3

MATERIALS AND METHODS

This chapter deals with the methodology utilized for achieving the desired objective including pertinent information on data sources and necessary use of relevant software to arrive at the goal of the research. This chapter also deals with the materials that have been used for the purpose of the proposed research, described in the earlier chapter.

3.1 Study Area

Out of India's 7516.60 km, Maharashtra's coastline is 652.6 km long the western coast of Mumbai from Pali to Sasane having the following co-ordinates with a shoreline distance of approximately 67 km has been considered as the chosen stretch of consideration for the purpose of the present study.

Points	Lat/Long	UTM 33 Decimal Degrees
Mumbai North End	$19^{0}17'53.2''$ N &	19.298111111111112
	72^{0} $7'03.02''$ E to	72.11750555555555
South End towards	$18^{0}47'04.93''$ N &	18.78470277777778
Alibaugh	$72^{0}52'0$ $59''$ E	72.86794166666667

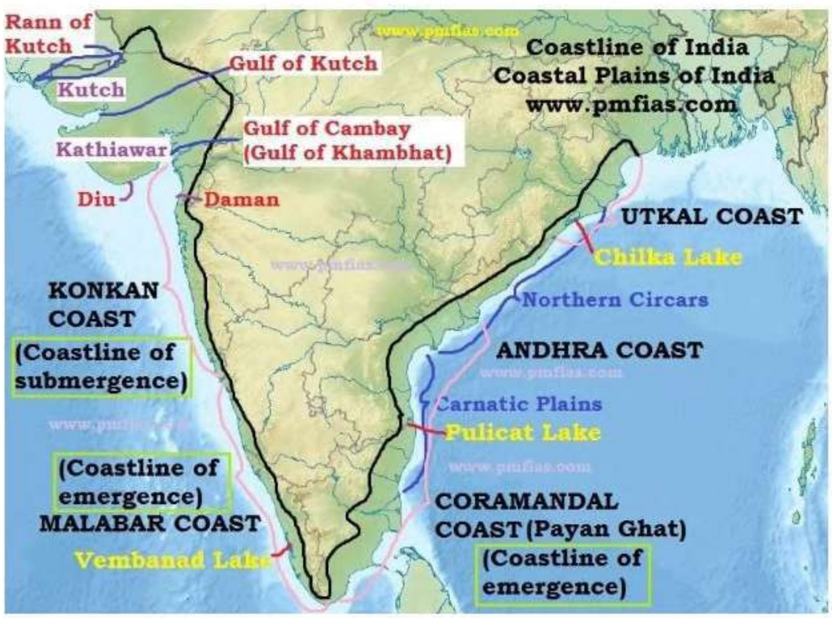


Figure 3.1: *Indian Coast*

For the purpose of calculation of rise in Sea Level, location at Gateway of India, famous monument at Nariman Point in Mumbai City has been chosen. The co- ordinates are Latitude/Longitude = 18.9220° N, 72.8347° E. The study area for the purpose of simulation inputs in MIKE software has been taken up to a bathymetryof (-) 30 m in the sea area (Figure 3.2).

The following assumptions [99] have been made for determination of SLR at thesaid co-ordinate.

i. The rate of increase in mean sea level (GMSL) has enhanced globally(high confidence).

ii. Since 1901 the rise in GMSL is 1.5 to 1.9mm/year (average 1.7 mm/year) and the rising rate became faster since 1993 to 3.3 mm/year.

iii. Rate of rise Sea water level at Indian Ocean during 1993-2015 is 3.3 mm/ year and this value is similar with the present rate of rise in GMSL. thermal expansion still dominates Indian Ocean sea-level rise

iv. Although presently rise in GMSL is majority from terrestrial ice-melting

v. In comparison to 1986–2005, rise in MSL by 2050 globally is expectedto be 26 cm and by 2100 will be about 53 cm

vi. Rise is Steric Sea level is likely to by about 20–30 cm under CP4.5 along the Indian coast. Along the Indian coast and tropical coasts extreme weather events areprojected to occur frequently which will raise the mean sea level.

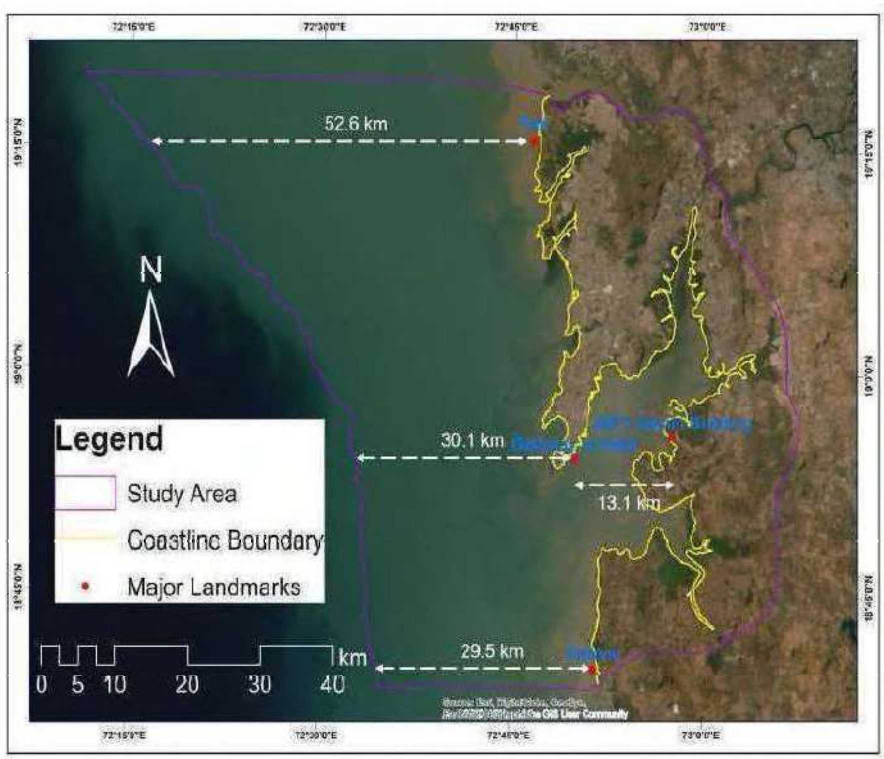


Figure 3.2: Gateway of India (Between Pali to Sasane)

3.2 Climate Model in MIKE 21

MIKE 21 is one of the third-generation trustworthy software model with broad area of applications. The MIKE climate change tool is capable of producing multiple climate change scenarios in accordance with the most common scenarios depicted by IPCC's reports mainly AR4, which are well-matched with equivalent scenarios of IPCC's AR5. The results of MIKE 21 are stated to be more reliable than other computational methodologies including Delft 3D Model [51]. The details of adaption of climate change projections by the MIKE Powered by DHI softwareis explained below and is used for the study area to find the SLR in 2050 for appropriate Climate Change Scenario.

3.3 Projections of Climate Variables

The delta change factor designates the change from baseline for all parameters during a period baseline. The delta change factor method constitutes the climate variable projections. According to the geographic location, the MIKE tool can modify time series of (i) precipitation (ii) temperature and (iii) potential Evapo-transpiration for a particular year. The climate model projections for various emission scenarios project the change factors.

3.4 Global Circulation Model Projections

The results of Global Circulation Models (GCM) are included in IPCC AR4 report, some of which are based on a number of emission scenarios considering future predicted changes in temperature and precipitation. The data are given asaverage values for the following time spans of 20 years:

- 2011-2030
- 2046-2065
- 2080-2099
- 2180-2199

The data varies spatially and over time as a function of the projected year (precipitation, air temperature and anomalies) per grid point per emission scenario. The MIKE software is equipped with any GCM and emission scenario, which considers variables like air temperature, precipitation and potential Evapo-transpiration.

(i) Temperature

The values represent the absolute deviations delta changes in co-ordinate from the reference if required data by linear interpolation between the years, whennot covered by the time span of 20-year.

(ii) Precipitation

Precipitation varies drastically with relative changes within a modeling area within the grid cells as per delta change

(iii) Potential Evapo-transpiration

Simple changes in Evapo-transpiration given to software in m/s [85].

3.5 Emission scenarios

MIKE software includes output of three most common scenarios SRA1B, SRA2 & SRB1 from IPCC. The Climate change tool is used to achieve the missionof the current research. The existing setup data is given as input to MIKE climate change tool, which modifies the data for a year, considering Climate models and emission scenarios. The base or original model consists of a MIKE 21 FM HD model, which recognizes a study area with open boundaries to the ocean. Before going to the Climate Model, the tide level rise was simulated up to 2050. The processes adopted in this Model and the Climate Model are furnished below.

3.6 Hydrodynamic Model

The process of calculation with basic features of Hydrodynamic (HD) model is presented below:

3.6.1 Model Setup

(a) Numerical Modeling Software

Numerical modelling is a widely applied technique and a powerful tool to tackle complex problems by computational simulation. For this study, all modelling works have been performed using numerical model of DHI's MIKE21 Flexible Mesh (FM) Flow module.

Continuity, momentum, temperature, salinity, and density comprise a model. Both Cartesian and spherical co-ordinates are accepted by MIKE in its horizontal domain. Finite volume method applied by discretization of the continuum. MIKE's own time integration scheme is used with an approximate Riemann solver is used, which makes it possible to handle discontinuous solutions [84].

The applied 2-D HD modelling tools is considered for the subsequent modelling components. The HD module of MIKE 21 simulates variation of water level. In the model the areas are flooded and dried during a tidal cycle as happens in nature.

3.6.2 Operation criteria in MIKE

The HD module in Mike21 stands upon principles of continuity ie., laws related topreservation of mass & energy being unified over the water column [84]. In order to solve the partial differential equations governing the simulated flow, boundary conditions must be specified. The Manning number is well known in both traditional as well as numerical hydraulics. The value of Manning number normally remains in the range of 20-40 $m^{1/3}/s$.

In most 2D hydrodynamic models the turbulence closure problem, resulting from the water column to yield the equations are solved. In this manner the problems of describing the turbulent fluctuations are transformed into a description of an eddy viscosity. The eddy viscosity may be modeled using various techniques ranging froma constant value to using a k-ε model [84]

It is essential to understand that in a numerical model classical turbulence is only one of several processes with similar behaviour and characteristics. In the discrete world, processes that are not resolved by the adopted grid are typically called sub-grid scale processes. A similar analogy for the turbulent fluctuations leads to terms similar to the eddy viscosity. Often all these terms are lumped together into one (eddy) formulation. The adopted grid resolution and time scales depend on significance of the physical processes.

3.7 Data Requirements

The data used to set up the Mike21 FM HD model comprise the following:

- Mesh file: to provide information on the model domain (extent, flexible mesh, bathymetry, and boundary locations)

- Water levels, velocity or flux values are the boundary conditions, which are used tomove energy into and out of the model domain (i.e., ‘drive’ the model)

- Wind (optional): to provide a surface boundary condition for your model domain so thatthe effect of wind-driven currents can be included

(a) Topographic Data

The globally available 30 m DEM (Digital Elevation Model) from the satellite of SRTM (Shuttle Radar Topography Mission) is processed to generate topography. It is highly recommended to use a high-resolution DEM for 2D model development. The topography map is presented in Figure 3.2.

(b) Bathymetric Data

The bathymetry information is taken from GEBCO data resolution 30 arc-seconds The bathymetry map is presented in Figure 3.3.

MIKE21 FM HD model incorporates a detailed elevation model (bathymetry and topography) of the ground surface. Both data were combined and processed and imported in grid editor for grid generation. The land value is provided on locations with high elevations. The land value is provided where the flood possibility is zero or out of study area. Generally, the land value is the maximum value of the elevation of the DEM. Bathymetric and topographic data were compiled into a consistent database, on a horizontal datum of Lat/long (WGS84 geographic co-ordinate system) and a vertical datum of Mean Sea Level (MSL) in support of model construction. Figure 3.3 and Figure 3.4 show the topography and the bathymetry respectively.

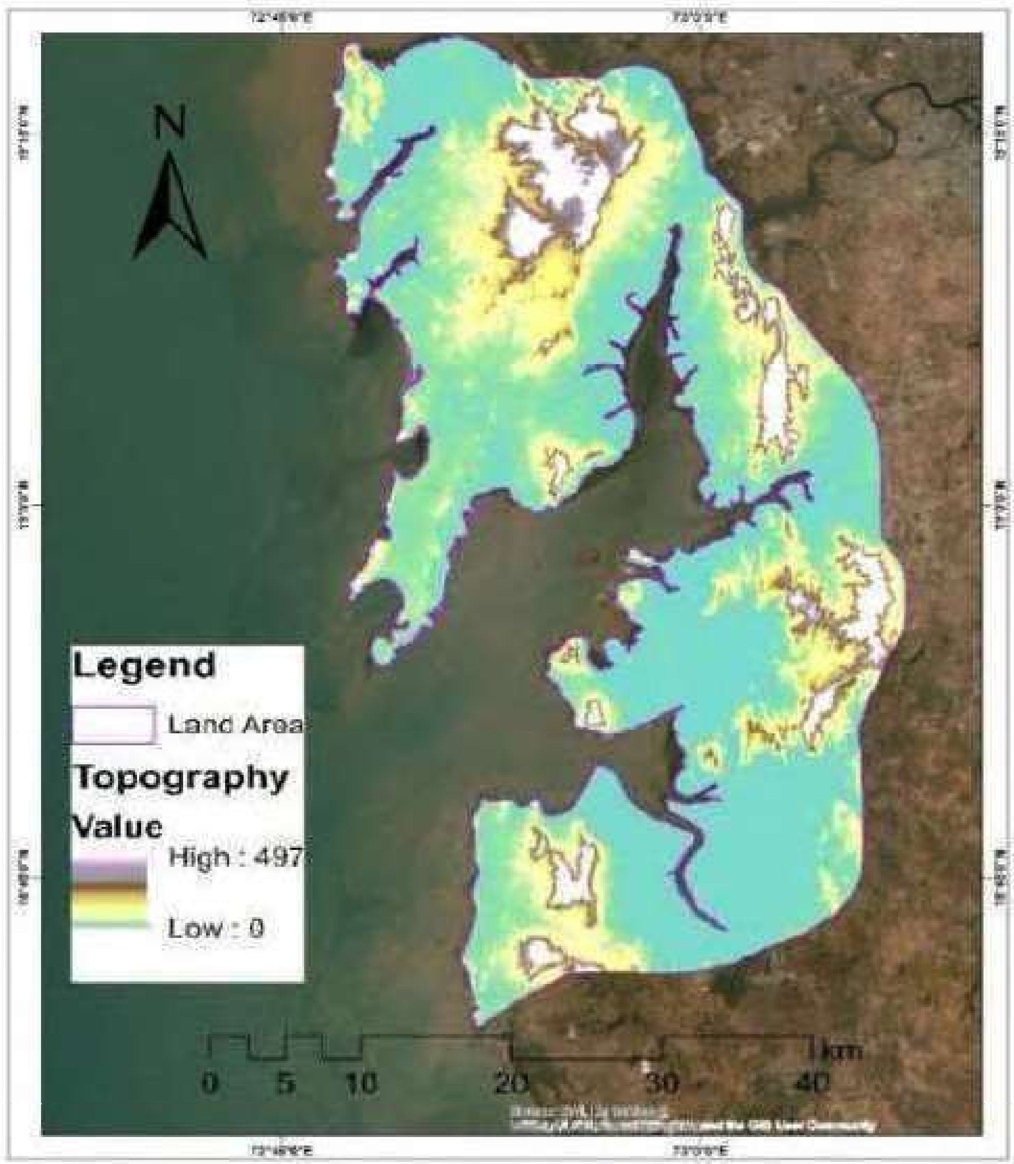


Figure 3.3: Map showing Topography in the study area

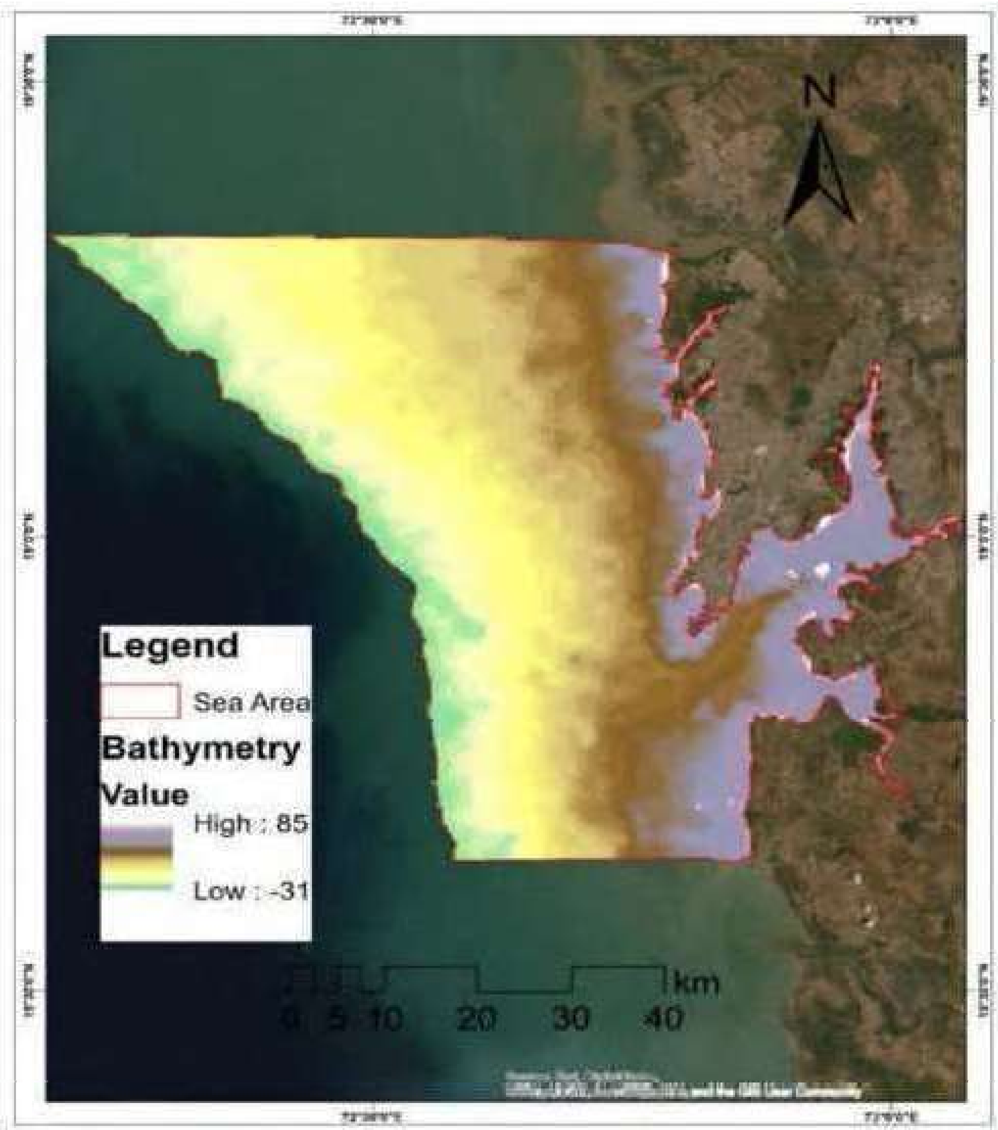


Figure 3.4: Map showing bathymetry in the study area

3.8 Coastline Boundary

Coastline boundary provides a land boundary to the model boundary. Moreover, coastline boundary is required to improve the accuracy of key coastal processes, land-ocean interactions, and the bathymetry effects. Figure 3.5 shows the combined map of topography and bathymetry data. Figure 3.6 shows the full level resolution coastline map for the study area.

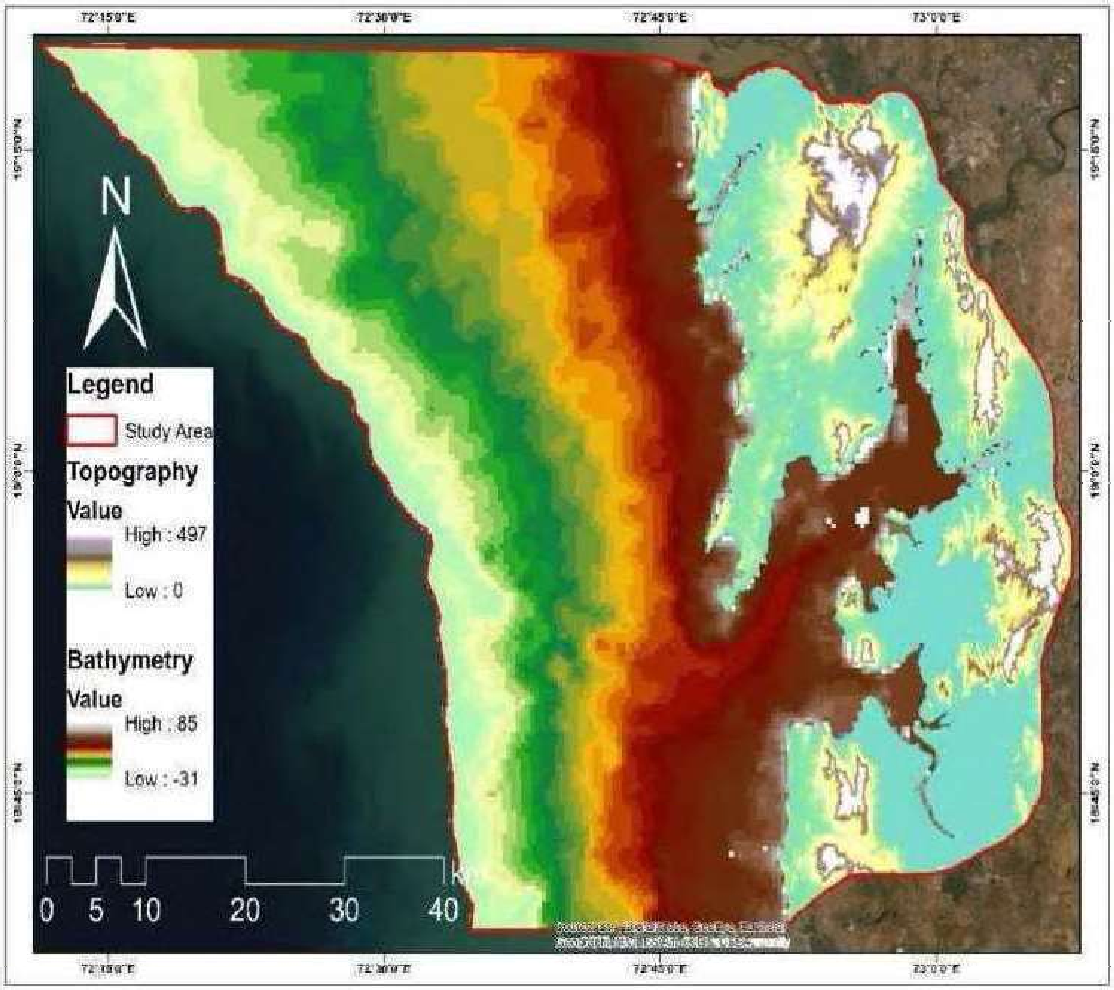


Figure 3.5: Combined map of topography and bathymetry data

3.9 Mesh Generation

Mesh defines the model area (delineation and topography) and is one of the most important characteristics of the HD model. The mesh features such as nodes, elements and its size affect the results and simulation time. In MIKE 21 FM, the mesh is created with triangle generator. The mesh so generated by MIKE itself is then refinedwith a linear relation between the element’s depth/gradient and its area.

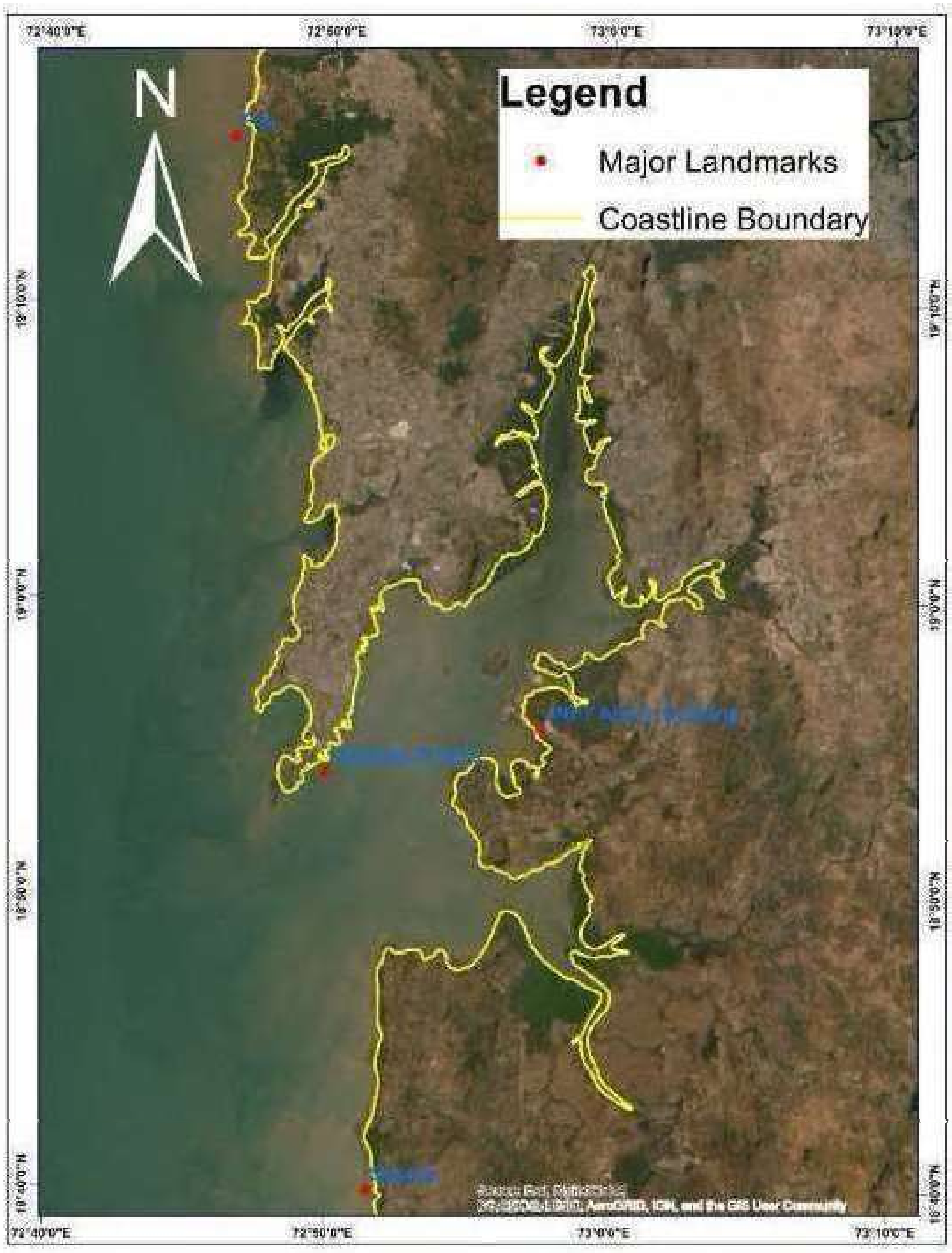


Figure 3.6: Map showing the coastline of the study area

The final mesh has around 9207 nodes and 16902 elements. The elements size varies between 3,808m^2 and 82,32,285 m^2. Figure 3.7 shows the final mesh used for the present study.

3.10 Boundary Condition

The HD model applies water level boundary condition extracted from the Global Tide Model at the lines indicated in Figure 3.8.

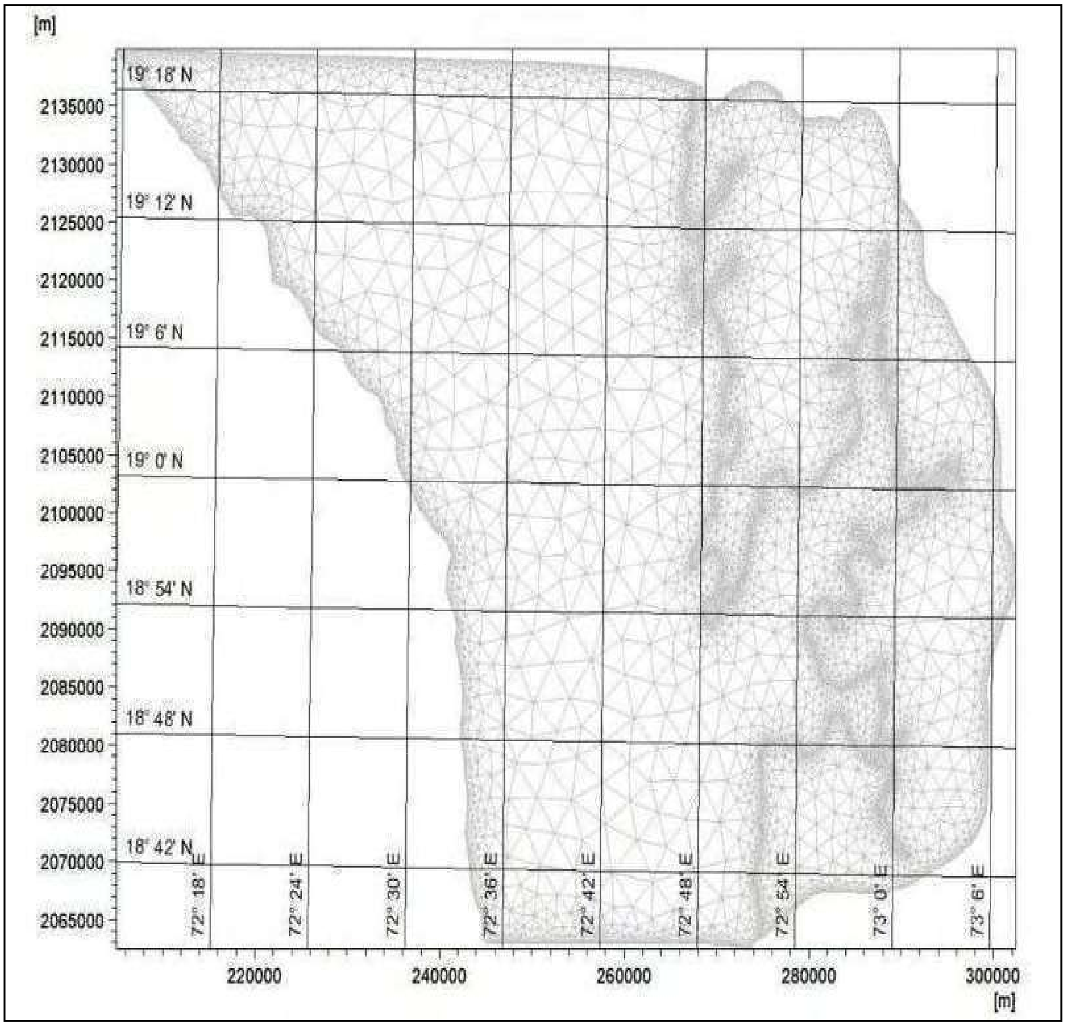


Figure 3.7: Mesh generated in MIKE Zero with detail of the study area

3.11 Bed Resistance

The MIKE21 hydrodynamic model generates depth-integrated over the water column to finally yield the equation. In the governing equations, the friction parameteris expressed as Manning's number.

3.12 Wind Forcing

As the focus is on Rise Sea Level based on impacts of considered scenarios(mainly warming), wind effects have not been considered in the present study. Windeffects are a much complex dynamic scenario and it is suggested that the effects of wind, storm and extreme weather can be a topic for further research.

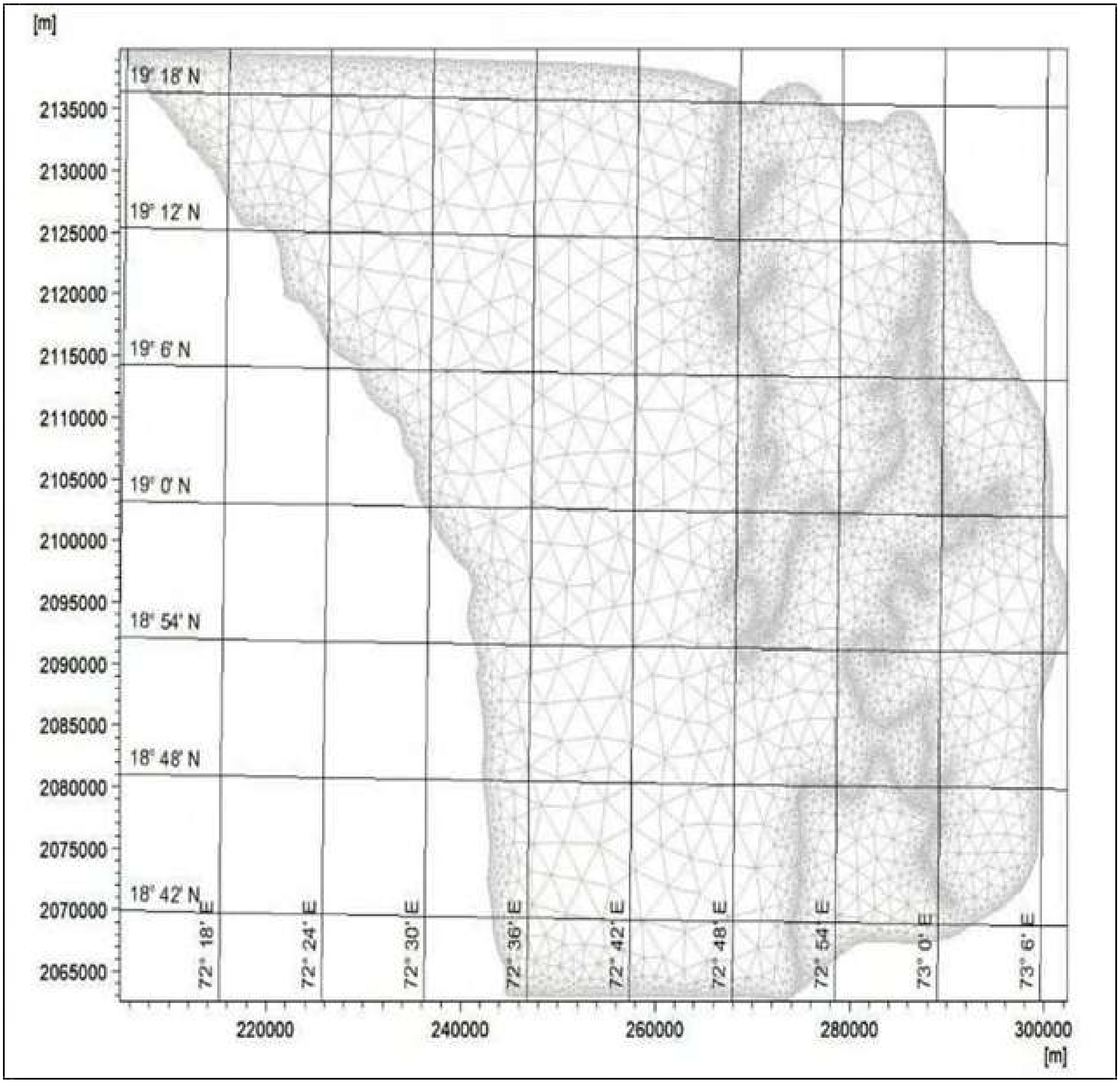
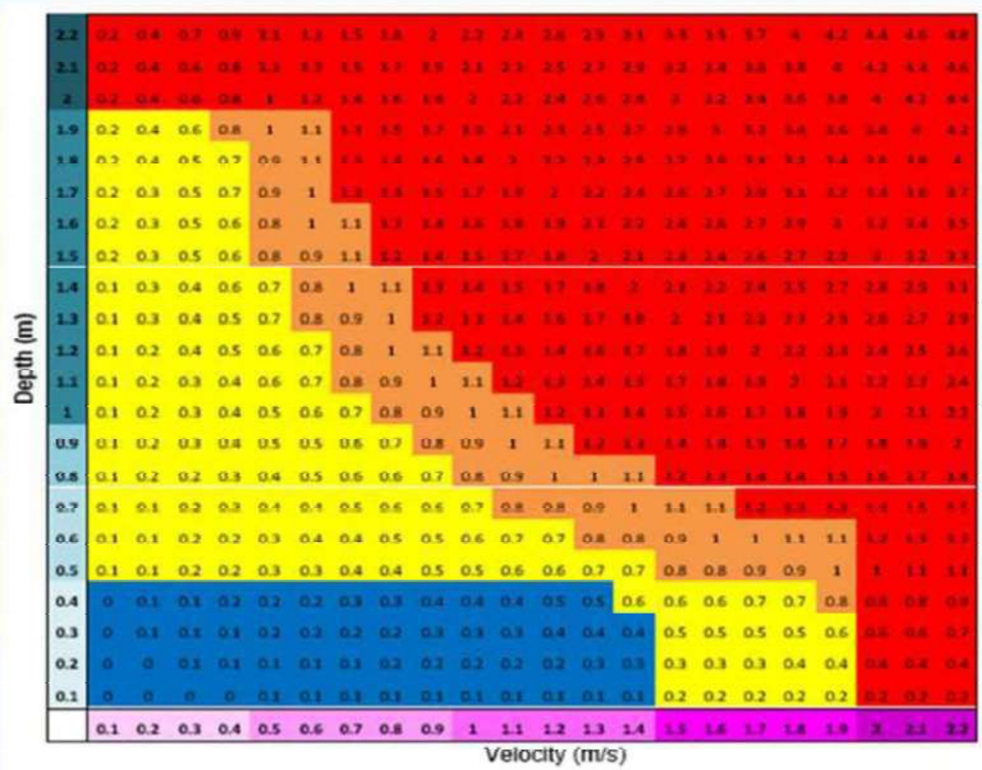


Figure 3.8: Mesh with Model Boundaries highlighted in red

3.13 Flood Hazard Categorization

Flood hazard classification was estimated based on the velocity-depth matrix shown in Figure 3.9. The 2D model results were post-processed to produce spatial grid outputs of maximum depth, level, speed, and flood hazard. The hazard wascomputed at each time step, with the maximum hazard in each grid cell exported as a raster for mapping purposes.



	Low	Significant	High	Extreme
Depth	<0.5	<2	<2	2+
Velocity	<1.5	<2	<2	2+
DxV Product	<0.6	0.6 to <0.8	0.8 to <1.2	1.2 +

Figure 3.9: Flood Hazard Classification
(Mapping Source: Queensland Reconstruction Authority)

Steps for Creating a MIKE21 FM HD Model:

i. Open a new MIKE21 FM HD interface
ii. Load the created mesh file
iii. Specify simulation time and time step
iv. Assign boundaries
v. Specify bed resistant
vi. Assign initial conditions
vii. Specify outputs
viii. Run simulation
ix. Analyze simulation results

3.14 Tidal Variation [2020-2050]

For modelling purposes, information on spatial variation in tidal constituents has been retrieved from the DTU-Space (DTU10) global tide model (resolution 0.125°×0.125°). The DTU10 tidal information was applied as a spatially and temporally variable boundary condition of the MIKE21 FM HD model, which in turn was used to force the boundaries of the 2D model by providing tidal water level.

3.15 Climate Change Model

3.15.1 Climate change impact

The MIKE Climate Change tool is based on IPCC AR4's CO_2 emission. This tool is designed to generate projected climate variables as function of emission rates and prediction year. Apart from the climate variable, this tool is also capable of generating projected rise in sea water level. In this study, only anticipated rise in sea water level for 2050 was generated using the MIKE climate change tool.

3.15.2 Emission scenarios

The Emission Scenarios of the IPCC quantifying global greenhouse gas emissions and most common three scenarios are included in the MIKE climate change tool as detailed in Table 3.1.

Table 3.1: Climate change scenarios

SN	Emission Scenarios	Specifications	Global Mean Warming ^0c 204 2065 #
1	SRAlB	Rapid growth in economy and effective technology	1.75
2	SRA2	Rapid growth in population growth,	1.65
3	SRBl	Convergence throughout the world with same population the **SRA1B,** reduction in carbon and change in technology	1.29

Reference Global Climate Projections Chapter 10 Table 10.5 IPCC AR4 [75]

The emission scenarios in AR4 are compatible with matching scenarios predicted in AR5. Comparing CO2 concentrations between AR4 and that of AR5 are:

1. SRES A1fI equivalent to RCP 8.5
2. SRES AlB equivalent to RCP 6.0 and
3. SRES B1 equivalent to RCP 4.5

Also, the most common scenarios for surface warming from multi-model global averages are: (1) A2, (2) A1B (RCP6.0) and (3) Bl(RCP4.5).

3.16 Workflow to Create a Scenario in MIKE Climate Change Tool

The MIKE climate change tool is capable of producing multiple climate change scenarios based on the same base set-up.

The steps to generate a new situation in the software:

1. Choose an existing baseline model
2. Select climate situation of study year (up to the year 2050).
3. Select one emission scenario (e.g., SRA1B, SRA2 or SRB1).
4. Choose one or more GCMs.
5. Select one or more sea level models.
6. Click the 'Generate default delta change values" button.
7. Inspect the modification factors for climate variables and sea level rise.
8. Modify the modification factors if needed.
9. If satisfied with the factors, click "Generate Climate Change Scenario".
10. Open the newly created set-up by clicking the "Open climate change model setupfile.
11. Run the model and compare with the base model results.