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Introduction

1.1 Introduction

This introductory chapter briefly presents the topic of present research ‘Sea Level Rise due to Climate Change and its Impact along the Coast of Mumbai’, stating the importance for the present research work and objectives of the research. The work has been carried out referring to the contributing factors like Global Warming, Green House Gas effect, Effects on Glaciers etc., which have culminated into the present alarming scenario of Sea Level Rise (SLR) across the globe.

Scientists, along with various stakeholders/policy makers of Coastal cities all over the world are seriously concerned about the ever-increasing and presently accelerating sea level rise. Globally, the low-lying island cities, cities on the coasts are under threat because of the quantum of SLR envisaged in coming years. Majority of the causes of global warming scenario being

anthropogenic, all stakeholders need to take appropriate measures for future planning of coastal developments including rehabilitation of habitats. History indicates that the civilization is going to face this challenge and scientific studies have established that we are going to a phase of no return, and there is no alternative than to find appropriate remedial measures to the extent possible. As a matter of fact, it is an issue of life and death for the mankind.

It is already an established fact that Earth's climate is changing and major components of this change happened due to human activities. The changes in climate calls for increase in protection to human habitation either by adapting with the changes or may be migration, which in any case will affect economy around the world. From the long-term observations it is observed that Greenhouse gases are being added to troposphere and increasing temperature therein; from top of the atmosphere to the lowest point of the oceans. These additions will keep on affecting the climate around the earth for the coming years for long. The future changes in environment are anticipated to imbibe additional upset in various aspects of life. While change in climate is an unavoidable worldwide phenomenon, the changes in climate are not even across the planet.

Some of the influences are by now apparent and are apprehended to develop progressively unsystematic condition across the world. The seriousness of effects arising out of future alteration in climate will largely persist subject to actions taken to decrease emissions of the greenhouse gases and society's reaction to aberrations that may occur. Policy makers are required to have an extremely important for, to have an unadulterated complete knowledge regarding imminent predictions about climate.

The fact that anthropogenic forcing has increased heating of surface of the Earth approximately by about 1°C in last one and half century, has been unequivocally agreed in the series of Assessment Reports of IPCC, the

international agency who deals with the science related to changes in climate (Kaufman, D. et.al. *Scientific Data* 7, 2020). Consequently, this warming has displayed changes in precipitation patterns, rise in water levels in sea, contributed by liquification of glaciers in a global-scale, including change in weather and overindulgences in extraordinary meteorological conditions.

The predictions in changes in climate, however, may have large doubts. One of such uncertainties is assessing the future quantum of greenhouse gas emissions. Sofar as the current scenario exists the following facts are noted as a matter of concern.

Since last century human activities have extensively increased absorptions of various gases, which has trapped heat in the atmosphere. heating GHG. These gases include CO₂, CH₄, N₂O and fluorine. CO₂ amongst other gases interrelated to anthropological actions within the GHGs which continuously last in the troposphere for long. Among other anthropogenic activities, the reason for fast increase of atmospheric CO₂ levels is using energy from fossilised fuels, reducing forestation, and changes in land use. According to AMS Bulletin (American Meteorological Society-Vol.101,2020; CO₂ levels in atmosphere have increased much in February 2020 (more than 416ppm) than what it was in from 1850 (280 ppm).

As the GHG concentrations continue to rise such changes in climate are anticipated to persist through the 21st century and beyond. One of the major consequences is the rise in water level at seas due to of warming of the oceans andthe liquification from glaciers. The probable changes in future scenarios of climate, which our world is likely to face are predicted by scientists using Climate models. What we are experiencing at present have more or less been accurately projected earlier projected through these models, derived from simulation which itself is a very complex scientific process. Through the continuously evaluating models of climate perpetuation of anthropogenic-

induced changes in climate during this century and even beyond are envisioned globally.

Near-shore cities throughout the world are exposed to such threats from SLR. India, being a country with a very long coastline about 7516.6 km in totality approximately considering 6,100 km in its mainland and 1416.6 Km around the large number of islands (Wikipedia), will also face similar consequences. As part of the present work, researches so far done by various academic and research institutions in the country and abroad along with data from satellite images, have been studied and reviewed. It is observed that various study reports on Sea Level Rise at India's East Coast, South Western Coast, Southern areas etc. are available in literature. However, thorough research on Rise in Sea Level at Mumbai coast including prediction of such rise on account of Global Warming for the coming few decades is not found in plenty.

It is felt by the author of this report that a thorough evaluation on the impact of SLR due to global change of climate on the coast of Mumbai is necessary, because Mumbai is an important city not only in India, but also in the world. The city is already flood prone in monsoon due to its low tidal locking period and antique drainage system. Any disaster happening out of rise in the sea level to this city can be catastrophic. It is trusted that this thesis report will be useful as a lead for taking decisions related to future planning and mitigation measures.

Accordingly, the study on vulnerability at the coast at Mumbai, arising out of rise in sea level has been proposed. Zone considered for the study and research is at approximately 67 Km long stretch of shoreline at coast of Mumbai from Pali(at North) to Sasane (towards Alibaugh at south i.e., from Latitude/Longitude- $19^{\circ}17'53.2''$ N & $72^{\circ}47'03.02''$ E to $18^{\circ}47'04.93''$ N & $72^{\circ}52'04.59''$ E. Rise in sea level is proposed to be studied for a period of

thirty (30) years from now i.e., from 2020 up to 2050.

1.2 Background

IPCC was formed by WMO and UNEP for evaluating the risk of variations in climate by understanding scientific, socio-economic and technical information. IPCC report shows that the ocean level (globally) is currently accelerating at the rate of about 3.6 mm per annum. Global emissions of Gases (GHG) are contributory to acceleration of change in Global climate and the process by which heat is trapped by Earth is termed as the greenhouse effect. Rapid industrialization, deforestation, pollution and other anthropogenic contributions related with various human needs by sacrificing the nature's original balance for decades particularly in the last century have been the major factors responsible for global warming. The trapped extra heat near earth's body has triggered the temperatures to rise. Over last 100 years, global temperatures have warmed by about 1.33°F (0.74°C) on the average. Approximately about 0.4°C (0.72°F) rise happened subsequent to 1979. As oceans have a tendency to be heated and cooling down in slower pace than land, continents over the North Hemisphere have been warmer by about 0.7°C (1.26°F) after 1979 (*IPCC's Climate Change 2007: Synthesis Report; Summary for Policymakers*).

Current scenario in Warming is globally alarming as the heat produced due to absorption of almost all of the greenhouse gases, humans spew into the atmosphere amounts to 228 sextillion (228×10^{21}) joules of heat above its average (*Cheng, L et.al. Adv. Atmos. Sci. 38, 2021*) which is a record-breaking high. The extent of heat may be compared with the energy released by explosion of 'Little Boy' type atom-bomb on August 06, 1945 at Hiroshima, which was about 63×10^{12} Joules (*Wikipedia*). Oceans are one of foremost unit of the climate arrangement and being exposed to solar heat more than 90% of the heat absorbed by the Earth is trapped by oceans. Over the last 50 to 100 years, it

carried and transported great quantities of heat which resulted to warming at global level [(G. C. Johnson et.al.; *AMS Bulletin (American Meteorological Society)*- Vol.102 (8),2021)]. Heat and saltiness both are significant for contributing towards local changes in water level sea, but the impact of temperature is the most ruling factor for changes in water level in sea. The severity of expanding of ocean water varies mainly on the amount of temperature and absorbed heat due to the rise in temperature (ocean water expands after warming), pressure (more expansion at depth), and saltiness (more in saltier water, although to a smaller extent than others). Rise in Sea Level relates to the variations of mass of water in the oceans(expansions), because of melting of ice sheets and ice cliffs within ocean and also from runoff at surface level of land. One important impact of anthropogenic contributions to changes in the environment is rise in Sea level which is a serious threat in coastal regions all over the globe.

Mean Sea Level Rises globally due to decrease in ice mass in addition to increase of ocean mass, happening due to warming. At any particular location, the local responses to SLR are known as relative sea level (RSL). In general, GMSL influenced by climate events varies by a dissimilarity of factors locally, some of which are predominantly influenced by human activity. Specifically, in delta regions and near shore cities, one such parameter because of SLR is anthropogenic subsidence, which increase rates of RSL rise by considerable order of magnitude. IPCC reports already documented that non-climatic anthropogenic driver have already played a very significant role in increasing vulnerability of coastlines to Rise in Level of Sea Water and extreme weather events. The combination of extreme sea level events such as surges and waves in association with the gradual change in Mean Sea Level cause serious effects on coasts. It is predicted that frequency of incidences of extreme weather events at many locations along the coast will occur more in the future, which for obvious reasons is a matter

of serious concern. Observational systems (remote sensing techniques, wave buoys and tide gauges) should be sufficiently activated such that intensities of ESL events are well understood with adequate observational data, which will be useful to strategize arrangements for remedial recourses to the damages/disturbances, which are likely to happen during future SLR.

Mixture of small particles with high variety in composition (chemical) and distribution (size) including those from liquid suspension or solid resulting from human activities are known as atmospheric aerosols which also influence climate.

However, as aerosols aren't distributed evenly round the planet like many greenhouse gases, aerosol impacts are mostly felt on a regional scale. Aerosol particles are either emitted directly or formed in the aerosphere from predecessor gases. Some aerosol particles primarily reflect radiation and influence the atmosphere by warming the encompassing air. When aerosols heat the atmosphere, they create an unstable disturbed environment. Global climate change is intricately related to aerosols from Green House Effect and indirectly contributes to Sea Level Rise.

Paris Agreement in 2016 was signed by 196 parties as per decisions taken at the Conference the UNFCCC at France on 12th December 2015. This agreement dealt mitigation, adaptation, and finance supported consensus related with emissions of greenhouse-gas. It was recognized that reduction of emissions is able to substantially lessen the menaces and effects of global change in climate. A long-term goal to retain rise of average temperature globally below 2 °C (3.6 °F) was decided in the Paris Agreement, in addition to creating policies to pursue diligence to restrict the rise within 2.7⁰F (1.5⁰C) compared to preindustrial time.

It is believed by Climate Scientists that at the top of this century, globally the rise in mean sea level effortlessly will surpass 1 m, together with

upsurge in intensity of storm (*Horton et.al. Climate and Atmospheric Science, 3, 2020*). The coastal changes due to Sea Level Changes also vary depending upon the Coastal Geometry, variation in Hydrodynamic factors, wind, wave, sedimentation patterns and bed soil parameters. Changes Climate although is a global phenomenon, the effects of these changes are likely to differ significantly in diverse regions.

1.3 Importance of the Present Work

The calculation of rise in sea level and its resultant effect on shoreline changes during the forthcoming decades will be helpful to find out the mitigation measures required to combat the challenges arising out of probable flooding, inundation, relocation of breakwaters, and redesigning the various marine structures in the ports. Influence of climate change on shorelines does not only depend on ocean parameters alone. Review of parameters like effect of longer-term rise of water level on evolving road networks, infrastructure, possible relocation of coastal habitants all these are equally important for long term planning.

Whatever happens in the coastal regions of other parts of the globe will not necessarily be same in Indian coasts. Even the impact of changes in climate is not likely to be same throughout the coastline. The effect of rise in Sea water Level is usually more at Eastern Coast than that in West Coast of India (*Shankar et.al.; Geophysical Research Letters, VOL. 28, NO. 4, 2001*). The various physical factors like geomorphology, gusts, surfs, surges, shoreline drift, sediment characteristics, shore geometry, effects of bays, estuaries and mud-banks etc. are also required to be studied in the West Coast of India including in particular those at Mumbai to arrive at accurate assessment of situation.

On reviewing the conditions post 2004 Tsunami and severe flooding at Mumbai in 2005, researchers pointed out (*Dhiman et.al. Appl Water*

Sci 9, 5,2019), that Mumbai will also be exposed to possible intensifications in risks related with rise in sea level, storms and heaves as the cascading consequences from heat waves.

The results from this study are intended to suggest alternate approaches to minimize the consequences out of change in climate at shorelines of Mumbai which will help stakeholders to budget and strategize the constructions at coasts by making it future-ready. The output of this study will act as an important scientific input to augment the decisions to be taken by the decision-makers for a better future.

1.4 Objectives

The subject study and research have been completed at a specific point Latitude/Longitude: 18.9220° N, 2.8347° E, particularly at shore point underneath Gateway of India, the historical monument, which lies in between the stretch of 67 Km shoreline of Mumbai (Para 1.2). The rise in sea level for a period of 30 years from 2020 i.e., up to 2050 has been calculated with the help of one state of the art software i.e., MIKE21.

The present research study has been taken up for exploring the following set of objectives:

- i. To find and predict climate change induced rise in sea level along the coast of Mumbai
- ii. To predict Sea Level Rise along Mumbai coast up to 2050 using IPCC AR4's method & Grinsted's method
- iii. To assess the probable consequences/effects of Rise in Sea Level along the Mumbai coast based on the present study
- iv. To propose changes on the codal provisions for Marine Structures and related regulations affected by sea level rise.