangladesh standard. An inspection should be made during the construction works, the surface water quality should not deteriorate from the Bangladesh standard, and for this point in view, the environmental management plan is to be followed strictly.

Biodiversity

It is a common environmental understanding that biodiversity has been on a decreasing trend, threatening extinction of many species, and causing imbalance in the natural environment. During the FGD with the local people, a reduction trend of many species has also been observed. For example, many amphibians, reptiles, mammals and birds, and some medicinal plants have been decreasing, because of over exploitation, excessive human habitation, development of agricultural lands, lack of local people's awareness, and other human-related factors. A field survey has been carried out to find out the type and extent of existing flora and fauna at and in the vicinity of the proposed canal restoration site. Information on existing wildlife, such as amphibians, reptiles, birds, fish, and mammals as well as trees, flowers, and other plants, has been collected through FGDs with the local population. The information on flora and fauna has been cross-checked with the IUCN Red list of Threatened Species to confirm the conservation status. Some fruit or timber trees, growing faster and bringing about economic benefits, are generally increasing. Those fruit trees are mango, jackfruit, guava, lichee, olive, and lemon, and such timber trees include mehogony, rain tree, akashmoni, shishu, and shegun.

Aquatic habitat

The aquatic system on both sides of the Korotoa Shuvaddya Canal, including the low lying areas around, *beel* or low-level crop land, and ponds and other wetlands have been considered. The aquatic life includes aquatic plants (flora) and animals (fauna). Aquatic flora includes Kochuri pana (water hyacinth), Dhol kalmi, Helencha, Shawla, etc. Among fauna, various kinds of fish, frogs, snail, tortoise and a few water birds are found in the area, although most of them are decreasing in numbers.

According to the local people, various kinds of fish are available in the Korotoa Shuvaddya Canal, as a wide variety of fish migrate from the up and downstream. In the cultivated areas, various fish species are also available, especially in the monsoon season. Some cultured species are also found in the Shuvaddya Canal, which come to the Shuvaddya Canal from up and downstream. A list of the fish species, available in the area, is enclosed. However, some fish species are on a decreasing trend. Local people including those catching fish by themselves pointed out that some fish species such as Bacha (*Eutropiichthus vacha*),Vetki (*Lates calcarifer*), Kaon and Mohashoul (*Tor tor*) are found on rare occasions. Fish species like Shoul (*Channa straitus*), Shing (*Heteropneustes fossilis*), Magur (*Clarius batrachus*), Pabda (*Ompok pabda*), and Bacha (*Eutropiichthys Vacha*), have decreased. However, the local people stated that the construction of the proposed canal restoration will not have a significantly adverse effect on fish production and availability. According to field visit, out of the fish species, only *Cyprinus carpio* or common carp is categorized as "Vulnerable" but the species has also been widely domesticated in the area. The species have been introduced in the area mainly for fish culture. Thus extinction of the species in the area is unlikely.

Terrestrial habitat

The terrestrial system in the vicinity of the proposed canal restoration site has a variety of flora and fauna, but they are decreasing in general. Many species of wildlife have been decreasing day by day. It is observed that quick growing timber trees such as mehogony, rain tree, and sishu are extensively grown in the area for quick commercial returns. In terms of fruit trees, a few species like mango and jackfruit are increasing, but they are on a decreasing trend in general. Plantations of fruit species like olive, banana, and lemon are increasing. In general, the diversity of tree species has been decreasing reportedly.

Among reptiles of the area no endangered species are found except for Ophiophagus hannah or king cobra, which has been rated "Vulnerable" According to IUCN (2012). However, the habitat of the species is usually forest or densely vegetated area, and such area is not observed at the proposed canal restoration site. Thus it is considered that the risk of negative impacts of the proposed canal restoration construction on the species is almost nil. In the list of mammals of the proposed canal restoration site, every species have been found to be threatened and within the list of birds, some Birds have been found to be threatened According to IUCN (2012). According to IUCN (2012), Delonix regia or flame tree has been identified as "Vulnerable." However, Delonix regia is endemic to Madagascar, and was introduced into the area by humans many years ago. Thus it is considered that there is the least concern of the extinction of the species.no medicinal plants have been found to be threatened. No such species has been threatened in crops, vegetables, and flowers.

5. ACTIONS

These cautionary measures should be followed at the time of excavation works.

- Different sizes of excavators (1.5 tons-50 tons) can be used for the desired action
- Before starting excavation work sufficient quantity survey is necessary
- Then all the specifications (tires, teeth, bucket, engine, lubricants) must be checked perfectly
- After that climbing over the excavator maneuver this accurately
- When the operation is finished, park the machine on firm level ground away from the excavation site

6. CONCLUSIONS

The study enables us to understand the feasibility of the restoration of the canal. Setting up the previous links with Buriganga River and Dhaleshwari River would bring about a great change not only in hydrology but also in biodiversity, aesthetics as well as the overall environment. Steps like land acquisition, limiting geo-textile usage should be started immediately to conduct the whole work. The stakeholders should work in great extent to bring a behavioural change in disposing their waste. The success of the projects depends largely on the overall integration of the step by step process following the masterplan.

7. ACKNOWLEDGEMENTS

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Productivity of the northern BoB in contrast with SST and SSHA

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Abstract
The present study was accompanied with two established models of estimating primary productivity as well as validation performed by in-situ measured productivity. In the study area, was seen with a shoaling of isotherm in the northern mouth of Bay of Bengal (BoB) and Sea Surface Temperature (SST) was much higher in the south part of the BoB. The northern mouth of BoB was characterized with upwelling phenomena and downwelling was found to the south part. In-situ measurement of primary productivity was carried out in three different station of coastal BoB following oxygen (light and dark bottle) method. Average estimated primary production was 450 $mgCm^{-2}d^{-1}$ following Ishizaka et al., 2007 and 462 $mgCm^{-2}d^{-1}$ from KIM for four months (December, January, February and March). In-situ measured productivity data showed a relevant validation for VGPM of Ishizaka 2007. More likely, the reason was chlorophyll-based calculation of euphotic depth in the model of Ishizaka 2007 where in KIM model PAR was used to calculate euphotic depth.

Keywords Primary Productivity, VGPM Model, SST, SSHA, BoB

1.Introduction

The BoB is traditionally considered to be a less productive basin compared to the Arabian Sea *(Kumar et al., 2002)*. Primary production, in general is regulated by the availability of sunlight and nutrients. In tropical aquatic basins where sunlight is not usually a limiting factor except during overcast conditions, the biological production is limited by the availability of nutrients and hence it is important to analyze the nutrient fields also. In one study in BoB, higher productivity was marked in summer monsoon and lower during winter irrespective of stations and the seasonal variation. It was related to temperature and photoperiod. Temperature was the major factor influencing primary productivity. The lower productivity was observed in winter and monsoon season and this might be due to low penetration of light and low light intensity in winter and high rainfall during monsoon *(Debansu and Mohanty, 2016)*. It is generally known that ocean primary productivity is a crucial component of the biogeochemical cycles of carbon and other major biological processes *(Field et al., 1998, Kahru et al., 2009)***.** The major source of organic compounds to the ocean comes from the primary production of marine plants *(Millero 2006)***.** There are four major factors that govern primary production in marine ecosystem, these are- light, nutrient, stability and mixing *(Falkowski et al., 1998)***.** Numerous measurement methods are typically used for primary production. Some of these methods are variations in oxygen concentration within a sealed bottle *(developed by Gaarder and Gran, 1927)***,** incorporation of inorganic carbon-14 (^{14}C in the form of sodium bicarbonate) into organic matter, stable isotopes of oxygen (^{16}O, ^{18}O and ^{17}O), fluorescence kinetics (technique still a research topic), multiplying the counted phytoplankton cell by the average mass per individual cell, biomass estimation by extracting chlorophyll from sample. Primary productivity due to

photosynthesis is commonly measured by quantifying oxygen production or CO_2 assimilation that means ^{14}C method *(Lalli and Parsons, 1997)***.** Satellite ocean sensor

routinely provides various seawater variables such as Chlorophyll-a (chl-a), Sea Surface Temperature (SST), Photosynthetically Active Radiation (PAR) over a large area and using these data Net Primary Production) NPP can be easily estimated. There are a number of models proposed to estimate vertically integrated primary productivity. Among these VGPM (Vertically Generalized Production Model) was used here. The VGPM model was first described by 'Behrenfeld' and is a commonly used algorithm for estimating regional to global ocean NPP. The VGPM is a chlorophyll-based algorithm and is similar in form to the early models of *Ryther and Yentch, 1957*. Foundation of the VGPM and other chlorophyll-based models is that NPP varies in a predictable manner with chlorophyll concentration. There are comparatively poor in-situ data in this region to study the environmental dynamic pattern. Therefore, present study was done with the objectives included herewith: a) to assess the upwelling and downwelling phenomena from Sea Surface Height Anomaly (SSHA) to compare the relation with productivity, b) to study about the Sea Surface Temperature (SST) pattern in the study region, C) to estimate and validate the global VGPM in north eastern BoB based on in-situ measured primary productivity, d) to apply the regional-scale models in analyzing the spatial and seasonal patterns of productivity, e) to determine euphotic depth from remote sensing (MODIS) data using Photosynthetically Active Radiation (PAR) and Kd (490), f) to determine daylength based on three established models of daylength calculation, the CBM model, Brock model and Herbert Glarner's formulae, g) to compare the performances of depth integrated primary production estimated from two models.

2. Materials and Methods

2.1 Study area

The area selected for the present study is in the northern part of BoB ranging from 86°0' 0" E to 93° 0' 0" E longitude and 18° 0' 0" N to 23° 0' 0" N latitude. Three stations were selected for in-situ measurement of primary productivity in the north-western coastal BoB.

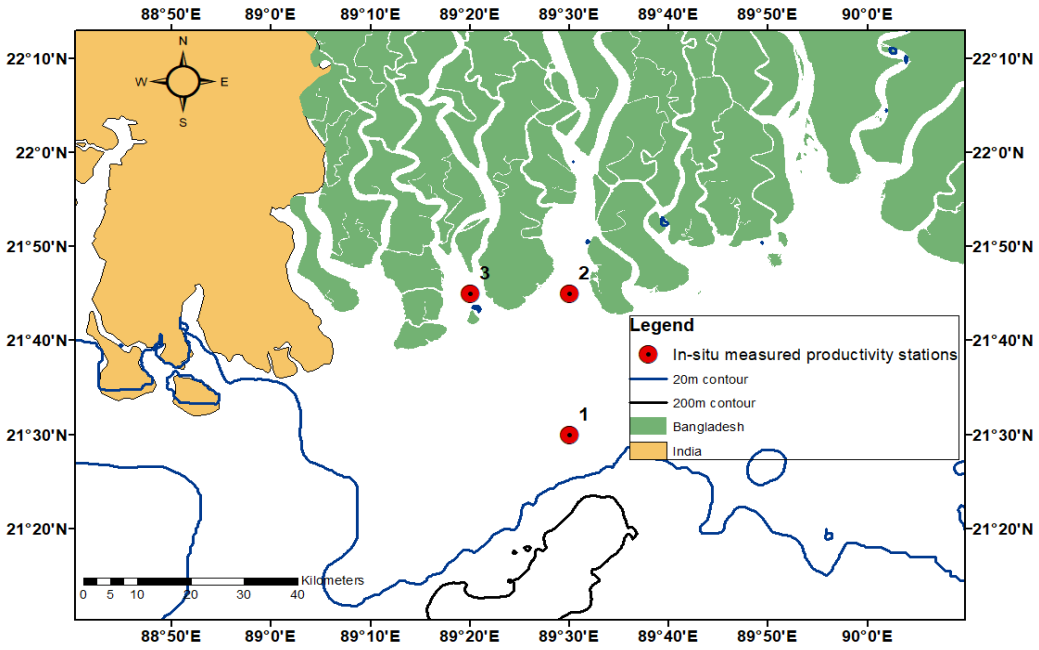


Fig.1 Schematic diagram showing stations of in – situ measured primary productivity in the north-western part of BoB.

2.2 Remote sensing (RS) data

Remote sensing data of chl-a was derived from MODIS from the site ERDDAP (Environmental Research Division's Data Access Program). Chl-a data was taken with a spatial resolution of 4km, 8-day composite data. Data were taken from 2012-2016(December, January, February, March) from the site http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMH1chla8day.graph?chlorophyll.

Then data was interpolate using ArcGIS and grid was taken on $1^0 \times 1^0$. SST data was derived with a spatial resolution of 4km, 8-day composite data. PAR (Photosynthetically Active Radiation) and K (490) was taken from Aqua MODIS with a spatial resolution of 4km, 8-day composite data for 5 years from 2012-2016 (December, January, February, March). Grid was taken on $1^0 \times 1^0$. SSHA was derived from the site AVISO. AVISO have been distributing altimetric data worldwide since 1992. Jason-2 SSHA data was downloaded from AVISO which was launched in 2008 and providing data till now. A total of 5years data were taken from 2012-

2016 for 4months (December, January, February, March) from http://aviso.altimetry.fr/index.php?id=1.

2.3 Methodology of VGPM model: model - 1 (Verified VGPM Model)

The original VGPM model proposed by BF is as follows:

$IPP = 0.66125 \times P^{B}opt \times [E0 / (E0 + 4.1)] \times Zeu \times Copt \times Dirr$ ..... (1)

In the above equation, (PP_{eu}) is the primary productivity from sea surface to the euphotic depth (mg C m^{-2} day^{-1}), $P^{B}opt$ is the estimated optimum biomass-specific photosynthesis rate (mg C mg Chl-a^{-1} h^{-1}), E0 is the daily sea surface PAR flux (mol quanta m^{-2}), Z_{eu} is the estimated euphotic depth, Copt (mg Chl-a m^{-3}) is the chl-a concentration where $P^{B}opt$ is located, the sea surface chl-a concentration was used as a replacement of PAR and Dirr is the daylength (h), which can be calculated using the date and location of each station *(Forsythe et al., 1995)***.** In Equation (1), BF expressed $P^{B}opt$ as a 7th order polynomial of temperature (T) *(Behrenfeld and Falkowski,1997)***.** Later KI modified the $P^{B}opt$ assuming two phytoplankton communities (large and small phytoplankton) both with 3rd order polynomial temperature dependency. They further assumed that one of the phytoplankton communities (the smaller one) has constant biomass and formulated the following equation:

$P^{B}opt = (0.071T - 3.2 \times 10^{-3} T^{2} + 3.0 \times 10^{-5} T^{3}) / C + (1.0 + 0.17T - 2.5 \times 10^{-5} T^{2} - 8.0 \times 10^{-5} T^{3})$..... (2)

Estimation of $P^{B}opt$ following the parameterizations of BF and KI were poorly correlated with in situ $P^{B}opt$ and a new formulation for $P^{B}opt$ was considered by (*Ishizaka at el., 2007)* following a second- order polynomial temperature dependence:

$P^{B}opt = (- 12.2 + 1.17T - 0.025T^{2})/ Chl + (13.3 - 0.916T + 0.0191T^{2})$.....(3)

Estimated $P^{B}opt$ following *Ishizaka at el., 2007*showed a smaller variation than the in-situ data but the variation was only 17% was explained by the model. However, the estimation was slightly better than the estimate was followed in *Kameda and Ishizaka, 2005* and this indicates the validity of the formulation. The use of in situ $P^{B}opt$ in VGPM explained only 47% of the variability of the integrated primary production and $P^{B}opt$ was not the only cause of the poor correlation and then estimated the parameters of the VGPM equation. Thus, the formula was fitted to estimate the light dependency parameters of the VGPM with in situ IPP, $P^{B}opt$, PAR, Zeu and Copt and the following equation was obtained:

$IPP = 4.19 \times P^{B}opt \times [E0 / (E0 + 336)] \times Zeu \times Copt \times Dirr$.....(4)

Finally, the Zeu model based on Copt was formulated. A linear regression model for inverse of Z_{eu} was used:

$Zeu = 1/ (0.0186 + 0.00720 Copt)$.....(5)

The relation between Zeu and Copt suggested by *Morel and Berthon, 1989* was used by BF and the relationship was similar to this regression analysis. Chl-a concentration is another important component for the primary productivity model which is associated with the phytoplankton biomass in the water. In coastal waters, optical properties are influenced by continental discharge. Copt (mg Chl-a m^{-3}) the chl-a concentration where $P^{B}opt$ is located were derived from remote sensing data. Daylength, Dirr (h) was calculated according to three established models and the error were compared among three model following *Forsythe et al., 1995***.**

Model – 2 (*Kameda and Ishizaka, 2005*)

Kameda and Ishizaka, 2005 proposed a two-phytoplankton community model in the original VGPM of *Behrenfeld and Falkowaski, 1997*. This model is based on the two assumptions that changes in chlorophyll concentration result from changes of large sized phytoplankton abundance and chlorophyll specific productivity of phytoplankton tends to be inversely proportional to phytoplankton size. ***Behrenfeld and Falkowaski*** proposed depth-integrated primary production was calculated as:

$$\mathrm{IPP} = 0.66125 \times \mathrm{P}^{\mathrm{B}}_{\mathrm{opt}} \times \frac{\mathrm{E}_0}{\mathrm{E}_0 + 4.1} \times \mathrm{Z}_{\mathrm{eu}} \times \mathrm{Chl}_{\mathrm{opt}} \times \mathrm{D}_{\mathrm{irr}}$$

In order to estimate parameters of this equation from the relationship between SST, SSC and P^{B}_{opt} a nonlinear regression analysis was used, resulting in:

$$\mathrm{P}^{\mathrm{B}}_{\mathrm{opt}} = \frac{0.071 \times \mathrm{T} - 3.2 \times 10^{-3} \times \mathrm{T}^2 + 3.0 \times 10^{-5} \times \mathrm{T}^3}{\mathrm{Chl}_{\mathrm{total}} + (1.0 + 0.17 \times \mathrm{T} - 2.5 \times 10^{-3} \times \mathrm{T}^2 + 8.0 \times 10^{-5} \times \mathrm{T}^3)}$$

This two-phytoplankton community model is valid for SST ranging from 0° to 30°C and for chlorophyll concentration above 0.05 mg m^{-3}. Derivation of other parameters such as Z_{eu} and D_{irr} was same as model-1 of this manuscript.

2.4 In-situ Primary Productivity measurement

In-situ primary productivity was measured following oxygen method using light and dark bottle from three different sampling stations.

3.Result

3.1 Sea Surface Temperature (SST) pattern in the northern BoB

SST can couple with high sea surface height anomalies (SSHAs), which is unusual for a basin where SST is normally uncorrelated with SSHA. Surface heating trapped in the thin mixed layer of BoB, causing the fresh layer to warm, whereas the increase in buoyancy from low-salinity waters enhanced the high SSHA. Thus, high SST coincided with high SSHA *(Lisan and Michael , 2011)***.** Sea surface temperature anomalies (SSTA) exhibit large variations associated with ISV *(Vecchi and Harrison, 2002)* and in the Indian Ocean, this variability is high in regions where SST is >28°C, known as the tropical warm pool *(Hoyos and Webster,2007)***.** One of the local maximum of summer monsoon rainfall is located in the northeastern corner of the BoB (*Hoyos and Webster, 2007*)**.** This region also has large Intraseasonal Variability (ISV) in rainfall (*Kim et al., 2011*). In the present study, spatio-temporal distribution of SST was observed for a time period of 2012-2016 for four months (December, January, February and March) covering the northern part of BoB. This study has revealed that the mouth of BoB was experienced with a cool water of lower temperature covering both of eastern and western part. Generally, BoB is experienced with organized thermal inversion during winter season. Spatially organized temperature inversion occurs in the coastal waters of the western and northeastern Bay during winter (November–February). Although the inversion in the northeastern Bay is sustained until February (with remnants seen even in March), in the western Bay it becomes less organized in January and almost disappears by February. Inversion is confined to the fresh water induced seasonal halocline of the surface

layer. Inversions of large temperature difference (of the order of 1.6–2.4°C) and thin layer thickness (10–20 m) are located adjacent to major fresh water inputs from the Ganges, Brahmaputra, Irrawaddy, Krishna and Godavari rivers *(Thadathil et al., 2002)*.

3.1 (a) Spatio-temporal distribution of SST in December

Present study has revealed with the cooling of water at the mouth of BoB in the month of December(fig.2). Study with a time period of from 2011-2015 showed that sea surface temperature was ranged from 22^0C to 28^0C in December. However, it was seen with a higher temperature to the southward region where the east coastal area toward Myanmar coast was governing with a higher temperature zone. Study with Sea Surface Height anomaly (fig.6) also revealed these phenomena, that the mouth of northern bay was experienced with upwelling of lower Sea level anomaly in the month of December, whether the southward area was occupied with downwelling phenomena of higher sea level anomaly. In relating with sea surface temperature and sea surface height anomaly the estimated primary production was comparatively higher (fig. 11 & 15) at the northern mouth of BoB rather than rest of the area. Upwelling responsible for the mixing of nutrient rich bottom water to the upper layer of ocean, resulting in increase of primary productivity and this study was also revealed with this distributing pattern of productivity.

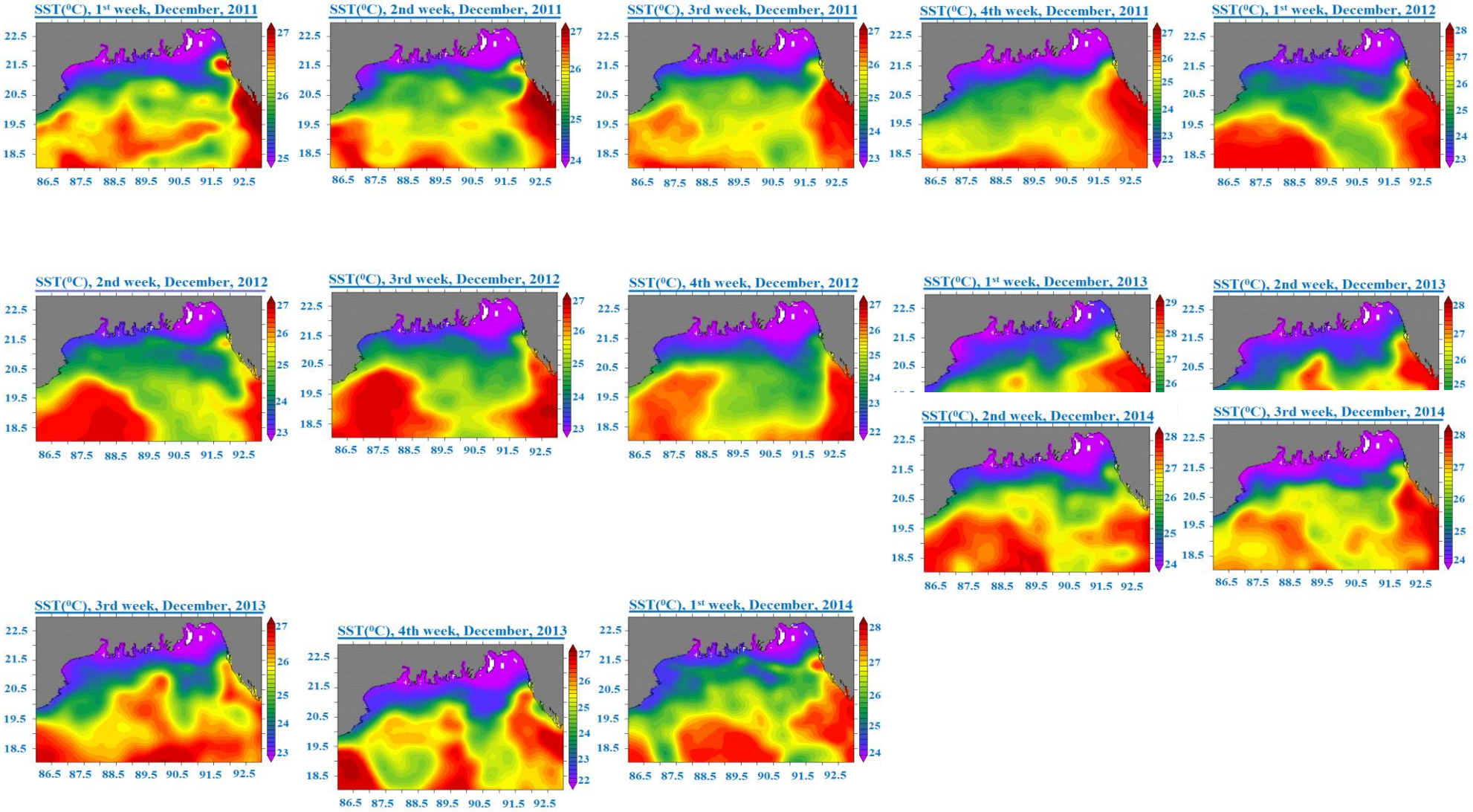
3.1 (b) Spatio-temporal distribution of SST in January

Observed sea surface temperature showed a similar pattern of distributing as December where, January was also occupied with a cooling of temperature at the mouth of northern BoB. Temperature was ranged from 21^0C to 28^0C in January, where it was fall by 1^0C compare to December. Sea surface height anomaly profile showed an upwelling phenomenon where there was lower sea surface temperature in the month of January. Concerning with that, the southward area was occupied with comparatively higher water temperature where the estimated primary productivity was lower (fig. 12 & 16).

3.1 (c) Spatio-temporal distribution of SST in February

Sea surface temperature for a time period of 2012-2016 in the month of February was governing with a higher of 28^0C of temperature and the lower value was 22^0C to the mouth of BoB. Bay of Bengal receive a large amount of freshwater influx at the mouth of the bay that makes a less haline water layer at the surface and in the winter season the north-eastern bay is governing with an organized thermal inversion that inhibits the mixing of bottom water to the upper layer and finally contributing to less productivity in the BoB. Sea level anomaly in the month of February showed an upwelling phenomenon to the northern part and downwelling phenomena to the southern part (fig. 8) in the month of February.

LONGITUDE(E)



LATITUDE(N)

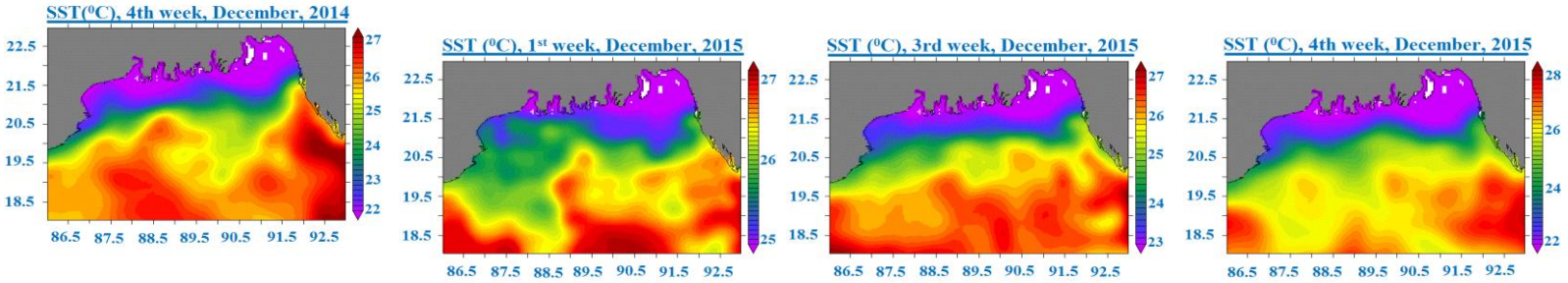
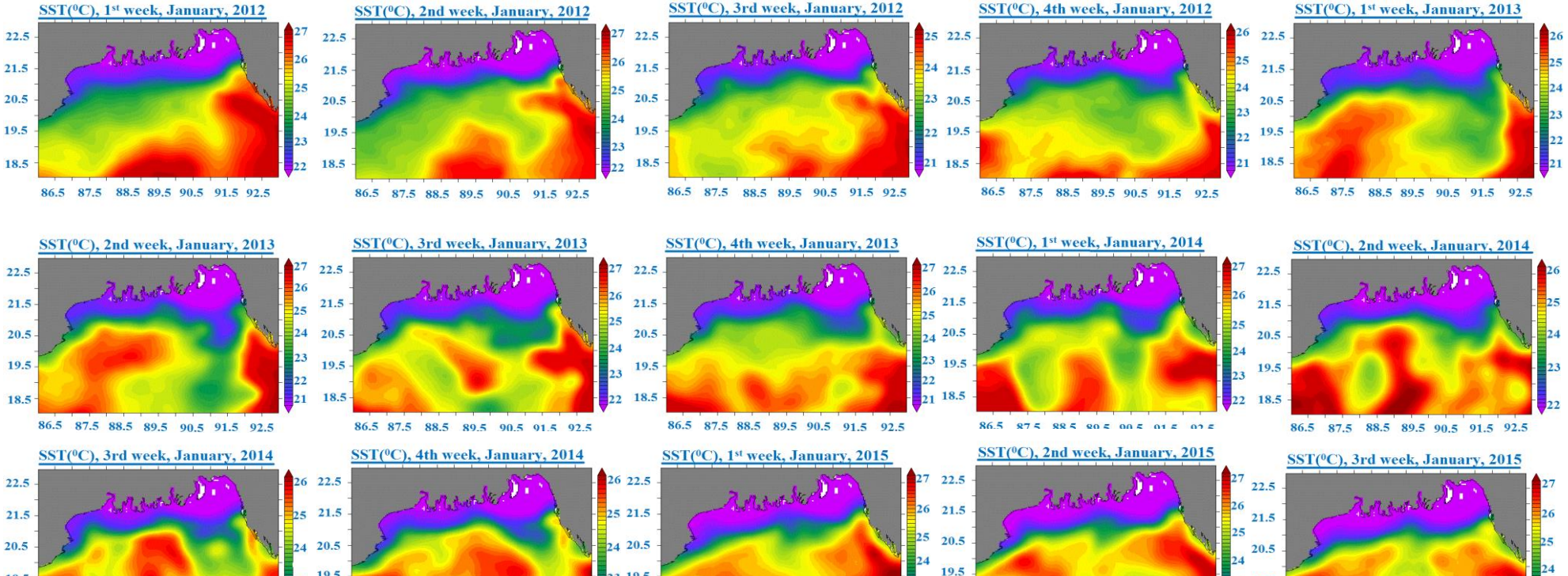
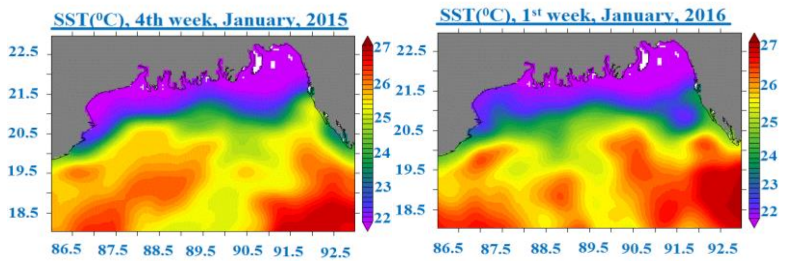


Fig. 2 Weekly Spatio-temporal distribution of MODIS – derived Sea Surface Temperature (SST) in northern part of BoB in December (2011-2015).

LONGITUDE(E)



LATITUDE(N)



SST(⁰C), 4th week, January, 2015
SST(⁰C), 1st week, January, 2016
22.5
21.5
20.5
19.5
18.5
86.5 87.5 88.5 89.5 90.5 91.5 92.5
27 26 25 24 23 22

LONGITUDE(E)

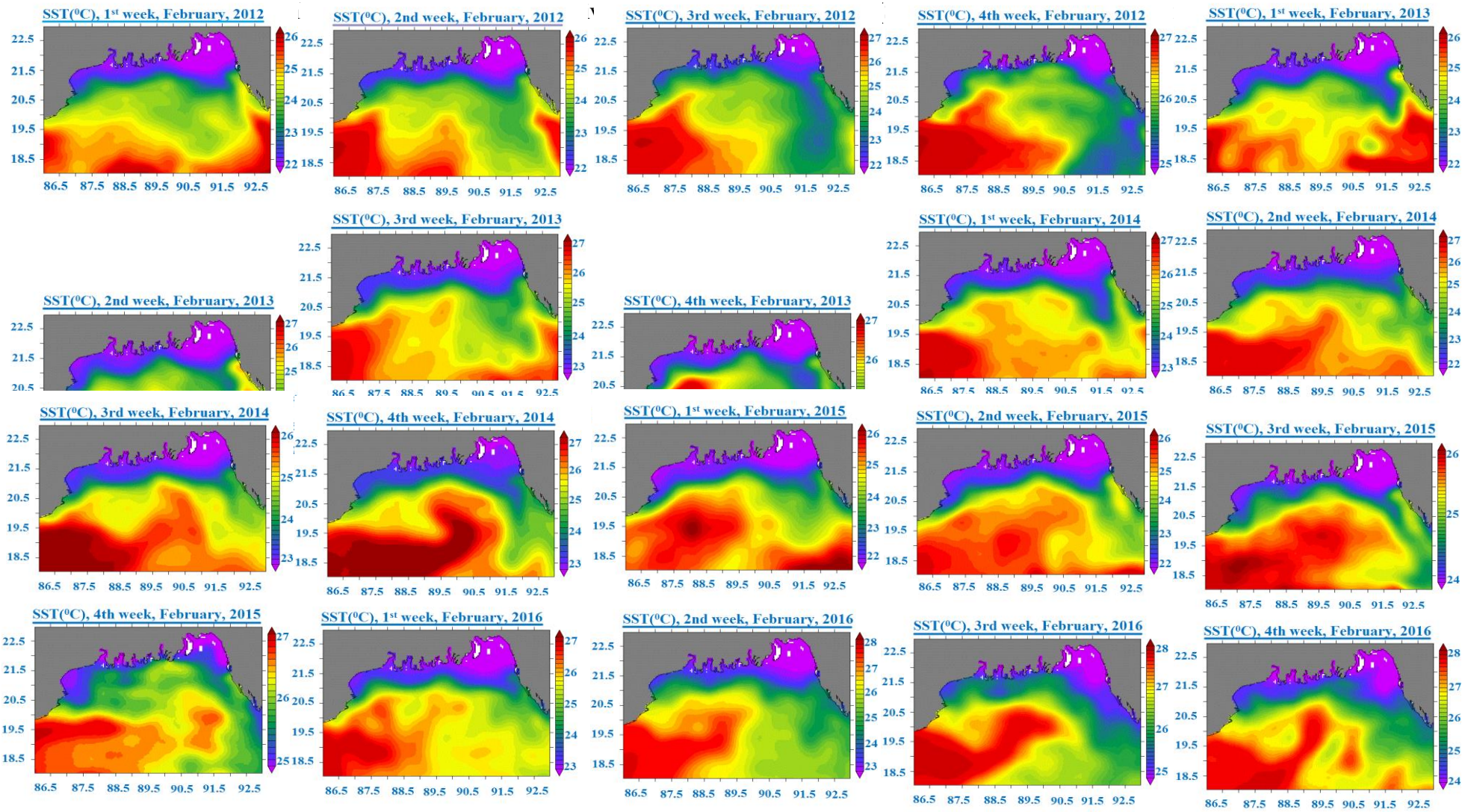
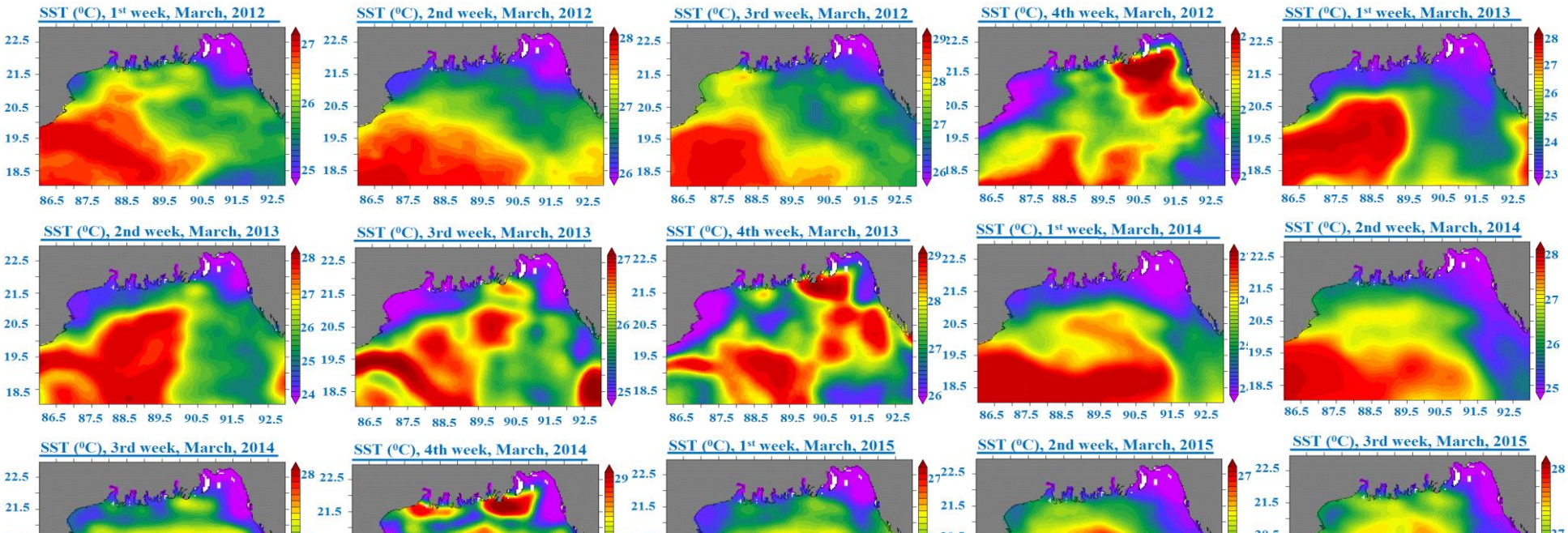

SST(⁰C), 1st week, February, 2012
SST(⁰C), 2nd week, February, 2012
SST(⁰C), 3rd week, February, 2012
SST(⁰C), 4th week, February, 2012
SST(⁰C), 1st week, February, 2013
SST(⁰C), 2nd week, February, 2013
SST(⁰C), 3rd week, February, 2013
SST(⁰C), 4th week, February, 2013
SST(⁰C), 1st week, February, 2014
SST(⁰C), 2nd week, February, 2014
SST(⁰C), 3rd week, February, 2014
SST(⁰C), 4th week, February, 2014
SST(⁰C), 1st week, February, 2015
SST(⁰C), 2nd week, February, 2015
SST(⁰C), 3rd week, February, 2015
SST(⁰C), 4th week, February, 2015
SST(⁰C), 1st week, February, 2016
SST(⁰C), 2nd week, February, 2016
SST(⁰C), 3rd week, February, 2016
SST(⁰C), 4th week, February, 2016
LATITUDE(N)

Fig. 4 Weekly Spatio-temporal distribution of MODIS – derived Sea Surface Temperature (SST) in northern part of BoB in February (2012-2016).



LATITUDE(N)

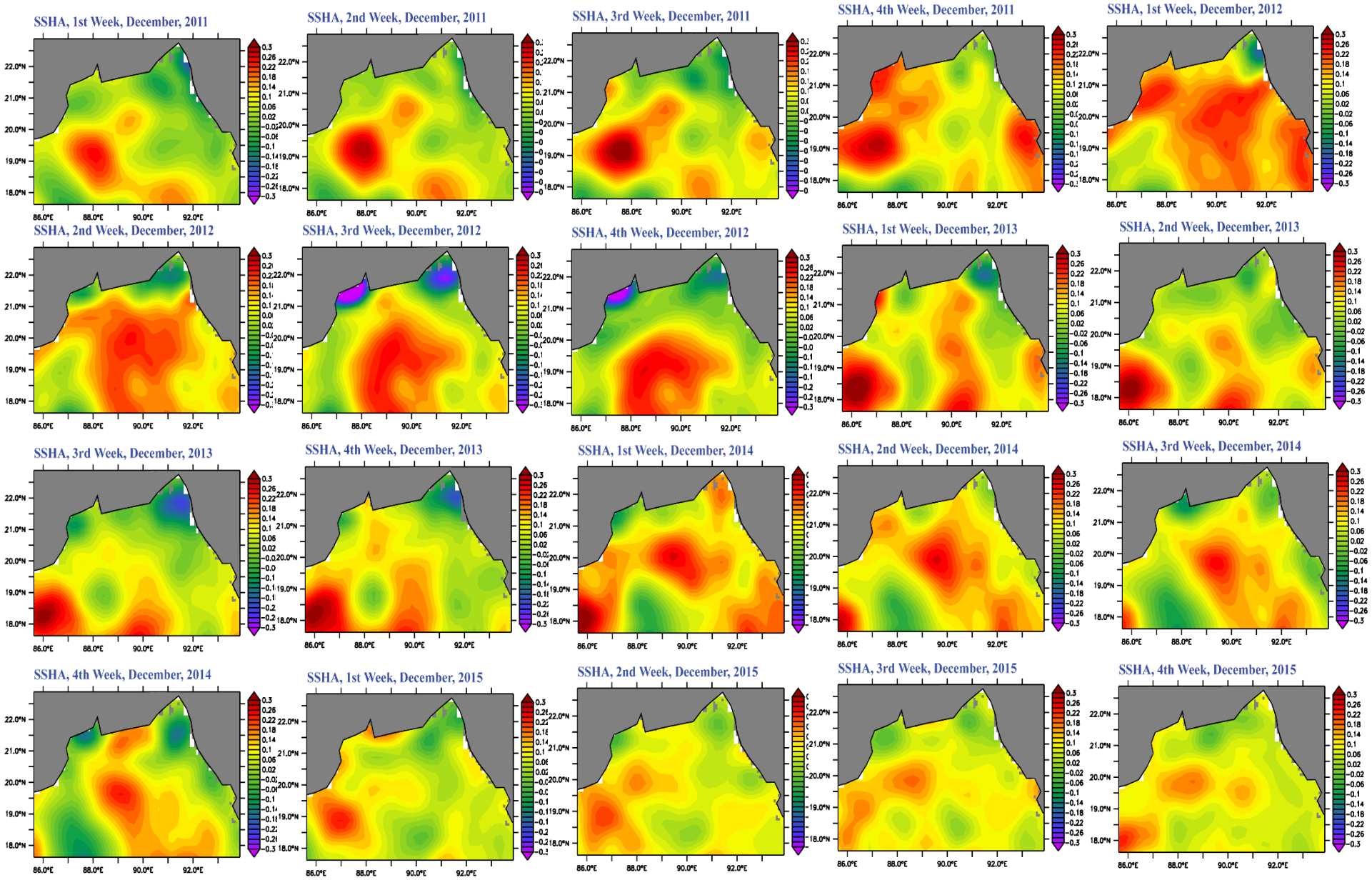
Fig. 5 Weekly Spatio-temporal distribution of MODIS – derived Sea Surface Temperature (SST) in northern part of BoB in March (2012-2016).

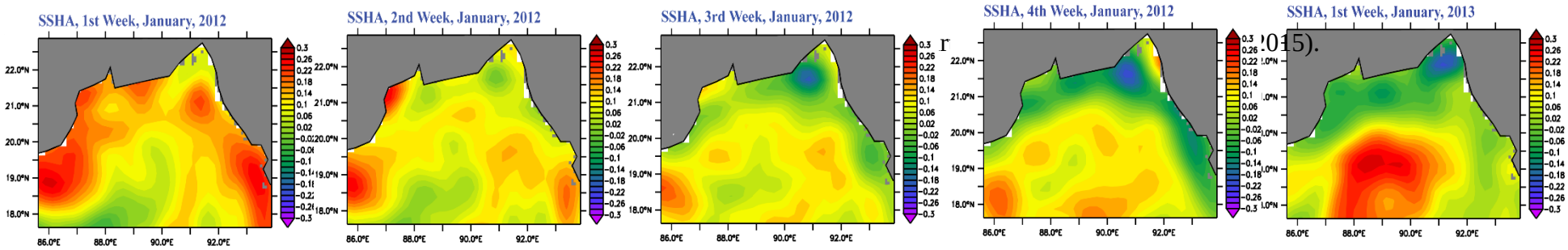
3.1 (d) Spatio-temporal distribution of SST in March

Spatio-temporal distribution of sea surface temperature was regarding with a comparatively higher temperature rather than December, January and February. Sea surface temperature was ranged from 24^0C to 29^0C in March (fig. 5). Higher temperature was increased by 1^0C in March, where the lower temperature was increased by 2^0C compare with December, January and February. A different type of sea level anomaly was observed in March (fig. 9) and found with frequently occurring of downwelling at the mouth of northern bay with high sea level but there were opposite types of distributing pattern found for December, January and February. From the present study it was observed that, northern mouth of BoB is characterized with upwelling for three months including December, January and February where frequently occurring downwelling was found in March with high sea level at the mouth of northern BoB. In spatial distribution of sea surface temperature, the higher temperature was governing to the southern part of BoB.

3.2 SSHA

Study with SSHA in the northern part of BoB was observed with the formation of cold core eddy in March (fig. 9) covering to the southward area. December (fig. 6) was characterized by upwelling to the northward mouth of BoB where the southward area was seen with downwelling phenomena. Upwelling area toward northern mouth of BoB was occupied with higher primary production (fig. 11 & 15) under this study in the month of December. Study with Sea level anomaly for a time period of 2011-2015 in the month of December showed that there was not strong downwelling in 2015 toward the southern part, while strong downwelling zone was observed from 2011-2014 toward the southern part in December. Downwelling was strong enough in the middle of the study area in 2012 with a comparatively higher sea level. Northern mouth of BoB was characterized with upwelling phenomena for entire time period with an exception in 1st week December 2014 (fig. 6). Estimated primary production by VGPM revealed that the upwelling area toward the northern mouth of BoB contained a higher productivity rather than rest of the area where upwelling zone was responsible for mixing of nutrient rich bottom water coming to the surface. SSHA in the month of January (fig. 7) was also supported by upwelling zone toward the northern mouth and downwelling zone toward the southward area except in 1st week January 2012, 2nd and 3rd week January 2015 where the entire study area was dominated by strong downwelling phenomena. Comparing with the primary productivity estimated following *Ishizaka at el. 2007* (fig. 11) showed a relation with the downwelling phenomena and the productivity was found to be lower where downwelling occurred. Sea level anomaly in the month of February (fig. 8) for a time period of 2012-2016 showed a distinct upwelling and downwelling zone over the entire month but in relation with December and January the northern mouth of BoB was concerned with upwelling phenomena covering February from 2012- 2016. In the present study, the strong and more organized downwelling zone was confined to the south-west part, whether the north and east part of BoB was concerned with an upwelling zone over the entire month and noticed that most of the area except few to the south-west was characterized by upwelling in the month of February. SST profile in March (fig. 5) showed a higher temperature confined to the southward with downwelling phenomena including the transfer of warm surface water to the deep of water column replacing by cold nutrient rich bottom water to the northern mouth of BoB. Warm water downwelling confined to the south-west part make higher sea level to the southward area.


SSHA, 1st Week, December, 2011
SSHA, 2nd Week, December, 2011
SSHA, 3rd Week, December, 2011
SSHA, 4th Week, December, 2011
SSHA, 1st Week, December, 2012
SSHA, 2nd Week, December, 2012
SSHA, 3rd Week, December, 2012
SSHA, 4th Week, December, 2012
SSHA, 1st Week, December, 2013
SSHA, 2nd Week, December, 2013
SSHA, 3rd Week, December, 2013
SSHA, 4th Week, December, 2013
SSHA, 1st Week, December, 2014
SSHA, 2nd Week, December, 2014
SSHA, 3rd Week, December, 2014
SSHA, 4th Week, December, 2014
SSHA, 1st Week, December, 2015
SSHA, 2nd Week, December, 2015
SSHA, 3rd Week, December, 2015
SSHA, 4th Week, December, 2015


SSHA, 1st Week, January, 2012
SSHA, 2nd Week, January, 2012
SSHA, 3rd Week, January, 2012
SSHA, 4th Week, January, 2012
SSHA, 1st Week, January, 2013
SSHA, 2nd Week, January, 2013
SSHA, 3rd Week, January, 2013
SSHA, 4th Week, January, 2013
SSHA, 1st Week, January, 2014
SSHA, 2nd Week, January, 2014
22.0°N
21.0°N
20.0°N
19.0°N
18.0°N
86.0°E
88.0°E
90.0°E
92.0°E

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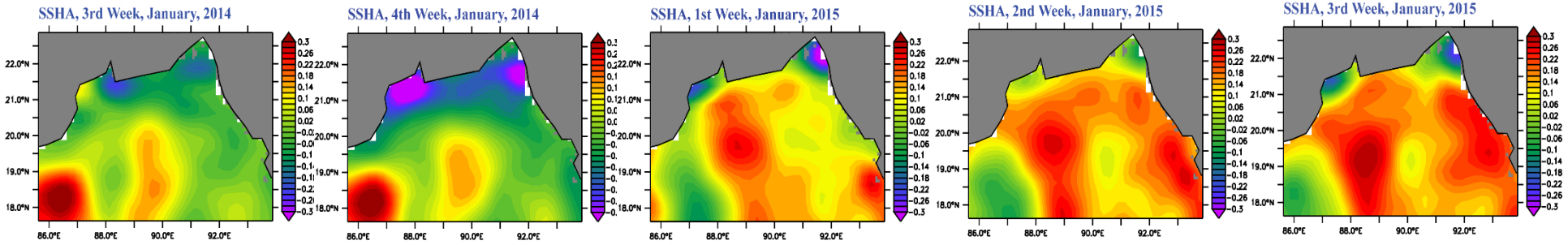
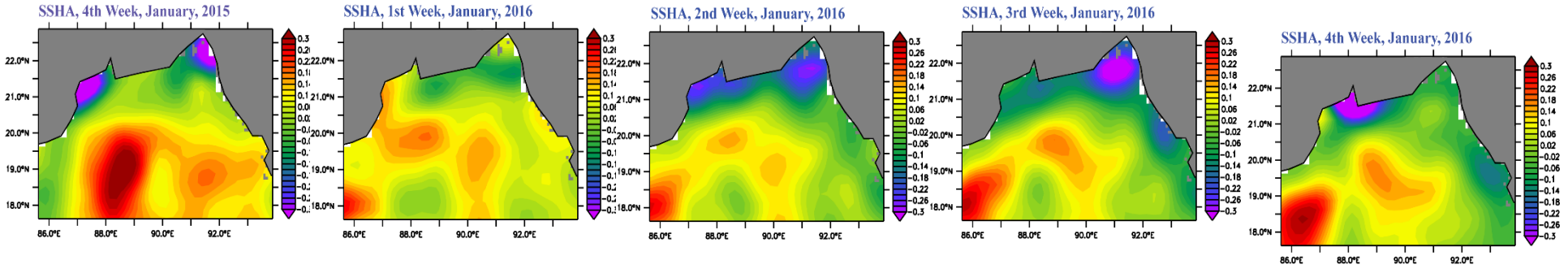
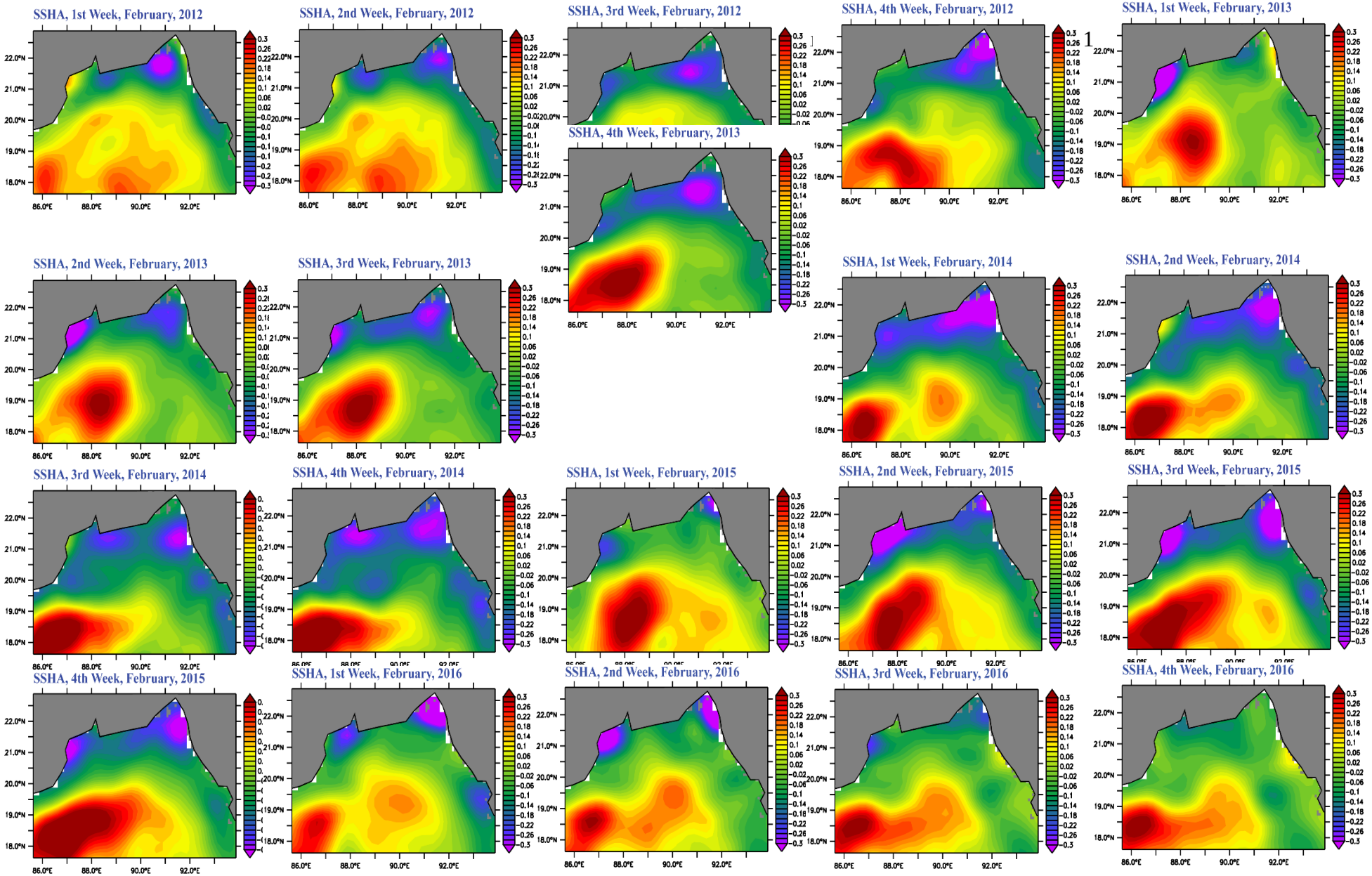
015).


SSHA, 3rd Week, January, 2014
SSHA, 4th Week, January, 2014
SSHA, 1st Week, January, 2015
SSHA, 2nd Week, January, 2015
SSHA, 3rd Week, January, 2015


SSHA, 4th Week, January, 2015
SSHA, 1st Week, January, 2016
SSHA, 2nd Week, January, 2016
SSHA, 3rd Week, January, 2016
SSHA, 4th Week, January, 2016


SSHA, 1st Week, February, 2012
SSHA, 2nd Week, February, 2012
SSHA, 3rd Week, February, 2012
SSHA, 4th Week, February, 2012
SSHA, 1st Week, February, 2013
SSHA, 4th Week, February, 2013
SSHA, 2nd Week, February, 2013
SSHA, 3rd Week, February, 2013
SSHA, 1st Week, February, 2014
SSHA, 2nd Week, February, 2014
SSHA, 3rd Week, February, 2014
SSHA, 4th Week, February, 2014
SSHA, 1st Week, February, 2015
SSHA, 2nd Week, February, 2015
SSHA, 3rd Week, February, 2015
SSHA, 4th Week, February, 2015
SSHA, 1st Week, February, 2016
SSHA, 2nd Week, February, 2016
SSHA, 3rd Week, February, 2016
SSHA, 4th Week, February, 2016
86.0°E
88.0°E
90.0°E
92.0°E
22.0°N
21.0°N
20.0°N
19.0°N
18.0°N

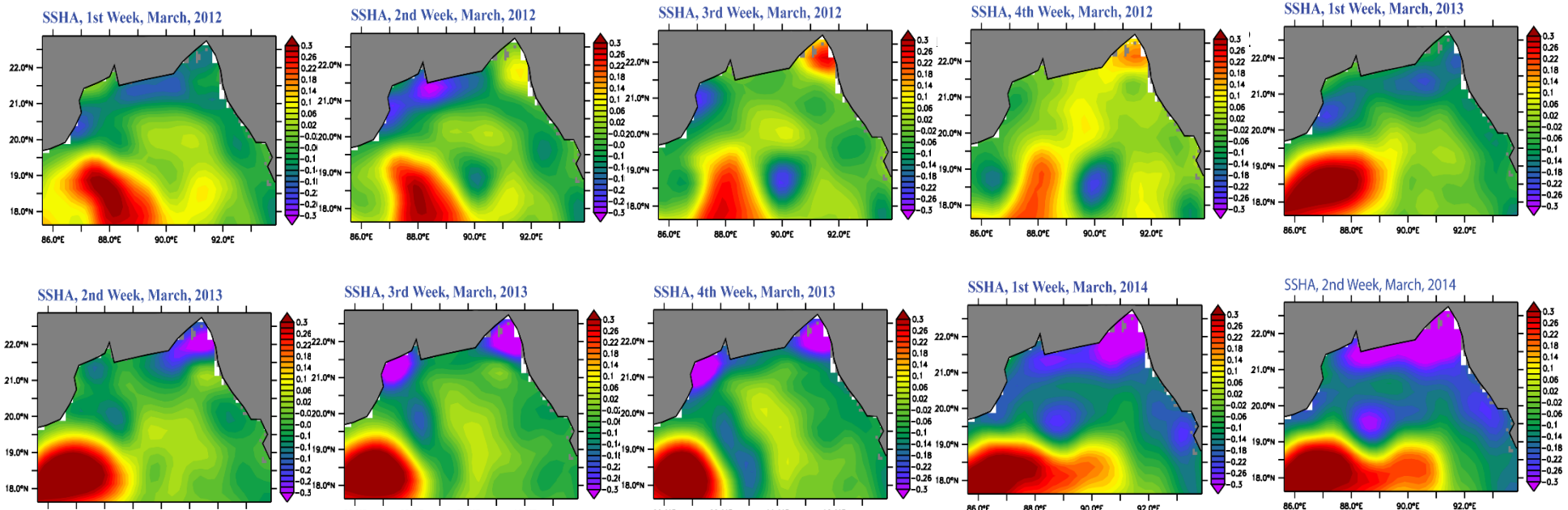

SSHA, 1st Week, March, 2012
SSHA, 2nd Week, March, 2012
SSHA, 3rd Week, March, 2012
SSHA, 4th Week, March, 2012
SSHA, 1st Week, March, 2013
SSHA, 2nd Week, March, 2013
SSHA, 3rd Week, March, 2013
SSHA, 4th Week, March, 2013
SSHA, 1st Week, March, 2014
SSHA, 2nd Week, March, 2014

Fig. 9 Weekly distribution of Sea Surface Height Anomaly (SSHA) profile in northern part of BoB in March (2012-2016).

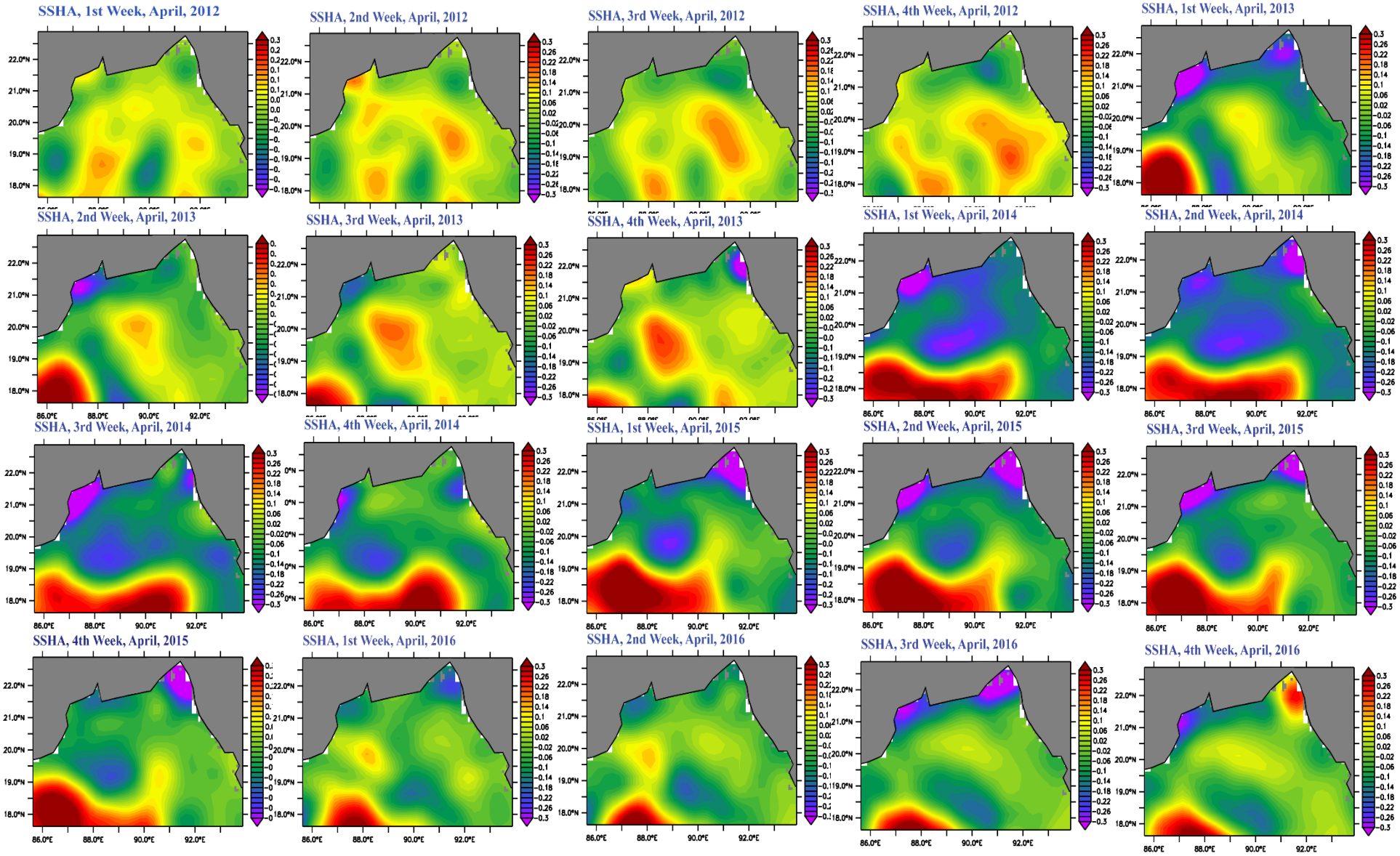

SSHA, 1st Week, April, 2012
SSHA, 2nd Week, April, 2012
SSHA, 3rd Week, April, 2012
SSHA, 4th Week, April, 2012
SSHA, 1st Week, April, 2013
SSHA, 2nd Week, April, 2013
SSHA, 3rd Week, April, 2013
SSHA, 4th Week, April, 2013
SSHA, 1st Week, April, 2014
SSHA, 2nd Week, April, 2014
SSHA, 3rd Week, April, 2014
SSHA, 4th Week, April, 2014
SSHA, 1st Week, April, 2015
SSHA, 2nd Week, April, 2015
SSHA, 3rd Week, April, 2015
SSHA, 4th Week, April, 2015
SSHA, 1st Week, April, 2016
SSHA, 2nd Week, April, 2016
SSHA, 3rd Week, April, 2016
SSHA, 4th Week, April, 2016

Fig. 10 Weekly distribution of Sea Surface Height Anomaly (SSHA) profile in northern part of BoB in April (2012-2016).

3.3 Model derived primary productivity

The VGPM with open ocean parameters including P^B_{opt}, maximum primary production per unit of chl-*a* in the water column, explained only 40% of the variability of integrated primary production. Formulations of the open ocean P^B_{opt} showed no correlation with *in situ* P^B_{opt} *(Ishizaka at el., 2007)***.** Adjustment of the parameters of chl-*a* and temperature dependent P^B_{opt} improved the estimation of integrated primary production to 47% of the variation. Integrated primary production calculated with a stronger light dependency and with the adjusted P^B_{opt} model can explain 74% of the variation. As use of in-situ P^B_{opt} in VGPM explained only 47% of the variability of the integrated primary production then the equation of original VGPM by BFM was fitted to estimate the light dependency parameters of the VGPM with in situ IPP, P^B_{opt}, PAR, Z_{eu} and chl and the modified equation was used in the present study. This study in the northern part of BoB revealed that the estimated primary production following the modified equation provide good estimation rather than another model. Estimated IPP was ranged from 300-1375 $mgCm^{-2}d^{-1}$ with an average value of 450 $mgCm^{-2}d^{-1}$ following *Ishizaka at el., 2007*, for four months (December, January, February, March) with five years time period from 2012-2016. IPP estimated a higher productivity for March where lower productivity was concerned with the month of December (fig. 11) and there was lower sea surface temperature in December compared to March.

3.3 (a) December

Estimated IPP was ranged from 250-1000 $mgCm^{-2}d^{-1}$ with an average value estimate of 450 $mgCm^{-2}d^{-1}$. IPP in the month of December showed a higher temporal variability rather than spatial variation while the northern mouth of BoB was observed with higher productivity than the southern part. A higher temporal variation was observed between 1st week and 2nd week 2013 where the IPP was changed with a higher variability in 2nd week 2013, also it was found for 4th week December 2015(fig. 11).

3.3 (b) January

Estimated IPP was ranged from 300-1000 $mgCm^{-2}d^{-1}$ with an average of 400 $mgCm^{-2}d^{-1}$ in January (fig. 12) following Ishizaka, 85-3000 $mgCm^{-2}d^{-1}$ estimated by KIM with an average of 600 $mgCm^{-2}d^{-1}$. It was observed that IPP estimated following Ishizaka was more fitted than other model and January was occupied with less spatial variability except a few temporal variations.

3.3 (c) March

IPP in March (fig. 14) was varied from 328-2000 $mgCm^{-2}d^{-1}$ 600 $mgCm^{-2}d^{-1}$1with an average of 600 $mgCm^{-2}d^{-1}$, in February IPP was ranged from 350-1500 $mgCm^{-2}d^{-1}$ while the average production was 500 $mgCm^{-2}d^{-1}$. March was characterized with a higher productivity than February but there was less spatio-temporal variation was observed.

IPP showed a range from 1.2-4000 $mgCm^{-2}d^{-1}$ with the average estimates value of 430 $mgCm^{-2}d^{-1}$ in March in KIM model (fig. 18).

KIM 2005:

Estimated IPP was varied from 200-3500 $mgCm^{-2}d^{-1}$ (average 500 $mgCm^{-2}d^{-1}$) in February estimated from KIM model, 80- 1600 $mgCm^{-2}d^{-1}$ (average 400 $mgCm^{-2}d^{-1}$) in December and

85-3000 $mgCm^{-2}d^{-1}$ (average 520 $mgCm^{-2}d^{-1}$) in January. Two- phytoplankton community model results showed that the chlorophyll-specific productivity of small-sized phytoplankton tends to be higher than that of large-sized phytoplankton.

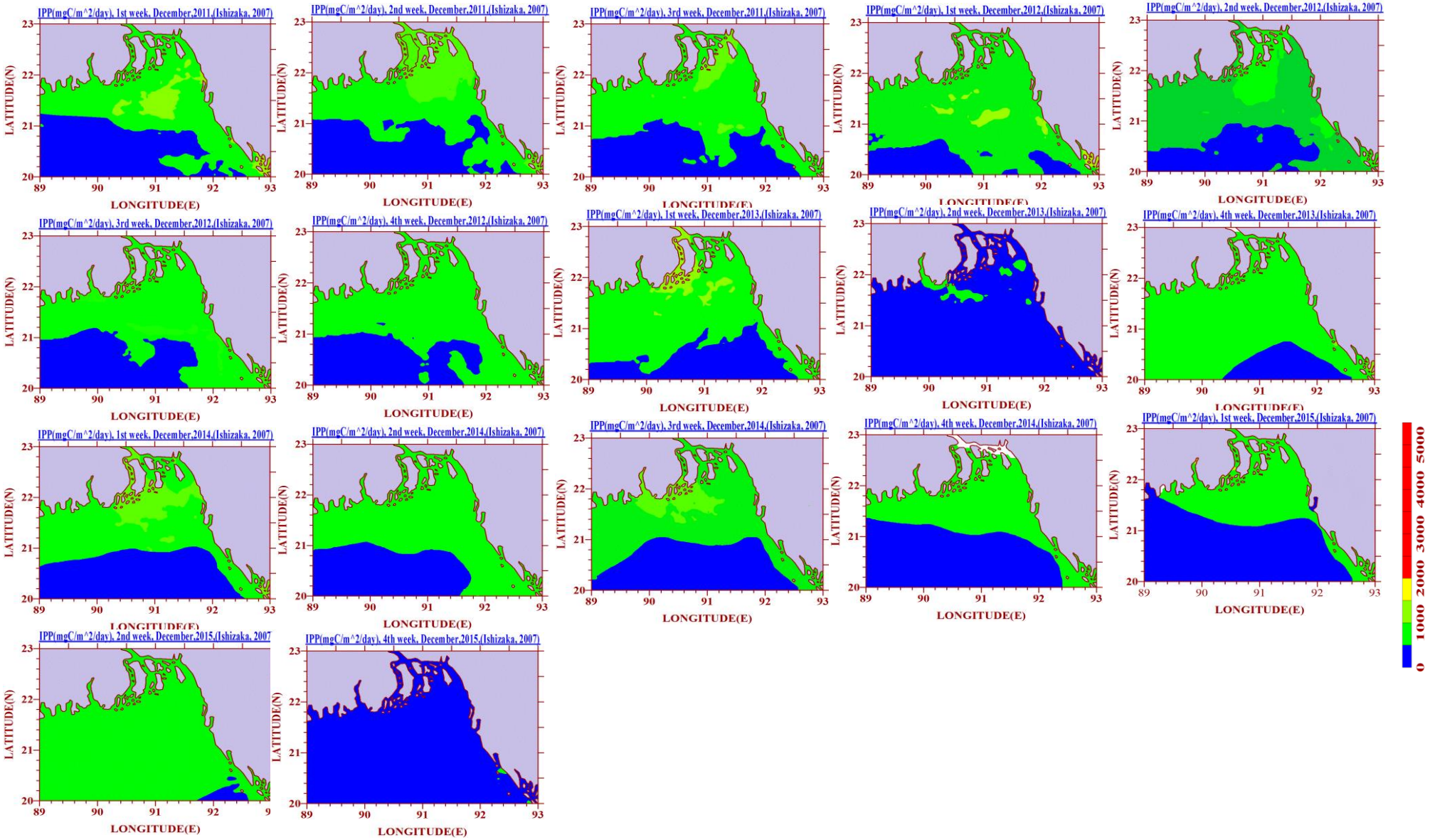
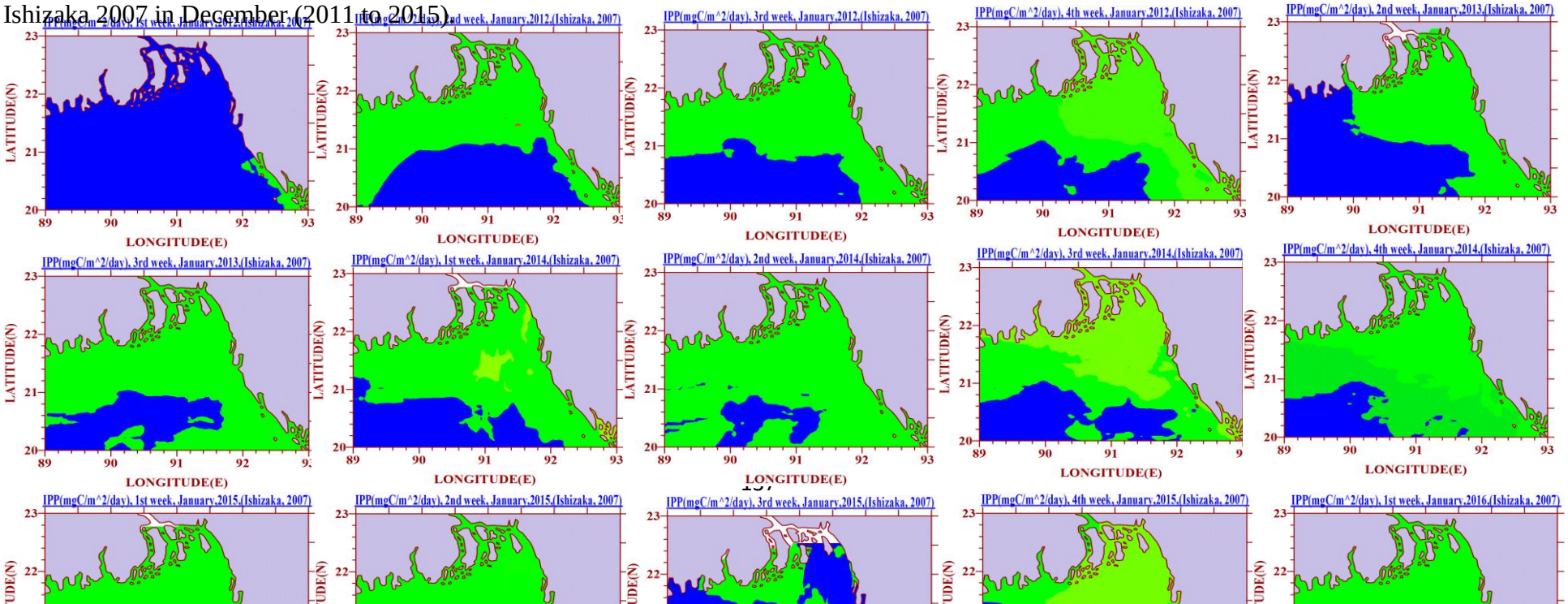

IPP(mgC/m^2/day), 1st week, December,2011,(Ishizaka, 2007)
IPP(mgC/m^2/day), 2nd week, December,2011,(Ishizaka, 2007)
IPP(mgC/m^2/day), 3rd week, December,2011,(Ishizaka, 2007)
IPP(mgC/m^2/day), 1st week, December,2012,(Ishizaka, 2007)
IPP(mgC/m^2/day), 2nd week, December,2012,(Ishizaka, 2007)
IPP(mgC/m^2/day), 3rd week, December,2012,(Ishizaka, 2007)
IPP(mgC/m^2/day), 4th week, December,2012,(Ishizaka, 2007)
IPP(mgC/m^2/day), 1st week, December,2013,(Ishizaka, 2007)
IPP(mgC/m^2/day), 2nd week, December,2013,(Ishizaka, 2007)
IPP(mgC/m^2/day), 4th week, December,2013,(Ishizaka, 2007)
IPP(mgC/m^2/day), 1st week, December,2014,(Ishizaka, 2007)
IPP(mgC/m^2/day), 2nd week, December,2014,(Ishizaka, 2007)
IPP(mgC/m^2/day), 3rd week, December,2014,(Ishizaka, 2007)
IPP(mgC/m^2/day), 4th week, December,2014,(Ishizaka, 2007)
IPP(mgC/m^2/day), 1st week, December,2015,(Ishizaka, 2007)
IPP(mgC/m^2/day), 2nd week, December,2015,(Ishizaka, 2007
IPP(mgC/m^2/day), 4th week, December,2015,(Ishizaka, 2007)
LATITUDE(N)
LONGITUDE(E)
0 1000 2000 3000 4000 5000

Fig. 11 Weekly spatio-temporal distribution of estimated integrated primary productivity ($mgCm^{-2}d^{-1}$), in the northern part of BoB based on Ishizaka 2007 in December (2011 to 2015)




0
1000
2000
3000
4000
5000

Fig. 12 Weekly spatio-temporal distribution of estimated integrated primary productivity ($mgCm^{-2}d^{-1}$), in the northern part of BoB based on Ishizaka 2007 in January (2012 to 2016).

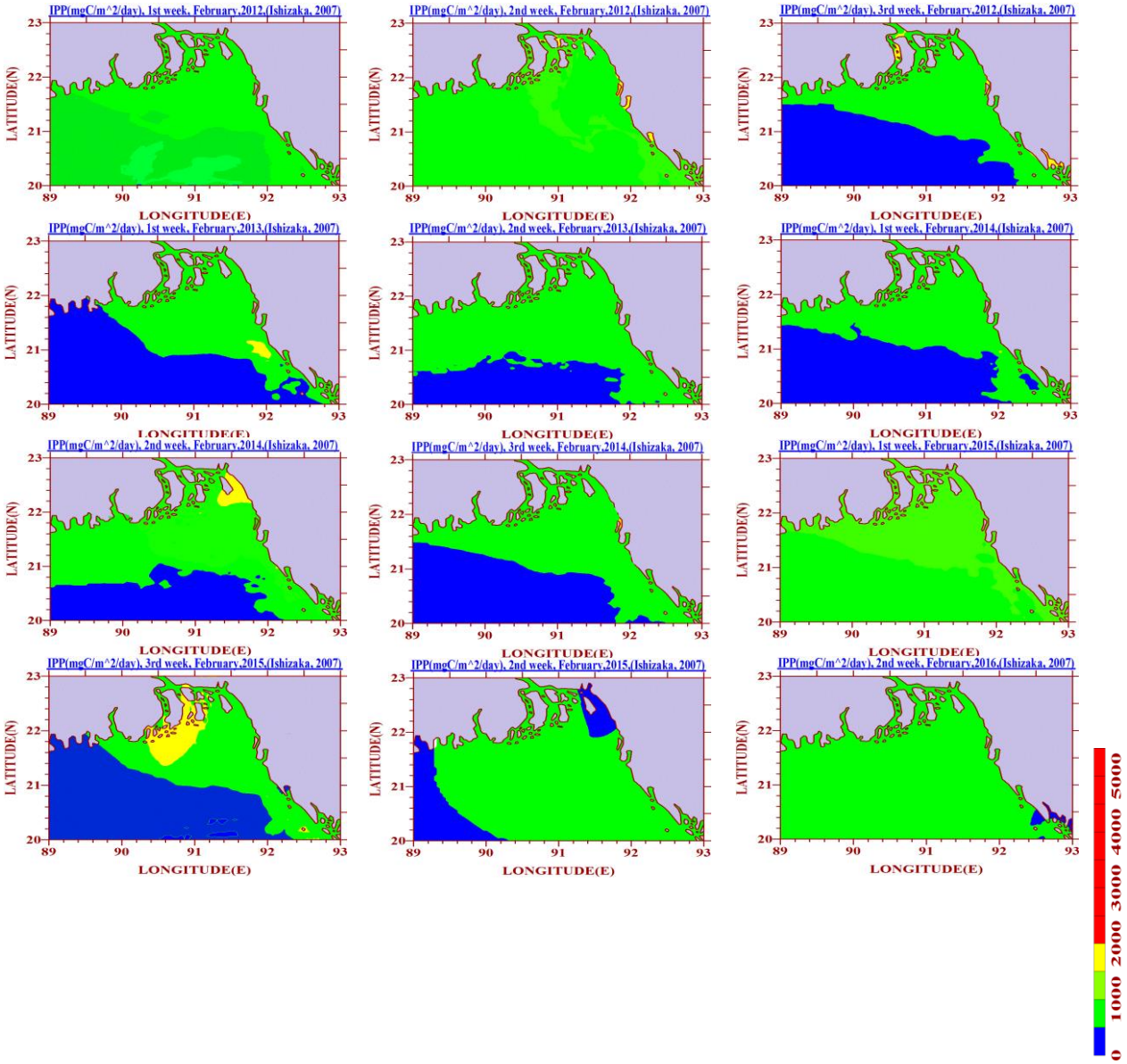
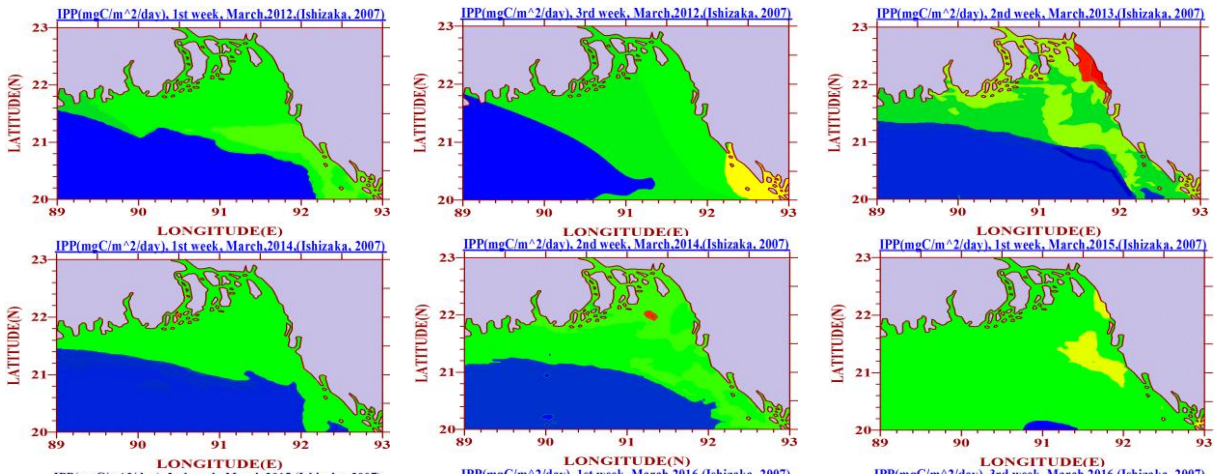


Fig. 13 Weekly Spatio-temporal distribution of estimated integrated primary productivity ($mgCm^{-2}d^{-1}$), in the northern part of BoB based on Ishizaka 2007 in February (2012 to 2016)



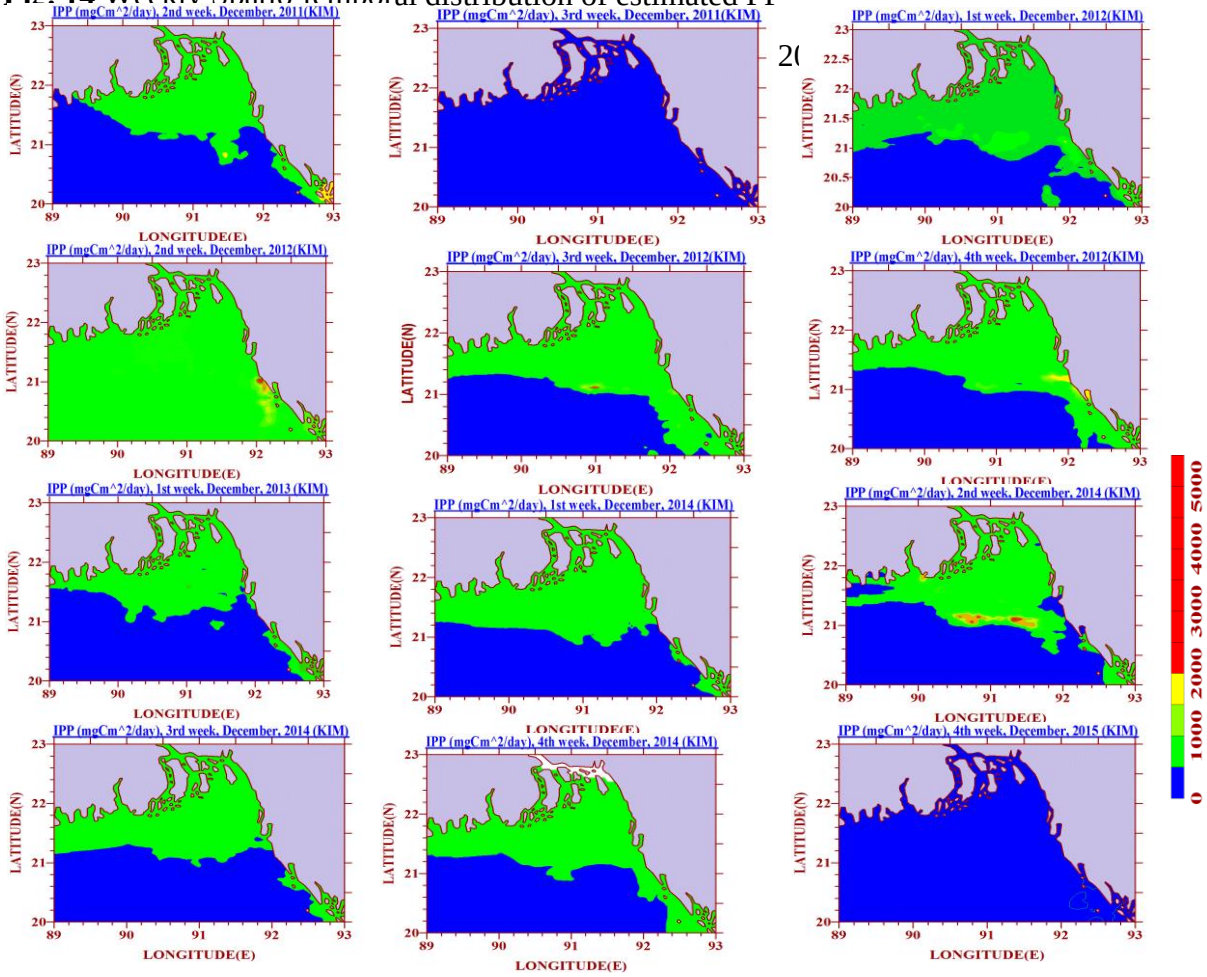


Fig. 14 Weekly Spatio-temporal distribution of estimated PP 2(

Fig. 15 Weekly Spatio-temporal distribution of estimated PP ($mgCm^{-2}d^{-1}$), in the northern part of BoB based on KIM, 2005 in December (2011 – 2015).

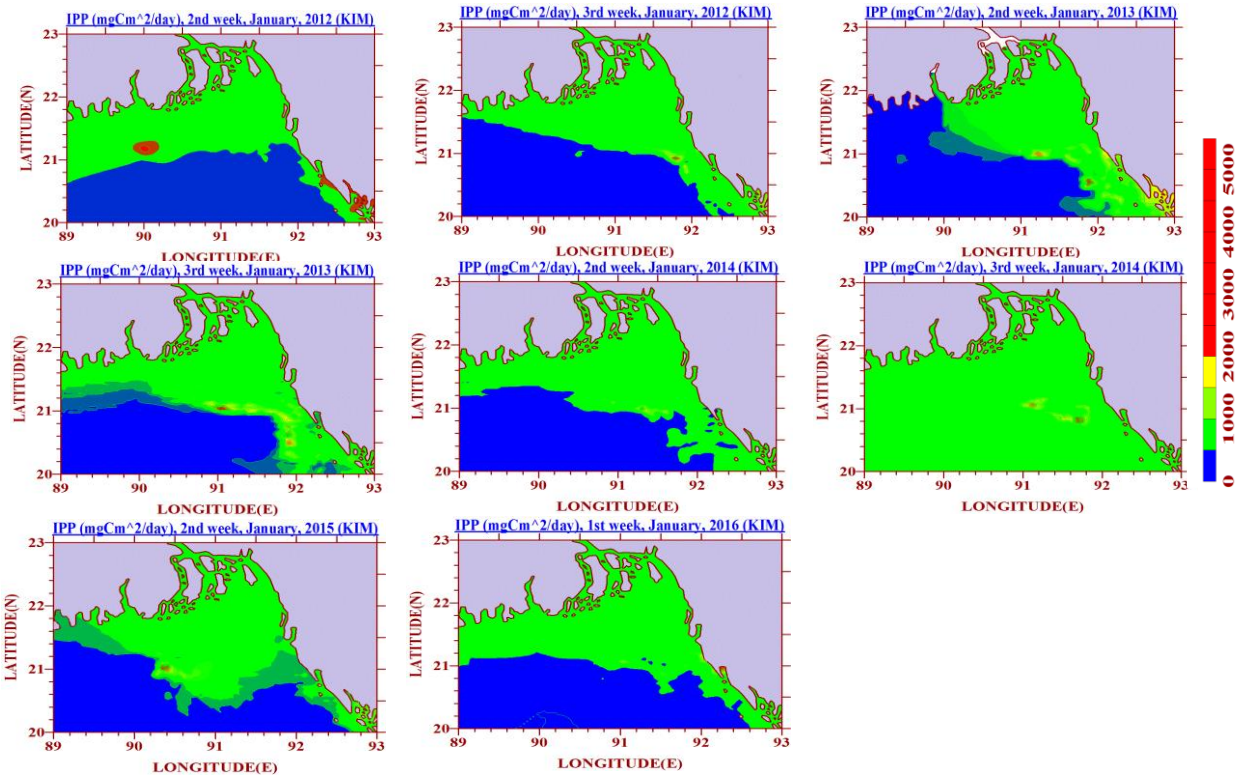
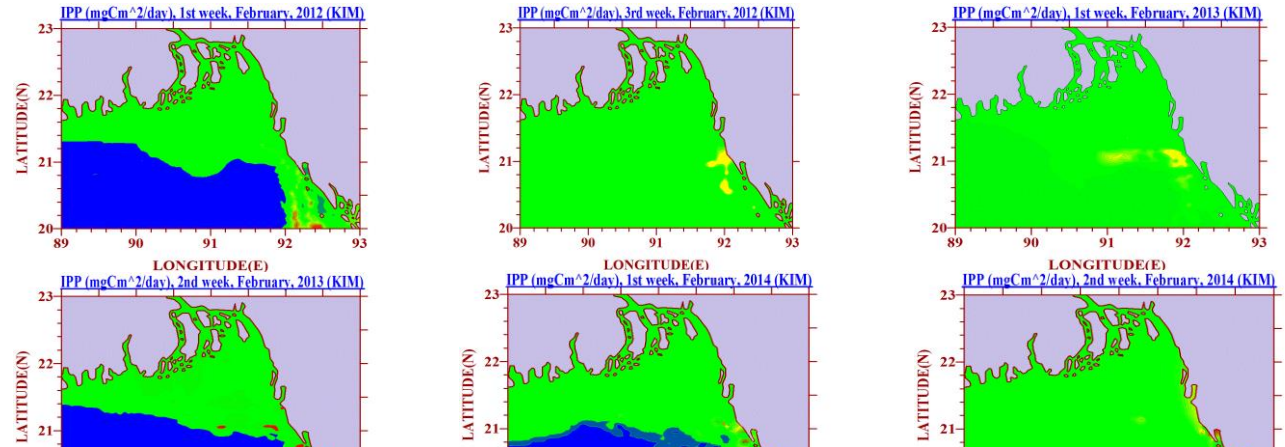


Fig. 16 Weekly Spatio-temporal distribution of estimated PP ($mgCm^{-2}d^{-1}$), in the northern part of BoB based on KIM, 2005 in January (2012 – 2016).



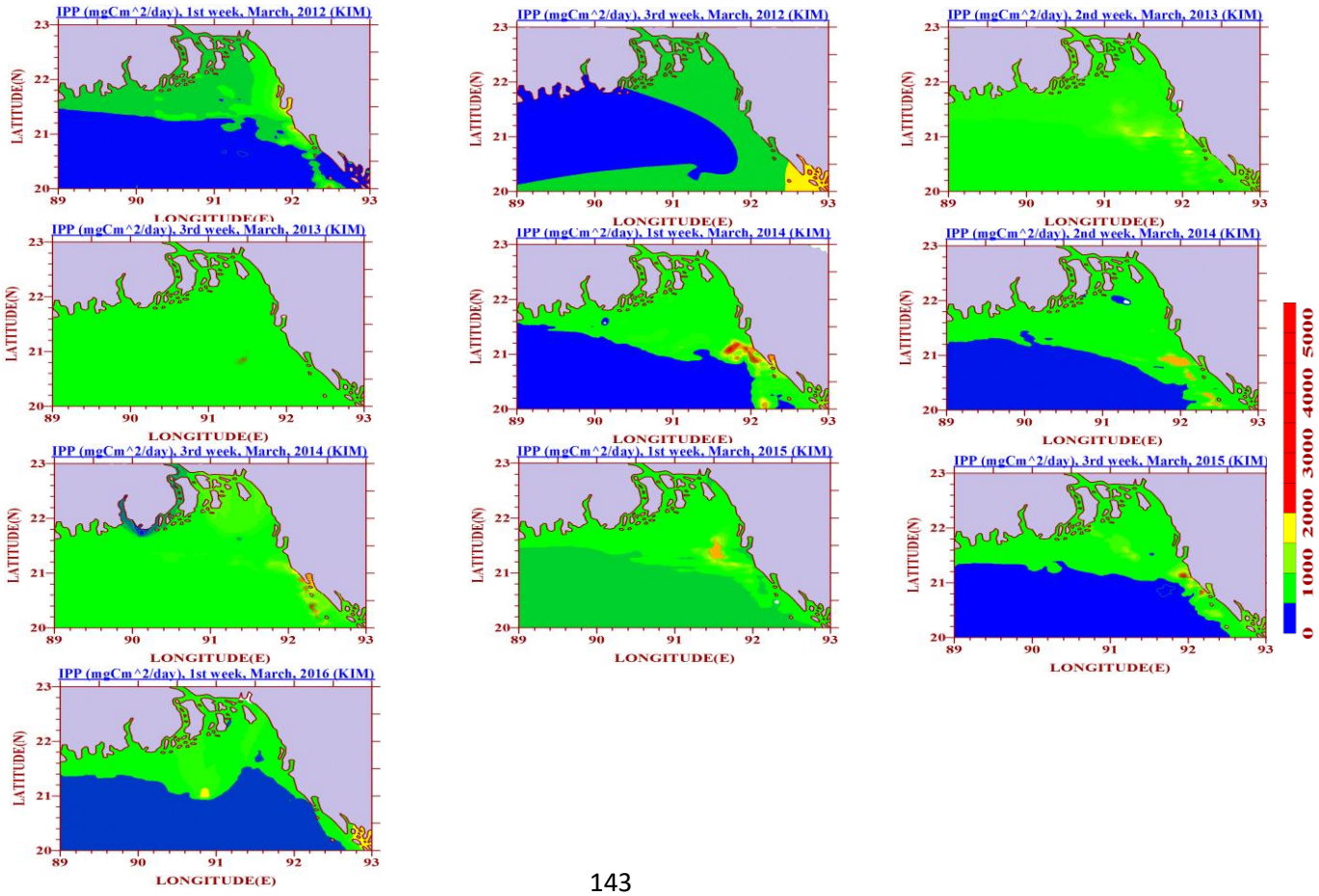


Fig. 17 Weekly Spatio-temporal distribution of estimated PP ($mgCm^{-2}d^{-1}$), in the northern part of BoB based on KIM, 2005 in February (2012 – 2016).

Fig. 18 Weekly spatio-temporal distribution of estimated PP ($mgCm^{-2}d^{-1}$), in the northern part of BoB based on KIM, 2005 in March (2012 – 2016).

3.4 In-situ measured primary productivity

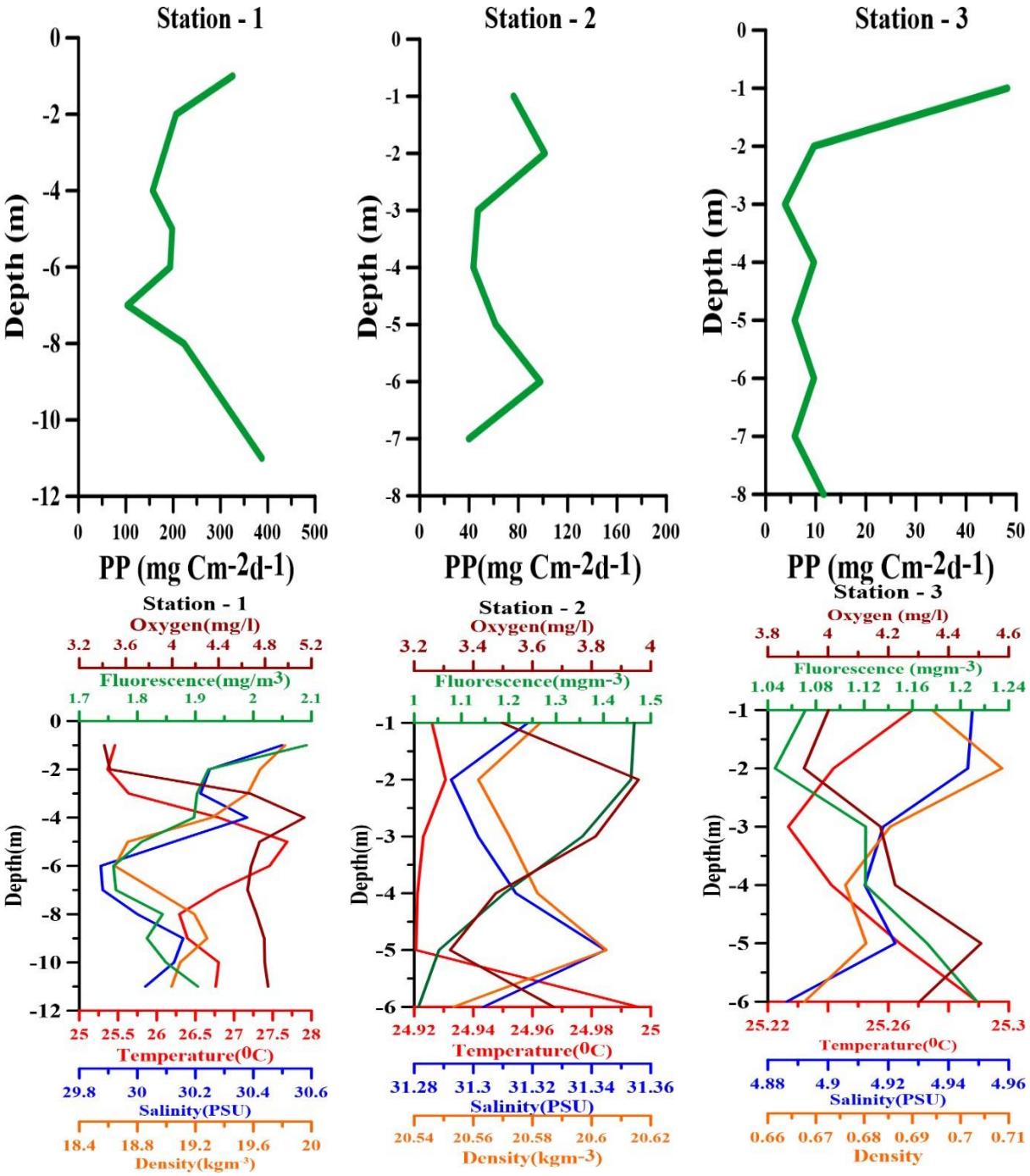


Fig. 19 Vertical profile of in-situ measured primary productivity and physical parameters. Measured Primary productivity was ranged from 8 – 400 $mgCm^{-2}d^{-1}$. Lower value of IPP was also governing with March when estimated by VGPM of Ishizaka and the higher value was confined to February but the value was different when estimated by KIM and the average lower value was confined to January where the higher value was in February 2016. Higher variability of IPP was observed from 2012-2016 and also among different months. Standard deviation and average primary productivity showed a less variation among the estimated value from VGPM of BFM and Ishizaka where a large variability was observed when IPP estimated with KIM.

Table 1 Pearson correlation matrix among the parameters derived for estimation of primary productivity, VGPM model by Ishizaka 2007.

Variables	**(X1)**	**(X2)**	**(X3)**	**(X4)**	**(X5)**	**(X6)**	**(X7)**	**(X8)**	**(X9)**
Chlorophyll (mgm^{-3}) (X1)	1								
SST (^0C) (X2)	-0.164 [a]	1							
PAR (einstein m^{-2} day^{-1}) (X3)	0.009[a]	0.035[a]	1						
k490 (X4)	0.131 [a]	-0.129[a]	0.075[a]	1					
Popt (photosynthesis rate) (X5)	**-0.718***	0.212[a]	-0.063[a]	-0.138[a]	1				
Kpar (X6)	0.131 [a]	-0.129[a]	0.075[a]	**1***	-0.138[a]	1			
Zeu (euphotic depth, m) (X7)	**-0.916***	0.177[a]	-0.026[a]	-0.132[a]	**0.896***	-0.132[a]	1		
Daylength (hour) (X8)	**-0.340***	**0.553***	-0.042[a]	**-0.336***	**0.412***	**-0.336***	**0.352***	1	
Primary Productivity ($mgCm^{-2}d^{-1}$) (X9)	**0.902***	-0.168[a]	0.180[a]	0.139[a]	**-0.887***	0.139[a]	**-0.986***	**-0.349***	1

a = Absolute correlation values below 0.291 are not statistically significant *(Neto et al., 2015)*, *** =** Absolute correlation values above 0.291 are statistically significant. Photosynthesis rate negatively correlated with chlorophyll concentration. Primary productivity estimated by Ishizaka followed by a positive relation with chlorophyll concentration where negatively correlated with photosynthesis rate, euphotic depth and daylength of the day.

Table 2 Person correlation matrix among the parameters derived for estimation of primary productivity, VGPM model by KIM 2005.

Variables	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(X7)	(X8)	(X9)
Chlorophyll (mgm^{-3}) (X1)	1								
SST (^0C) (X2)	-0.233 [a]	1							

PAR (einstein m^{-2} day^{-1}) (X3)	0.007	-0.058 [a]	1						
k490 (X4)	0.998*	-0.214 [a]	0.0007 [a]	1					
Popt (photosynthesis rate) (X5)	0.223 [a]	-0.924*	0.160 [a]	0.202 [a]	1				
Kpar (X6)	0.998*	-0.214 [a]	0.0007 [a]	1	0.202 [a]	1			
Zeu (euphotic depth, m) (X7)	-0.955*	0.176 [a]	-0.041 [a]	-0.965*	-0.162 [a]	-0.965*	1		
Daylength (hour) (X8)	-0.171 [a]	0.442*	-0.291*	-0.138 [a]	-0.527*	-0.138 [a]	0.094 [a]	1	
Primary Productivity ($mgCm^{-2}d^{-1}$) (X9)	0.890*	-0.573*	0.129 [a]	0.884*	0.561*	0.884*	-0.869*	-0.365*	1

a = Absolute correlation values below 0.291 are not statistically significant *(Neto et al., 2015)*, *** =** Absolute correlation values above 0.291 are statistically significant. Photosynthesis rate showed a different type of relation in KIM model where the rate is negatively correlated with sea surface temperature, whether it was related with only chlorophyll in the model of Ishizaka. Finally, primary productivity found to be positively correlated with chlorophyll concentration, k490, photosynthesis rate, Kpar and negatively correlated with SST, euphotic depth and daylength of the day.

Conclusion

Established two different forms of VGPM model of estimating primary production was performed for this region to show the primary productivity and in additional, SST and SSHA was studied for this region to describe upwelling and downwelling phenomena with its further influence with temperature. Sea surface temperature over the northern part of BoB varied from 21^0C to 29^0C and the northern head of the BoB was experienced with a lower of 21^0C temperature. Lower temperature area at the head of the BoB was observed with upwelling zone with lower sea level but these upwelling was not strong enough for mixing of water column. These upwelling phenomena over northern part of BoB cannot break the thick Barrier Layer and this Barrier Layer inhibits mixing of nutrients rich bottom water coming to the surface, finally makes the BoB less productive. Estimated primary production from three different form of VGPM model was revealed for a higher production at the northern head of the BoB and comparatively lower production was confined to the southward area of BoB. Among two models of estimating primary production, the modified model of Ishizaka 2007 in the original VGPM was fitted more for the present study, where weekly average Integrated Primary production was 450 $mgCm^{-2}d^{-1}$ in December, 400 $mgCm^{-2}d^{-1}$ in January, 500 $mgCm^{-2}d^{-1}$ in February, 600 $mgCm^{-2}d^{-1}$ in March, estimated for a time period of 2012-2016 in north-eastern part of BoB. Probably the use of PAR (Photosynthetically Active Radiation) in calculating euphotic depth for BFM model and KIM model make them less valid for north-eastern part of BoB and the use of chlorophyll (C_{opt}) in calculating euphotic depth for VGPM of Ishizaka 2007 make it more valid for this region. Upwelling area observed from Sea Surface Height Anomaly was governed with higher productivity and the downwelling area toward the south part found with lower primary productivity.

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